

Updated Site-Specific Biosafety and Biosecurity Mitigation Risk Assessment



February 2012
Final Report

Volume II



**Homeland
Security**

Science and Technology Directorate

Defending America Against Foreign Animal Diseases

Cover Photo Credits:

Pablo A. Puente/Photos.com	Cows in field
Thinkstock	Female scientist
Jupiterimages/Photos.com	Red test tubes
Jupiterimages/Photos.com	Girl with pig
Perkins + Will	Building
newphotoservice/Photos.com	Scientist with flask

Table of Contents

Glossary of Acronyms and Terms	xvi
6. Epidemiological Model.....	403
6.1 Modeling Approach	403
6.1.1. Overview.....	403
6.1.2 Region Modeled	404
6.1.3 Determining Outbreak Starting Locations	405
6.1.3.1 Aerosol Pathways	405
6.1.3.2 Transference Pathways	409
6.1.3.3 Waste Pathways	412
6.1.4 Estimating Extent of Outbreaks in Kansas	413
6.1.4.1 Choice of Epidemiological Model.....	413
6.1.4.2 USDA NAADSM Parameter Sets	413
6.1.4.3 NAADSM Modeling Parameter Development and Data Collection	413
6.1.5 Estimating Probability of Spread to States Other than Kansas	461
6.1.6 Estimating Extent of Outbreaks in Other States.....	463
6.1.6.1 General NAADSM Setup.....	463
6.1.6.2 Production Types.....	463
6.1.7 Determine Overall Risk Should an Accident Occur.....	468
6.1.8 Considering Uncertainty.....	469
6.1.9 Example: Putting It All Together.....	471
6.2 Results.....	476
6.2.1 Summary of Impact	476
6.2.1.1 Effect of Conservative Parameters.....	478
6.2.1.2 Modeling the Consequence of Large Outbreaks.....	478
6.2.1.3 How Wildlife May Affect the Results	479
6.2.1.4 Summary of Results by Event.....	480
6.2.2 Comparing SSRA Results to those of Other Modeling Teams	484
6.2.3 FMD Epidemiological Impact by Event	485
6.2.3.1 Overview of Aerosol Events (AA10, NA10, EA10, OA2, OA3).....	485
6.2.3.2 Aerosol Releases from BSL-3Ag Animal Holding Rooms (Event AA10— High Q).	485
6.2.3.3 Releases from the BSL-3Ag Necropsy Suite (Event NA10—High Q).....	487
6.2.3.4 Releases from the BSL-3E/BSL-3E SP Rooms (Event EA10).....	489
6.2.3.5 Non-Containment Releases (Events OA2, OA3).....	489
6.2.3.6 Solid Waste Releases from the Transfer Station (AS5-AS6, NSW4- NSW6, NST2-NST4, ES4-ES6)	491
6.2.3.7 Solid Waste Releases from the Landfill (AS5- AS6, NSW4 -NSW6, NST2-NST4, ES4-ES6)	492
6.2.3.8 Liquid Waste Location A (Events AL3-AL4, AL7-AL8, NL3-NL4, NL7-NL8, EL5)	494
6.2.3.9 Liquid Waste Location B (Events AL3-AL4, AL7-AL8, NL3-NL4, NL6-NL8, EL5).....	495
6.2.3.10 Liquid Waste Location C (Events AL3-AL4, AL7-AL8, NL3-NL4, NL7-NL8, EL5)	496
6.2.3.11 Liquid Waste Location D (Events AL4, AL8, NL7-NL8, EL5).....	498

6.2.3.12	Tornado (Medium Q Release—Event T-Medium)	502
6.2.3.13	Tornado (High Q Release—Event T-High)	503
6.2.3.14	Earthquake (High Q Release—Event E-High)	505
6.3	Cost-Benefit and Sensitivity Analyses	507
6.3.1	Considering Large Outbreaks	507
6.3.2	Effect of Culling Rate	508
6.3.2.1	Effect of Changing the Culling Rate	509
6.3.2.2	Cost of Increasing Culling Rate	513
6.3.3	Effect of Contact Restrictions after Outbreak Detection	517
6.3.3.1	Changing Minimum Direct Contact Rate	518
6.3.3.2	Changing Minimum Indirect Contact Rate	519
6.3.3.3	Changing the Time Needed to Reduce Direct Contacts	520
6.3.3.4	Changing the Time Needed to Reduce Indirect Contacts	521
6.3.3.5	Cost of Improving Movement Restrictions	522
6.3.4	Observation and Reporting	526
6.3.4.1	Changing the Probability that a Sick Animal Would be Observed	526
6.3.4.2	Improving the Probability that a Sick Animal is Reported to a Veterinarian	527
6.3.4.3	Air Samplers, Sentinel Animals, and Active Surveillance	528
6.3.4.4	Cost of Improving Surveillance and Detection	530
6.3.5	Conclusions	534
6.3.6	Other Sensitivity Analysis	534
6.3.6.1	Effect of Aerosol Dose Threshold	534
6.3.6.2	Effect of Direct Contact Rates	537
6.3.6.3	Effect of Indirect Contact Rates	538
6.3.6.4	Conclusions	539
7.	Economic Assessment	541
7.1	Objective	541
7.2	Technical Approach	541
7.2.1	Regional Background	542
7.2.2	Special Considerations	543
7.2.2.1	Trade Bans	543
7.2.2.2	Effective Trade Bans	543
7.3	Methods	544
7.3.1	Partial Equilibrium Model for the Agricultural Sector	544
7.3.1.1	Data	544
7.3.1.2	Parameters	545
7.3.1.3	Economic Shocks	545
7.3.1.4	Outcomes	565
7.3.2	Regional Non-Agricultural Impacts	565
7.4	Results Summary	569
7.4.1	Economic Impacts	570
7.4.2	Discussion and Implications	575
8.	Risk Calculations	577
8.1	Loss-of-Containment Event-Specific Risk Calculations	578

8.1.1	Risk and Uncertainty Calculation Approach	578
8.1.1.1	Input Parameters.....	578
8.1.1.2	Event-Specific Risk Values and Associated Uncertainties	579
8.1.1.3	Event-Tree Risk Values and Associated Uncertainties	580
8.1.2	Aerosol Events	582
8.1.3	Solid Waste Events	586
8.1.4	Liquid Waste Events	590
8.1.5	Transference Events	593
8.1.6	Catastrophic Events.....	606
8.2	Risk Rankings for FMDv-Related Events	607
8.2.1	Aerosol Pathway.....	610
8.2.2	Liquid Pathway	610
8.2.3	Solid Waste Pathway	611
8.2.4	Catastrophic Events.....	611
8.2.5	Transference Events	612
8.3	Cumulative Risk Calculations	612
8.3.1	Cumulative Risks Across Events.....	613
8.3.2	Cumulative Risks Across Time	614
9.	Large Animal BSL-4 Assessment	619
9.1	Introduction.....	619
9.2	ABSL-4 Assessment Approach	621
9.3	BSL-4 Large Animal Research at the NBAF	623
9.3.1	Types of Research Proposed.....	623
9.3.2	Updated Nipah and Hendra Pathogen Characteristics.....	623
9.4	BSL-4 Facilities	629
9.4.1	ABSL-4 Animal Holding Rooms	631
9.4.2	ABSL-4 Necropsy.....	632
9.4.3	BSL-4 Laboratory.....	633
9.5	ABSL-4 Release Pathways and Associated Mitigations	633
9.5.1	Aerosols	634
9.5.1.1	ABSL-4 Animal Holding Rooms.....	635
9.5.1.2	ABSL-4 Necropsy	636
9.5.2	Solid Waste and Equipment/Property.....	638
9.5.2.1	ABSL-4 Animal Holding Rooms.....	640
9.5.2.2	ABSL-4 Necropsy	641
9.5.3	Liquid Waste	642
9.5.3.1	ABSL-4 Animal Holding Rooms.....	644
9.5.3.2	ABSL-4 Necropsy	644
9.5.4	Transference.....	646
9.5.4.1	BSL-4 Animal Holding Rooms and Necropsy Room Transference.....	646
9.6	Event Summary.....	653
9.6.1	Event Circumstances.....	653
9.7	Pathogen Source Terms.....	656
9.7.1	Animal Holding Rooms	657

9.7.1.1	Use and Frequency – AHRs.....	657
9.7.1.2	Aerosol Contributions – AHRs	659
9.7.1.3	Liquid Waste – AHRs	661
9.7.1.4	Solid Waste – AHRs	662
9.7.1.5	Transference – AHRs	663
9.7.2	Necropsy.....	665
9.7.2.1	Use and Frequency – Necropsy.....	665
9.7.2.2	Aerosol Contributions – Necropsy	666
9.7.2.3	Liquid Waste – Necropsy.....	668
9.7.2.4	Solid Waste – Necropsy.....	668
9.7.2.5	Transference – Necropsy.....	670
9.8	Event Analyses.....	673
9.8.1	Animal Holding Room Events	678
9.8.1.1	AHR – Aerosol Release Through Dropped Inoculum (L4AAi)	678
9.8.1.2	AHR – Aerosol Release Respiratory Shedding (L4AA)	683
9.8.1.3	AHR – Liquid Waste (L4AL)	687
9.8.1.4	Animal Holding Room – Solid Waste (L4AS).....	691
9.8.1.5	Animal Holding Room – Transference (Injection from Inoculum) (L4ATi) .	693
9.8.1.6	Animal Holding Room – Transference (Respiratory from Cut Suit) (L4ATR).....	696
9.8.1.7	Animal Holding Room – Transference (Injection from Animal Bite) (L4ATI)	699
9.8.1.8	Animal Holding Room – Transference (Respiratory through Suit Tear) (L4ATRs)	702
9.8.2	Necropsy.....	707
9.8.2.1	Necropsy – Aerosol Release (L4NA)	707
9.8.2.2	Necropsy – Liquid Waste (L4NL).....	711
9.8.2.3	Necropsy – Solid Waste from Red Biohazard Bags (L4NSW)	715
9.8.2.4	Necropsy – Solid Waste from Tissue and Carcasses (L4NST)	717
9.8.2.5	Necropsy – Transference (Respiratory through Suit Leak) (L4NTRs)	719
9.8.2.6	Necropsy – Transference (Injection from Cut with Tool) (L4NTI)	721
9.8.2.7	Necropsy – Transference (Contact with Palm through Cut PPE) (L4NTCp).	723
9.8.2.8	Necropsy – Transference (Contact with Fomite) (L4NTCf)	726
9.9	ABSL-4 Impact Analyses.....	729
9.9.1	The Historical Perspective	729
9.9.1.1	Summary of HeV and NiV Outbreak Impact.....	729
9.9.1.2	Documented Outbreak Transmission Factors.....	734
9.9.2	Estimating the Impact at the NBAF	736
9.9.2.1	Probability of an Index Case.....	736
9.9.2.2	Relative Impact.....	755
9.9.2.3	Special Consideration for Emerging Pathogens	757
9.10	Risk Ranking, Conclusions and Recommendations:	758
9.10.1	Risk Calculations and Risk Ranking	758
9.10.2	Conclusions and Recommendations.....	771
10.	Conclusions and Recommendations	803
10.1	Conclusions.....	804

10.1.1	Conclusions and Risk Rankings for FMDv-Related Events	804
10.1.2	Cumulative Risk Calculations for FMDv-Related Accidents.....	806
10.1.3	Summary of Risks Associated with Infected Livestock in BSL-4 Containment	807
10.2	Recommendations.....	809
10.2.1	Design and Construction	809
10.2.1.1	Disinfection Fixtures	810
10.2.1.2	Time Interlocked Shower Doors	810
10.2.1.3	Earthquake Performance Analysis.....	810
10.2.1.4	Beneficial Reuse Considerations.....	810
10.2.2	Operational Planning.....	811
10.2.3	Response Planning.....	812
10.2.4	Recommendations Summary Table.....	813
10.3	Continuing Risk Management and Advancements Following the 2010 SSRA.....	815
10.3.1	Implementation of 2010 SSRA Recommendations	815
10.3.2	NBAF Design Evolution	819
10.3.2.1	Redundant HEPA Caissons and Autoscan Capability	819
10.3.2.2	Carcass Disposal.....	820
10.3.2.3	On-Site Wastewater Pretreatment	820
10.3.2.4	Potable Water.....	820
10.3.2.5	Tornado Hardening.....	820
10.3.3	DHS/USDA Operational and Response Planning	821
10.3.4	Response to NAS SSRA Committee Findings	821
	Acknowledgements	825
	Bibliography	841

List of Figures

Figure 6.1.3-1:	Threshold dose of FMDv to generate a 50% probability of at least one infection in a herd of swine. Both axes are log scale.....	407
Figure 6.1.4-1:	Kansas Cattle Latent Disease Phase.....	424
Figure 6.1.4-2:	Kansas Cattle Subclinical Disease Phase	424
Figure 6.1.4-3:	Kansas Cattle Clinical Disease Phase	424
Figure 6.1.4-4:	Kansas Cattle Immune Period.....	424
Figure 6.1.4-5:	Kansas Swine Latent Disease Phase	425
Figure 6.1.4-6:	Kansas Swine Subclinical Disease Phase.....	425
Figure 6.1.4-7:	Kansas Swine Clinical Disease Phase	425
Figure 6.1.4-8:	Kansas Swine Immune Disease Phase	425
Figure 6.1.4-9:	Kansas Small Ruminants Latent Disease Phase	426
Figure 6.1.4-10:	Kansas Small Ruminants Subclinical Disease Phase	426
Figure 6.1.4-11:	Kansas Small Ruminants Clinical Disease Phase	426
Figure 6.1.4-12:	Kansas Small Ruminants Immune Disease Phase	426
Figure 6.1.4-13:	Kansas Cattle Within-Herd Prevalence.....	428
Figure 6.1.4-14:	Kansas Small Ruminants Within-Herd Prevalence	428
Figure 6.1.4-15:	Kansas Swine Within-Herd Prevalence.....	428

Figure 6.1.4-16: Average Estimated Reduction in Direct Contact and Indirect Contact for One 10-km Zone Around an FMD Infected Farm According to Interviews with State Officials	439
Figure 6.1.4-17: Universal Movement Control Functions Entered in NAADSM	440
Figure 6.1.4-18: Distribution of Virus from a Location Near Manhattan, Kansas, Using Local Weather Conditions.....	441
Figure 6.1.4-19: The Mean PFU Uptake by Cows Decreases Exponentially with Distance Irrespective of Wind Directions.....	442
Figure 6.1.4-20: Kansas Cattle Production Type “obs and rep fxs” (NAADSM observation functions)	444
Figure 6.1.4-21 Kansas Swine Production Type “obs and rep fxs” (NAADSM observation functions).....	445
Figure 6.1.4-22 Kansas Small Ruminants Production Type “obs and rep fxs” (NAADSM observation functions).....	445
Figure 6.1.4-23: Total Time to Herd Depopulation for the Facilities of the Most Prevalent Production Types.....	452
Figure 6.1.4-24: Mean Destruction Capacity Function (herds/day)	454
Figure 6.1.6-1: Map of Swine Populations in the Modeled Region [The University of Georgia College of Veterinary Medicine, 2007].....	464
Figure 6.1.9-1: Cumulative Risk Distribution Function Showing Median Impact vs. Possible Starting Locations for the Example	471
Figure 6.1.9-2: Cumulative Risk Distribution Function Showing Impact vs. Possible Starting Locations for the Example, Given Uncertainty in the NAADSM Outputs.....	472
Figure 6.1.9-3: Impact of Outbreaks in Kansas (left) and Impact of Outbreaks Summed Across all States (right) as a Function of Probability the Spread Would Occur	473
Figure 6.1.9-4: Impact of Outbreaks in Kansas (left) and Impact of Outbreaks Summed Across all States (right) as a Function of Probability the Spread Would Occur	474
Figure 6.1.9-5: Impact of Outbreaks Summed Across all States as a Function of Probability the Spread Would Occur.....	475
Figure 6.2.3-1: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by an Aerosol Release from an AHR	487
Figure 6.2.3-2: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by an Aerosol Release from the BSL-3Ag Necropsy Suite.....	488
Figure 6.2.3-3: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by an Aerosol Release from Non-Containment.....	490
Figure 6.2.3-4: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Solid Waste from the Transfer Station.....	492
Figure 6.2.3-5: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Solid Waste from the Landfill	493
Figure 6.2.3-6: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Liquid Waste from Location A	495
Figure 6.2.3-7: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Liquid Waste from Location B	496
Figure 6.2.3-8: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Liquid Waste from Location C	497

Figure 6.2.3-9: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Waste from Location D.....	499
Figure 6.2.3-10: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated from Transference Events	500
Figure 6.2.3-11: Impact in Kansas of Surreptitious (baseline) and Self-Announcing (unicorn and min mv). Releases of 10^8 PFU of FMDv from the NBAF as a Function of Initial Premises Infected	501
Figure 6.2.3-12: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by a Medium Aerosol Release from a Tornado	503
Figure 6.2.3-13: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by a High Aerosol Release from a Tornado	504
Figure 6.2.3-14: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by a High Aerosol Release Caused by an Earthquake.....	506
Figure 6.3.1-1: Consequences as a Function of the Percentile of the NAADSM Output for a Notional Large Outbreak with Baseline Parameters and in the Context of a Notional Improved Mitigation System.....	508
Figure 6.3.2-1: Effect of Changes to the Culling Rate on Outbreak Duration in Kansas.....	509
Figure 6.3.2-2: Effect of Changes to the Culling Rate on Number of Animals Culled in Kansas.....	510
Figure 6.3.2-3: Effect of Changes to Culling Rate on Head Culled in the Outbreak in Kansas.....	511
Figure 6.3.2-4: Effect of Changes to the Culling Rate on Number of Animals in the Context of Changed Direct and Indirect Contact Rates	512
Figure 6.3.3-1: Effect of Reducing the Minimum Direct Contact Rate After an Outbreak on Head Culled for Two Example Model Runs (One Starting in a Cow-Calf Operation and One in a Feedlot) for Two NAADSM Outputs	519
Figure 6.3.3-2: Effect of Reducing the Minimum Indirect Contact Rate After an Outbreak for Two Premises Types, NAADSM Outputs, and Vaccination Strategies	520
Figure 6.3.3-3: Effect of Changes of the Time to Reduce Direct Contact Rates on Head Culled for Two Example Model Runs (One Starting in a Cow-Calf Operation and One in a Feedlot)	521
Figure 6.3.3-4: Effect of Changes to the Time to Reduce Indirect Contact Rates on Head Culled for Six Example Model Runs (Three Starting in a Cow-Calf Operation and Three in a Feedlot)	522
Figure 6.3.4-1: Effect of Changing the Observation Probability for Two Premises Types and NAADSM Outputs.....	527
Figure 6.3.4-2: The Effect of Improving the Probability that a Producer Calls a Veterinarian Soon After Observing Signs of FMD Relative to the Baseline Probability	528
Figure 6.3.6-1: Effect of Changing the Aerosol Infection Threshold on the Number of Premises Initially Infected for a Release Outside of Containment (left) and a Release in Containment where HEPA Filtration is Not Operating (right).....	535
Figure 6.3.6-2: Effect of Changing the Aerosol Infection Threshold on the Number of Premises Initially Infected for a Release Due to Lack of HEPA Filtration in the BSL3 Animal Room.....	536
Figure 6.3.6-3: Effect of Changing the Aerosol Infection Threshold on the Number of Premises Initially Infected for a Release Due to a Tornado. (The left panel is the release of 10^8 PFU and the right panel is the release of 10^{10} PFU)	537
Figure 6.3.6-4: Effect of Doubling or Halving the Direct Contact Rate on Outbreak Duration (left) or Head Culled (right) Compared to Baseline	538

Figure 6.3.6-5: Effect of Doubling or Halving the Indirect Contact Rate on Outbreak Duration (left) or Head Culled (right) Compared to Baseline	539
Figure 7.4.1-1: Changes in Producer Welfare by Commodity Throughout the Study Period for Liquid A p5/p5	571
Figure 7.4.1-2: Changes in Producer and Consumer Welfare Throughout the Study Period for Liquid A p5/p5	572
Figure 8.2-1: Frequency-Consequence Plot for All Event Trees	607
Figure 8.2-2: Aggregate Risk by Event Tree	609
Figure 8.3.2-1: Cumulative Probability of an Infection Over the 50-Year NBAF Operating Lifetime.....	616
Figure 8.3.2-2: Cumulative Risk (\$M) Over 50-Year NBAF Operating Lifetime.....	616
Figure 9.4-1: NBAF Main Building First Floor Plan [NDP, 2011].....	629
Figure 9.4-2: BSL-4 Facilities	630
Figure 9.4-3: BSL-4 Facilities Flow.....	631
Figure 9.4.2-1: ABSL-4 Large Animal Holding Room and Necropsy Showing Entry Protocol and Relationship of the Two Areas	632
Figure 9.5-1: Pathways for Loss of Containment from ABSL-4 to the Environment.....	634
Figure 9.5.1-1: Conceptual Model of ABSL-4 Animal Holding Room & Necropsy Exhaust System	636
Figure 9.5.2-1: Conceptual Diagram for Solid Waste and Removal of Other Items from ABSL-4 AHRs and ABSL-4 Necropsy Room	639
Figure 9.5.3-1: Conceptual Diagram for Liquid Effluent Collection and Treatment for All Originating Locations in BSL-4 Containment.....	643
Figure 9.5.4-1: Conceptual Diagram for Transference Events.....	647
Figure 9.8.1-1: Conceptual Diagram of the HEPA Filtration Events for Aerosol Releases	678
Figure 9.8.1-2: Event Tree for Aerosol Release via Dropped Inoculum in AHRs (L4AAi).....	679
Figure 9.8.1-3: Event Tree for Aerosol Release via Respiratory Shedding of Infected Animals in AHRs (L4AA)	683
Figure 9.8.1-4: Event Tree for Liquid Waste Release in AHRs (L4AL).....	688
Figure 9.8.1-5: Event Tree for Solid Waste Release in AHRs (L4AS)	691
Figure 9.8.1-6: Event Tree for Transference Injection from Inoculum in AHRs (L4ATli).....	694
Figure 9.8.1-7: Event Tree for Transference Respiratory from Cut Suit in AHRs (L4ATR)	697
Figure 9.8.1-8: Event Tree for Transference Injection from Animal Bite in AHRs (L4ATI)	700
Figure 9.8.1-9: Event Tree for Transference Respiratory from Suit Tear in AHRs (L4ATRs)	703
Figure 9.8.2-1: Event Tree for Aerosol Release from Aerosolized Tissue and Blood in Necropsy (L4NA)	707
Figure 9.8.2-2: Event Tree for Liquid Waste Release in Necropsy (L4NL).....	712
Figure 9.8.2-3. Event Tree for Solid (Red Bag) Waste Release in Necropsy (L4NSW)	715
Figure 9.8.2-4: Event Tree for Solid Tissue Waste Release in Necropsy (L4NST)	717
Figure 9.8.2-5: Event Tree for Transference Respiratory through Suit Leak in Necropsy (L4NTRs)	719
Figure 9.8.2-6: Event Tree for Transference Injection from Cut with Tool in Necropsy (L4NTI)	721
Figure 9.8.2-7: Event Tree for Transference Contact with Palm in Necropsy (L4NTCp).....	724
Figure 9.8.2-8: Event Tree for Transference Contact with Fomite in Necropsy (L4NTCf)	726
Figure 9.9.2-1: Swine Farms within a 200km Radius of the NBAF	741
Figure 9.10.2-1: NiV Event Risk Summary by Release Pathway.....	791

Figure 9.10.2-2: HeV ABSL-4 Event Risk Summary by Release Pathway.....	793
Figure 10.3-1: Iterative Risk Model.....	815

List of Tables

Table 6.1.2-1: Data Used to Select States to be Included in the Region Modeled	404
Table 6.1.3-1: The Probit Slope and ID ₅₀ for Cattle, Swine and Sheep Exposed to FMDV via Aerosol	406
Table 6.1.3-2: Smallest Minimum Infectious Doses Proposed in the Literature, as Described in Appendix A6.....	408
Table 6.1.3-3: Probit Slope and ID ₅₀ for Cattle, Swine, and Sheep/Goats Exposed to FMDV via Aerosol	409
Table 6.1.3-4: Descriptive Statistics of Distances to Potential Infection Starting Locations (in miles from the NBAF).....	411
Table 6.1.3-5: Locations of Farms Visited by Interview Subjects.....	411
Table 6.1.4-1: Production Types Used for the Updated SSRA Epidemiological Model	414
Table 6.1.4-2: NAADSM Model Dataset Format	417
Table 6.1.4-3. Number of Facilities and Animals in the Final Kansas Population File	422
Table 6.1.4-4: Direct Contact Originating from Cow-Calf Operations	431
Table 6.1.4-5: Direct Contact Originating from Beef (BY-SS) Operations	432
Table 6.1.4-6: Distance Distribution of Recipient Parameters for all USDA 2009 Production Type Pairs with a Direct Contact Greater than Zero.....	433
Table 6.1.4-7: Example Indirect Contact Values for Contacts Originating at Cow-Calf Operations From USDA 2009.....	434
Table 6.1.4-8: Average Visits Per Year Between Backyard Facilities and Each Professional Service Provider (Indirect Fomite).....	435
Table 6.1.4-9: Estimated Percent of Visits of Each Fomite Type to the Backyard Facility*	436
Table 6.1.4-10: Example of BY-SS Indirect Contact Rates (Contacts/Day).....	436
Table 6.1.4-11: Example Probability of Infection Given Exposure, Given Indirect Contact.....	437
Table 6.1.4-12: Airborne and Local Area Spread Parameters from USDA 2011	441
Table 6.1.4-13: Multiplier Functions for all Production Types (NAADSM Reporting Functions)	446
Table 6.1.4-14: Parameter Values for “Unicorn” Premises	446
Table 6.1.4-15: Tracing Parameters (Both for Direct and Indirect Tracing).....	448
Table 6.1.4-16: Multiplier for the Probability of Detection for Units Identified by Trace-out of Direct and/or Indirect Contacts	448
Table 6.1.4-17: Diagnostic Testing: Sensitivity, Specificity, and Delay in Obtaining Test Results for All Production Types in All States	449
Table 6.1.4-18: Time Estimates for Each Stage of Herd Depopulation.....	451
Table 6.1.4-19: Total Time to Herd Depopulation for the Largest Facilities of Each Production Type	452
Table 6.1.4-20: Range of Depopulation Teams Available from States in the Modeled Region.....	453
Table 6.1.4-21: Notional Destruction Capacity Calculation	454
Table 6.1.4-22: Production Type Destruction Priority in NAADSM	455
Table 6.1.4-23: Production Type Specific Vaccination Rates	457

Table 6.1.4-24: Time to Vaccinate All Herds Given a Few Vaccination Rates and the Percent of Premises Sizes Left Out of the Analysis	458
Table 6.1.6-1: Sources Used to Create Each Animal Population File	465
Table 6.1.6-2: Number of Facilities Identified, Divided by Production Type and State	465
Table 6.1.6-3: Number of Animals Identified, Broken Down by Production Type and State	466
Table 6.2.1-1: Summary of Disease Duration Estimates across Events	480
Table 6.2.1-2: Summary of Head Culled Estimates Across Events.....	482
Table 6.2.1-3: Summary of Head Vaccinated Estimate Across Events	483
Table 6.2.3-1: Probability that Meteorological Conditions will Prevail to Cause at least a Threshold Number of Initial Premises Infected upon an Aerosol Release from an AHR	486
Table 6.2.3-2: Probability of Interstate Spread of FMD from an Infection Initiated by an Aerosol Release from an AHR	486
Table 6.2.3-3: Duration of Disease Outbreaks from an Infection Initiated by an Aerosol Release from an AHR.....	486
Table 6.2.3-4: Probability of Interstate Spread of FMD from an Infection Initiated by an Aerosol Release from the BSL-3Ag Necropsy Suite.....	487
Table 6.2.3-5: Duration of Outbreaks from an Infection Initiated by an Aerosol Release from the BSL-3Ag Necropsy Suite.....	488
Table 6.2.3-6: Probability of Interstate Spread of FMD from an Infection Initiated by an Aerosol Release from Non-Containment.....	490
Table 6.2.3-7: Duration of Outbreaks from an Infection Initiated by an Aerosol Release from Non- Containment.....	490
Table 6.2.3-8: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Solid Waste at the Transfer Station.....	491
Table 6.2.3-9: Duration of Outbreaks from an Infection Initiated by Release of Infectious Solid Waste from the Transfer Station.....	491
Table 6.2.3-10: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Solid Waste from the Landfill	492
Table 6.2.3-11: Duration of Outbreaks from an Infection Initiated by a Release of Infectious Solid Waste from the Landfill	493
Table 6.2.3-12: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Liquid Waste from Location A	494
Table 6.2.3-13: Duration of Outbreaks from an Infection Initiated by Release of Infectious Liquid Waste from Location A	494
Table 6.2.3-14 Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Liquid Waste from Location B	495
Table 6.2.3-15: Duration of Outbreaks from an Infection Initiated by Release of Infectious Liquid Waste from Location B	496
Table 6.2.3-16: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Liquid Waste from Location C	497
Table 6.2.3-17: Duration of Outbreaks from an Infection Initiated by Release of Infectious Liquid Waste from Location C	497

Table 6.2.3-18: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Liquid Waste from Location D	498
Table 6.2.3-19: Duration of Outbreaks from an Infection Initiated by Release of Infectious Liquid Waste from Location D	498
Table 6.2.3-20: Probability of Interstate Spread of FMD from an Infection Initiated from Transference Events	499
Table 6.2.3-21: Duration of Outbreaks from an Infection Initiated from Transference Events	500
Table 6.2.3-22: Probability that Meteorological Conditions will Prevail to Cause at Least a Threshold Number of Initial Premises Infected upon a Medium Aerosol Release Caused by a Tornado.....	502
Table 6.2.3-23: Probability that FMD will Spread to Other States upon a Medium Aerosol Release Caused by a Tornado.....	502
Table 6.2.3-24: Duration of Outbreaks from an Infection Initiated by a Medium Aerosol Release Caused by a Tornado.....	503
Table 6.2.3-25: Probability that Meteorological Conditions will Prevail to Cause at Least a Threshold Number of Initial Premises Infected after a High Aerosol Release Caused by a Tornado	503
Table 6.2.3-26: Probability that FMD will Spread to Other States from a High Aerosol Release Caused by a Tornado	504
Table 6.2.3-27: Duration of Outbreaks from an Infection Initiated by a High Aerosol Release Caused by a Tornado	504
Table 6.2.3-28: Probability that Meteorological Conditions will Cause at Least a Threshold Number of Initial Premises Infected upon a High Aerosol Release Caused by an Earthquake	505
Table 6.2.3-29: Probability that FMD will Spread to Other States Upon a High Aerosol Release Caused by an Earthquake	505
Table 6.2.3-30: Duration of Outbreaks from an Infection Initiated by a High Aerosol Release Caused by an Earthquake	505
Table 6.3.2-1: Cost of Training 13 Culling Teams.....	514
Table 6.3.2-2: Cost of 3D Training for an Additional Five All-Hazards Response Companies.....	515
Table 6.3.2-3: Cost of Culling Equipment Procurement for the Captive Bolt Strategy.....	516
Table 6.3.2-4: Cost of Culling Equipment Procurement for the Mixed Bolt/Electrocution Strategy in which Half of New Culling Capacity is Provided by Mobile Electrocution Units.....	516
Table 6.3.2-5: Total Cost to Double Culling Capacity in a Single State for Captive Bolt and Mixed Bolt/Electrocution Strategies	517
Table 6.3.2-6: Total Costs to Increase Culling Capacity to Various Levels According to the Captive Bolt and Mixed Bolt/Electrocution Strategies	517
Table 6.3.3-1: Costs to Purchase Emergency Radios to Improve Communication of Animal Movement Requirements	523
Table 6.3.3-2: Cost and Reach of Animal Disease Response Training Course AWR-206 Developed by Kirkwood Community College, Fiscal Year 2010-2011	526
Table 6.3.4-1: The Probability of Detection of an Aerosol Release that Causes a Downwind Infection as a Function of Entrainment Rate of an Air Sampler and the Limit of Detection of the Assay Used on the Air Sample	530
Table 6.3.4-2: Costs to Conduct Producer Awareness Sessions Across Various Areas Around the NBAF531	

Table 6.3.4-3: Costs to Print and Mail Laminated Agricultural Emergency Quick-Reference Sheets to Producers Within Various Areas Around the NBAF.....	532
Table 6.3.4-4: Costs to Place Emergency Reference Gatefold Inserts in Yellow Page Phone Books Serving Various Regions Around the NBAF	532
Table 6.3.4-5: Costs to Conduct County-Level Emergency Planning Sessions Across Various Areas Around the NBAF.....	533
Table 6.3.4-6: Costs to Conduct Both County Planning and Producer Awareness Sessions Across Various Areas Around the NBAF.....	533
Table 6.3.4-7: Percentage of Initial Infections Caused by Transference Events as a Function of Distance From the NBAF	533
Table 7.2.1-1: Regional Economic Value of Livestock Sectors	542
Table 7.3.1-1: Retail Demand Elasticities for Agricultural Commodities	545
Table 7.3.1-2: Number of Animals in Impacted Region	546
Table 7.3.1-3: Number of Herds in Impacted Region	547
Table 7.3.1-4: Average Number of Animals Culled by Event	548
Table 7.3.1-5: Average Number of Herds Culled by Event	551
Table 7.3.1-6: Average Number of Animals Vaccinated by Event	553
Table 7.3.1-7: Average Number of Herds Vaccinated by Event.....	556
.....	559
Table 7.3.1-9: Demand Shocks.....	563
Table 7.3.1-10: Percentage Change Of International Trade Following FMD Outbreaks by Event	564
Table 7.3.2-1: Allocation of Travel Expenditure by Category (%)	567
Table 7.3.2-2: Travel Expenditures by State and Subcategory	568
Table 7.3.2-3: Government Cost Used in Calculations	569
Table 7.4.1-1: Economic Impacts Summary (Millions).....	573
Table 8.1.2-1: BSL-3Ag AHR Aerosol Event Tree (AA) – Risk Calculations	583
Table 8.1.2-2: Necropsy Suite Aerosol Event Tree (NA) – Risk Calculations.....	584
Table 8.1.2-3: BSL-3E/ BSL-3E SP Aerosol Event Tree (EA) – Risk Calculations.....	585
Table 8.1.2-4: Non-Containment Aerosol Event Tree (OA) – Risk Calculations.....	586
Table 8.1.3-1: BSL-3Ag AHR Solid Waste Event Tree (AS) – Risk Calculations	588
Table 8.1.3-2: Necropsy Suite Solid Waste Event Tree (NSW) – Risk Calculations	588
Table 8.1.3-3: Necropsy Suite Solid Waste (Carcasses/Tissues) Event Tree (NST) – Risk Calculations	589
Table 8.1.3-4: BSL-3E/ BSL-3E SP Solid Waste Event Tree (ES) – Risk Calculations	589
Table 8.1.4-1: BSL-3Ag AHR Liquid Waste Event Tree (AL) – Risk Calculations	591
Table 8.1.4-2: Necropsy Suite Liquid Waste Event Tree (NL)– Risk Calculations.....	592
Table 8.1.4-3: BSL-3E/ BSL-3E SP Liquid Waste Event Tree (EL)– Risk Calculations.....	593
Table 8.1.5-1: BSL-3Ag AHR Respiratory Transference Event Tree (ATR) – Risk Calculations	595
Table 8.1.5-2: BSL-3Ag AHR Fomite Transference Event Tree (ATF) – Risk Calculations.....	595
Table 8.1.5-3: Necropsy Suite Transference (Hand) Event Tree (NTH1-6) – Risk Calculations.....	596
Table 8.1.5-4: Necropsy Suite Transference (Hand) Event Tree (NTH7-12) – Risk Calculations.....	597
Table 8.1.5-5: Necropsy Suite Transference (Body) Event Tree (NTB) – Risk Calculations.....	598
Table 8.1.5-6: BSL-3E/BSL-3E SP Transference (Hand) Event Tree (ETP0-6) – Risk Calculations.....	599

Table 8.1.5-7: BSL-3E/BSL-3E SP Transference (Hand) Event Tree (ETP7-12) – Risk Calculations.....	600
Table 8.1.5-8: BSL-3E/BSL-3E SP Transference (Body) Event Tree (ETB) – Risk Calculations	601
Table 8.1.5-9: Non-Containment Transference (Hand) Event Tree (OTP) – Risk Calculations	602
Table 8.1.5-10: Non-Containment Transference (Foot) Event Tree (OTF) – Risk Calculations.....	603
Table 8.1.5-11: Non-Containment Transference (Body) Event Tree (OTB) – Risk Calculations.....	604
Table 8.1.5-12: Non-Containment Transference (Fomite) Event Tree (OTFom) – Risk Calculations	605
Table 8.1.5-13: Non-Containment Transference (Palm) Event Tree (OTPalm) – Risk Calculations.....	605
Table 8.1.6-1: Catastrophic Events – Risk Calculations.....	606
Table 8.2-1: Risk Values by Event Tree	608
Table 8.3.1-1: Cumulative Risks Across Events (for One Year)	614
Table 8.3.2-1: Cumulative Risks Across Events for the 50-Year Operating Lifetime of the NBAF	615
Table 9.3.2-1: Updated BSL-4 Pathogen Summary Matrix	625
Table 9.4-1: Gross containment space [NDP 65% Design, 2011].....	630
Table 9.5.1-1: HEPA Filter Pass-Through Factors.....	637
Table 9.5.4-1: Chemical Penetration Efficiency of ILC Dover Chemtursion Model 3525 BSL-4 Suits.....	650
Table 9.5.4-2: Efficacy of Chlorine Dioxide Disinfectant.....	651
Table 9.6.1-1: ABSL-4 Event Circumstance Summary	654
Table 9.7.1-1: Summary of Use and Frequency of ABSL-4 AHRs Per Year.....	658
Table 9.7.1-2: Animals per ABSL-4 AHR per Day and Animal Characteristics.....	659
Table 9.7.1-3: Distribution of NiV and HeV Inoculum Viral Concentrations.....	660
Table 9.7.1-4: Aerosol MAR from Dropped Inoculum	660
Table 9.7.1-5: Aerosol Respiration Concentrations in ABSL-4 AHR	661
Table 9.7.1-6: Viral Concentration Distribution in Urine and Feces (log PFU/g)	661
Table 9.7.1-7: Liquid Waste MAR for ABSL-4 AHRs	662
Table 9.7.1-8: Solid Waste MAR from AHRs	662
Table 9.7.1-9: Injected Inoculum MARs.....	663
Table 9.7.1-10: Respiratory MARs from Cut Suit by Rogue Animal.....	663
Table 9.7.1-11: Viral Concentration Distribution in Oral/Nasal Region (PFU).....	664
Table 9.7.1-12: MARs from Animal Bite Injection.....	664
Table 9.7.1-13: Respiratory MARs from Small Suit Tear.....	665
Table 9.7.2-1: ABSL-4 Necropsy Use and Frequency	665
Table 9.7.2-2: Viral Concentration Distribution in Blood and Tissue.....	666
Table 9.7.2-3: Aerosolized Tissue in ABSL-4 Necropsy per Day.....	667
Table 9.7.2-4: Aerosolized Blood in ABSL-4 Necropsy per Day.....	667
Table 9.7.2-5: Aerosol MARs for ABSL-4 Necropsy Room	668
Table 9.7.2-6: Liquid Waste MAR in ABSL-4 necropsy room	668
Table 9.7.2-7: Solid Waste Contributions in ABSL-4 Necropsy Room (per Study).....	669
Table 9.7.2-8: Solid Waste Contributions in ABSL-4 Necropsy Room (per Necropsy Day).....	669
Table 9.7.2-9: Solid (Red Bag) Waste MARs from ABSL-4 Necropsy Room	670
Table 9.7.2-10: Solid Tissue and Carcass Waste from ABSL-4 Necropsy Room.....	670
Table 9.7.2-11: Respiratory MARs for ABSL-4 Necropsy Room	671
Table 9.7.2-12: Transference Injection MAR for ABSL-4 Necropsy Room	671

Table 9.7.2-13: Transference Palm Contact MAR for ABSL-4 Necropsy Room.....	672
Table 9.7.2-14: Transference Fomite Contact MAR for ABSL-4 Necropsy Room	672
Table 9.8-1: Summary of Mitigating Systems and Nodes – Reduction Factors and Probabilities	674
Table 9.8.1-1: ABSL-4 Animal Holding Room – Aerosol Release Through Dropped Inoculum (L4AAi)	681
Table 9.8.1-2: ABSL-4 Animal Holding Room – Aerosol Release Respiratory Shedding (L4AA).....	685
Table 9.8.1-3: ABSL-4 Animal Holding Room – Liquid Waste (L4AL)	689
Table 9.8.1-4: ABSL-4 Animal Holding Room – Solid Waste (L4AS)	692
Table 9.8.1-5: ABSL-4 Animal Holding Room – Transference (Injection from Inoculum) (L4ATli).....	695
Table 9.8.1-6: ABSL-4 Animal Holding Room – Transference (Respiratory from Cut Suit) (L4ATR)	698
Table 9.8.1-7: ABSL-4 Animal Holding Room – Transference (Injection from Animal Bite) (L4ATI)	701
Table 9.8.1-8: ABSL-4 Animal Holding Room – Transference (Respiratory through Suit Tear) (L4ATRs) .	705
Table 9.8.2-1: ABSL-4 Necropsy – Aerosol Release (L4NA).....	709
Table 9.8.2-2: ABSL-4 Necropsy – Liquid Waste (L4NL)	713
Table 9.8.2-3: ABSL-4 Necropsy – Solid Red Bag Waste (L4NSW)	716
Table 9.8.2-4: ABSL-4 Necropsy – Solid Waste from Tissue and Carcasses (L4NST).....	718
Table 9.8.2-5: ABSL-4 Necropsy – Transference (Respiratory through Suit Leak) (L4NTRs).....	720
Table 9.8.2-6: ABSL-4 Necropsy – Transference (Injection from Cut with Tool) (L4NTI).....	722
Table 9.8.2-7: ABSL-4 Necropsy – Transference (Contact with Palm through Cut PPE) (L4NTCp)	725
Table 9.8.2-8: ABSL-4 Necropsy – Transference (Contact with Fomite) (L4NTCf)	727
Table 9.9.1-1: Impact of the Hendra Outbreaks	730
Table 9.9.1-2: Summary of 1998-2001 NiV Outbreak Impacts	732
Table 9.9.2-1: Infectious Dose Thresholds for NiV and HeV	737
Table 9.9.2-2: Threshold Q Values for Infectious Dose to Large Mammal ^a	739
Table 9.9.2-3: Probability that Susceptible Species are Proximal to the Release (P_{i-2} proximal)	740
Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event	743
Table 9.9.2-5: Relative Impact Score Calculations	756
Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event.....	761
Table 9.10.2-1: Frequency of Infection, Impact, and Risk by Aerosol (Dropped Inoculum) Pathway (Sorted by NiV Risk, Low to High).....	773
Table 9.10.2-2: Frequency of Infection, Impact, and Risk by Aerosol Pathway (Sorted by NiV Risk, Low to High)	774
Table 9.10.2-3: Frequency of Infection, Impact, and Risk by Liquid Waste Pathway (Sorted by NiV Risk, Low to High)	779
Table 9.10.2-4: Frequency of Infection, Impact, and Risk by Solid Waste Pathway (Sorted by NiV Risk, Low to High)	780
Table 9.10.2-5: Frequency of Infection, Impact, and Risk by Transference Injection Pathway (Sorted by NiV Risk, Low to High)	783
Table 9.10.2-6: Frequency of Infection, Impact, and Risk by Transference Respiratory Pathway (Sorted by NiV Risk, Low to High)	784
Table 9.10.2-7: Frequency of Infection, Impact, and Risk by Transference Contact Pathway (Sorted by NiV Risk, High to Low)	789

Table 9.10.2-8: Events with Associated Risk and Proposed Risk Mitigations (Sorted by Event Frequency)	797
Table 10.2.5-1: Updated SSRA Recommendations Summary.....	814
Table 10.3-1: Summary of 2010 SSRA Recommendations and DHS Responses	816
Table 10.3.4-1: NAS SSRA Committee Findings Summary and DHS/Updated SSRA Response	822

Glossary of Acronyms and Terms

AAALAC	Association for Assessment and Accreditation for Laboratory Animal Care
AAHL	Australian Animal Health Laboratory
ABSL	Animal Biosafety Level
APHIS	Animal and Plant Health Inspection Service
APHIS-VS	Animal and Plant Health Inspection Service – Veterinary Services
ARF	Aerosol Release Fraction
ARS	Agricultural Research Service
AUSVETPLAN	Australian Veterinary Emergency Plan
ACVP	American College of Veterinary Pathologists
BDM	Biotechnology Development Module
BEA	Bureau of Economic Analysis
BMBL	Biosafety in Microbiological and Biomedical Laboratories
BRI	Biosecurity Research Institute
BSAT	Biological Select Agents and Toxins
BSC	Biological Safety Cabinet
BSL	Biosafety Level
CAFO	Concentrated animal feeding operation
CDC	Center for Disease Control (aka CDCP)
CDCP	Center for Disease Control and Prevention (aka CDC)
CEAH	Centers for Epidemiology and Animal Health
CFSPH	The Center for Food Security and Public Health
cGMP	current Good Manufacturing Practices
CSCHAH	Canadian Science Centre for Human and Animal Health
CSIRO	Commonwealth Scientific and Industrial Research Organization
CUP	Central Utility Plant
cwt	Hundredweight
D&B	Dunn and Bradstreet
DADS	Davis Animal Disease Simulation
DEFRA	United Kingdom, Department of Environment, Food and Rural Affairs
DHS	Department of Homeland Security
DoD	Department of Defense
DOT	Department of Transportation
DSAT	Division of Select Agent and Toxins
DTRA	Defense Threat Reduction Agency
DVM	Doctor of Veterinary Medicine
EDS	Effluent Decontamination System
EIS	Environmental Impact Statement

EOPs	Emergency Operations Plans
EPA	Environmental Protection Agency
EPCRA	Emergency Planning Community Right-to-Know Act
ERA	European Centre for Medium-Range Weather Forecasts Re-Analysis
ERA-Interim	European Centre for Medium-Range Weather Forecasts Interim Re-Analysis
ERP	Emergency Response Plan
ERS	Economic Research Service
EU	European Union
FAD	Foreign Animal Disease
FADD	Foreign Animal Disease Diagnostician
FADDL	Foreign Animal Disease Diagnostic Laboratory
FADRU	Foreign Animal Disease Research Unit
FEMA	Federal Emergency Management Agency
FMD	Foot and Mouth Disease
FMDv	Foot and Mouth Disease virus
GAO	Government Accountability Office [of US Congress]
GMP	Good Manufacturing Practices
GNL	Galveston National Laboratory
GSF	Gross Square Feet
HEPA	High Efficiency Particulate Air
HeV	Hendra virus
HHS	Health and Human Services
HPAC	Hazard Prediction and Assessment Capability
HSPD	Homeland Security Presidential Directive
HVAC	Heating, Ventilation and Air Conditioning
IAH	Institute of Animal Health
IATA	International Air Transport Association
ICC	International Code Council
ID	Infectious Dose
IMPLAN	Impact Analysis for Planning
ISC	Interagency Security Commission
ISO	International Standards Organization
JEM	Joint Effects Model
K-State	Kansas State University
LAI	Laboratory Acquired Infection
LEPCs	Local Emergency Planning Committees
LMIC	Livestock Marketing Information Center
MAR	Material available for release
MESA	Multiscale Epidemiological/Economic Simulation and Analysis
MFD	Manhattan Fire Department

MHK	Manhattan Regional Airport
MID	Minimum Infectious Dose
MOU	Memorandum of Understanding
MPH	Master of Public Health
MPH	Miles per hour
MPPS	Most Penetrating Particle Size
MRHC	Mercy Regional Health Clinic
MTV	Minute Tidal Volume
NAADSM	North American Animal Disease Spread Model
NAHLN	National Animal Health Laboratory Network
NAS	National Academy of Sciences
NASS	National Agricultural Statistics Service
NBACC	National Biodefense Analysis and Countermeasures Center
NBAF	National Bio and Agro-Defense Facility
NCAH	National Centers for Animal Health
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NCFAD	National Center for Foreign Animal Disease
NDP	NBAF Design Partnership
NEHRP	National Earthquake Hazards Reduction Program
NIH	National Institute of Health
NIMS	National Incident Management System
NiV	Nipah virus
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRC	Nuclear Regulatory Commission
NSF	Net Square Feet
NVSL	National Veterinary Services Laboratories
O&M	Operation and Maintenance
OHS	Occupation Health Services
OIE	World Organisation for Animal Health
OSHA	Occupational Safety and Health Administration
OSTP	Office of Science and Technology Policy (White House)
PFU	plaque-forming units
PIADC	Plum Island Animal Disease Center
PMP	Probable Maximum Precipitation
PPE	Personal protective equipment
PReP	Preparedness and Response Plan
R&D	Research and Development
RCEM	Riley County Emergency Management

RIMS	Regional Input/Output Modeling System
RVF	Rift Valley Fever
RVFv	Rift Valley Fever virus
S&T	Science and Technology
SARA	Superfund Amendments and Reauthorization Act
SCIPUFF	Second-order Closure Integrated PUFF (model)
SME	Subject Matter Expert
SOMs	Self Organizing Maps
SOP	Standard Operating Procedure
SPC	Storm Prediction Center
SSO	Sanitary Sewer Overflow
SSRA	Site-Specific Risk Assessment
STAR	Science and Technology in Atmospheric Research (Institute)
TAD	Targeted Advanced Development
TCID	Tissue Culture Infectious Dose
U.S.	United States
UFC	Unified Facilities Criteria (Department of Defense)
UK	United Kingdom
USDA	United States Department of Agriculture
USDHHS	United States Department of Health and Human Services
USGS	U.S. Geological Survey
V.M.O.	Veterinary Medical Officer
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

6. Epidemiological Model

6.1 Modeling Approach

6.1.1. Overview

For each release event from the NBAF that causes a Foot-and-Mouth Disease (FMD) infection at a livestock premises, the consequences of that outbreak must be calculated to understand overall risk. The following approach was taken to predict the probability of an outbreak occurring following a release, to determine where the outbreak begins, and to determine the corresponding consequences of the outbreak:

- Determine the probability that an outbreak starts in various possible locations given release quantity and transport pathways;
- Estimate the extent and duration of the possible FMD outbreaks in Kansas;
- Determine the probability that an outbreak would spread from Kansas to other states;
- Estimate the extent and duration of possible FMD outbreaks in states other than Kansas; and
- Determine overall risk by combining impact and probability of outbreaks occurring across the region for each release amount and transport pathway.

Although this analysis is extensive and is substantially based on data collected from the field and the scientific literature, it is fundamentally a modeling-based approach and therefore has limited ability to predict the absolute probability of an outbreak occurring and the corresponding consequences. That being said, given the shortcomings of the modeling approach (as described in section 6.2.2), the data presented include as thorough a treatment of uncertainty in the modeling as possible. Aleatory uncertainty related to the location in which the outbreak starts (which can be a function of the meteorology on the date the accident happens, for example) is displayed along with uncertainty related to how the outbreak unfolds. Outbreak consequences have components of aleatory and epistemic uncertainty. For example, one source of aleatory uncertainty arises from the timing of an animal shipment relative to the infection of animals on a premises. An example of a source of epistemic uncertainty is the probability of infection should a veterinarian visit an infected farm before visiting an uninfected farm. This uncertainty is presented to provide a reasonable range of possible outbreak risks. Given that the model is sensitive to many parameters that are themselves uncertain (for example, the risk of infection as a result of indirect contacts between two dairies separated by a distance), it is possible that the true absolute risk of an outbreak lies outside this range, but this is a shortcoming that cannot be addressed by modeling; only further data collection can reduce epistemic uncertainty.

Results that speak to the relative benefit and cost of measures to reduce risk are presented in the context of the uncertainty described above and also subjected to sensitivity analysis. In the uncertainty

analysis, modeling parameters are varied to ensure that the conclusions are robust. Uncertainty analysis is useful in this context because the value of risk mitigation measures can be understood by their relative effect on risk.

6.1.2 Region Modeled

The states modeled for the Updated SSRA were chosen based on SME input, the Interstate Livestock Movement Report [Shields & Mathews Jr., 2003] and destinations listed on Certificates of Veterinary Inspection (CVIs) issued for animals leaving the nine counties (Marshall, Washington, Clay, Riley, Pottawatomie, Geary, Waubunsee, Dickinson, and Morris Counties) nearest the NBAF during the first seven months of 2011 (see Appendix A6, Epidemiological Methods). The Interstate Livestock Movement Report carried more weight than the CVI data in this process because this report accounts for movement of animals from across the entire state for a full calendar year. Based on these sources, the region modeled included: Kansas, Nebraska, Colorado, Iowa, Missouri, Texas, and Oklahoma. These states account for 89% of animals leaving the state of Kansas, and 96.5% of animals leaving the area near the NBAF to travel to another state (Table 6.1.2-1). Like Oklahoma, Minnesota receives only 2% of total outbound animal shipments; however, Oklahoma was included in the modeling because it shares a border with Kansas. According to the National Agricultural Statistical Services (NASS), these seven states account for 66% of the total cattle, 47% of the total swine, 49% of the total sheep, and 32% of the total goat population in the United States. The approach to handling spread of FMD from Kansas to other states does not take into account secondary spread from other states and therefore animal shipments originating in states other than Kansas were not considered when determining which states to model (see section 6.1.5).

Table 6.1.2-1: Data Used to Select States to be Included in the Region Modeled

State	% of total movements out of Kansas in 2001 (Shields & Mathews Jr., 2003)	% of animals shipped from nine county area near the NBAF
Nebraska	35	53
Colorado	20	3
Iowa	14	35
Missouri	12	.5
Texas	6	4
Oklahoma	2	1

The 2010 SSRA was criticized for failing to include all 50 states, Canada, and Mexico. It was also criticized for modeling too large a region given the limitations of the modeling program used, the North American Animal Disease Spread Model (NAADSM, version 3.2.18) [NAADSM Development Team, 2011] and for using a single set of parameters to describe livestock agriculture in diverse regions of the United States. There are many impediments to adequately addressing these critiques in the Updated SSRA. To

date, no group has developed parameters for use within NAADSM that adequately account for interstate movement of animals, although one could approximate interstate transport by modeling states individually (as described here) or by using state-specific or region-specific parameterization. Next, the amount of effort needed to develop parameters to adequately model the diversity of agriculture in the United States, much less all of North America, would require multiple years of full-time investment. Even with the parameters and models in place, the computational power needed to run the experiments required for the Updated SSRA with such a model outstrips available resources. Given the approach chosen, it is important to note that economic estimates based on the outputs of the economic model for the Updated SSRA will, again, underestimate the absolute impact of an outbreak of FMD originating from the NBAF because the outbreak is artificially limited to the region modeled instead of the whole of North America. However, these data are still very useful for comparing the relative severity of an outbreak given different release events and mitigation strategies.

6.1.3 Determining Outbreak Starting Locations

To determine the consequences and extent of an FMDv outbreak resulting from a release from the NBAF, it must be determined where an outbreak starts. As discussed below (section 6.1.4), the impact and extent of the outbreak depends significantly on the type of livestock initially infected and the connectedness of the infected premises with the livestock industry as a whole. Section 4 describes the method to estimate the probability of an event occurring, the method to determine the amount of pathogen released and the means by which the infectious material is transported in the environment. This section describes the use of these outputs to calculate the probability that any given premises becomes infected with FMDv. The method to calculate risk of infection at any premises is specific to an event pathway. In the following subsections, the methods used for three pathways are described: infectious aerosol releases; contaminated personnel or fomites; and the release of contaminated waste.

6.1.3.1 Aerosol Pathways

Several release events at the NBAF generate an infectious aerosol. In this section, the method to predict where outbreaks begin due to the release of an aerosol of FMDv due to an event at the NBAF is described. This method was NOT used to predict how aerosols would contribute to the spread of FMD from one infected herd to a susceptible herd (NAADSM was used to predict the contribution of aerosols generated by infected animals outside of the NBAF to the spread of disease). As described in Section 5, the time-integrated concentration of FMDv in a release is calculated based on the possible meteorology at the site and is then used to calculate the risk that an accidentally generated aerosol starts an infection in any livestock premises downwind.

In the 2010 SSRA, any livestock premises where animals inhaled 0.1 plaque forming unit (PFU—a PFU of FMDv is roughly equivalent to one viable virus) or more on average were considered to be at a location where a single infection could occur. This approach was taken for several reasons. First, the plume models calculated mean dosage, while in reality some of the animals in this location received more than this amount and some received less. Secondly, a viral aerosol is composed of discrete biological particles which cannot deliver a nonzero dose less than 1 PFU (that is, an animal either inhales more than one

virus particle, one virus particle, or inhales none). Therefore in an area with a mean inhaled dose of 0.1 PFU, most of the animals present likely would inhale no pathogens, and a minority of the animals present would inhale one. Although a minimum infectious dose (MID) is often reported for FMD, other experts state that “when sufficient numbers of susceptible animals are exposed to products which have low levels of contamination (even if all animals receive less than the reported MID) there is still a likelihood of infecting one animal from the group” [Sutmoller et al., 1997]. For this reason, the 2010 SSRA assumed that an infection started at any premises that received more than 0.1 PFU on average.

However, the method used in the 2010 SSRA had several weaknesses. First, the dose threshold set was not strongly evidence-based. Secondly, this method does not consider that risk of at least one infection in a herd should be a function of the number of exposed animals in that herd. That is, a herd of 100 animals is more likely to suffer at least one infection if all animals received a small dose than is a herd of 10 animals receiving a similar dose. For these reasons, the Updated SSRA uses a more rigorous method to calculate the probability of infection from any dose downwind that explicitly considers the number of animals in each premises.

In the Updated SSRA, the time-integrated concentration of FMDv was obtained by atmospheric modeling at each exposed livestock premises. Using species specific minute-tidal volumes for sheep, swine and cattle, these data were used to calculate a dose for an average animal on that premises. For goats, the sheep minute tidal volume was used.

To calculate the probability that an individual animal would get infected by any given dose, probit analysis was used. The data sources used to support this analysis are provided in Appendix A6, Infectious Dose 50 (ID₅₀) and Probit Analysis: Aerosol and Intranasal Exposure. The probit relationship enables the calculation of a probability of infection for an animal for any given dose, not just the median infectious dose. Note that although the ID₅₀ for sheep was considered to be smaller than the ID₅₀ for cattle, the larger minute-tidal volume of cattle actually makes them more susceptible to an aerosol of a given concentration. For goats, the sheep dose-response curve was used.

Table 6.1.3-1: The Probit Slope and ID₅₀ for Cattle, Swine and Sheep Exposed to FMDV via Aerosol

Animal	Probit Slope	ID ₅₀ (PFU)
Cattle	0.33	15
Swine	0.89	30,000
Sheep (and goats)	0.72	3

Data supporting this analysis can be found in Appendix A6.

For swine, this relationship can be used to predict nonzero probabilities of infection at very low doses of FMDv. To account for the fact that larger herds will be at greater risk of suffering at least one infection from an aerosol than smaller herds, the probability of infection for an individual animal was used to determine the probability of infection of at least one animal in a herd by considering that each animal in that herd would have an independent chance of infection. Given this method, each premises was

assigned a dose threshold (which is a function of herd size), above which the probability of infection of at least one animal was greater than 50% (Figure 6.1.3-1). This analysis works well because there are no swine herds that have a threshold dose lower than one PFU that were exposed to artificially generated aerosols from the NBAF (which is approximately equal to one infectious viral particle of FMDv).

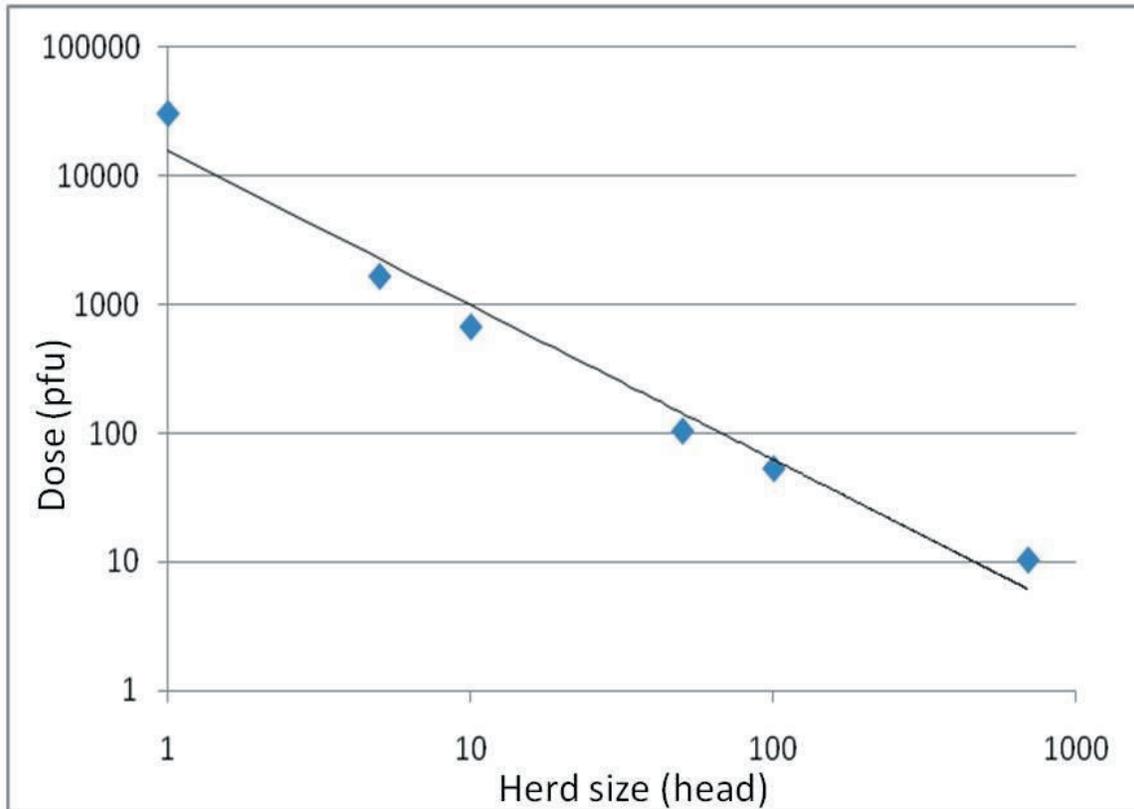


Figure 6.1.3-1: Threshold dose of FMDv to generate a 50% probability of at least one infection in a herd of swine. Both axes are log scale.

Note that the threshold for a herd of one animal is equal to the ID_{50} and the threshold drops below one PFU only for very large swine herds. Should a herd of swine with more than 1,000 be exposed to aerosols generated from accidents at the NBAF, this analysis would be extended.

For cattle and sheep, however, the shallow probit slope and low ID_{50} combine to predict significant probabilities of infection at doses well below 1 PFU. For example, probit analysis suggests that at least one animal in a herd of 10 cattle is likely to become infected by a dose of 0.001 PFU (a dose for which the probability of infection per animal is predicted to be near 7%). Therefore the method used for swine is unrealistic for cattle and sheep because an animal is not at risk if exposed to less than a single infectious viral particle and real aerosols can deliver only whole particles, not fractional ones. That is, a 50% probability of infection of at least one animal is predicted to occur when all the animals in the herd combined receives less than $1/100^{\text{th}}$ of a PFU, which the Updated SSRA team knows would pose no risk

of infection because no animal in the herd is predicted to inhale at least one virus particle. To further assess this very low threshold for cattle, a model was used in which 210 PFU of FMDv was released from the NBAF across the suite of meteorological conditions. Even though the premises infected represented less than 1/1,000th of the total footprint of the aerosol plumes generated, this tiny release resulted in the *simultaneous* infection of up to three different premises, further underscoring that this threshold is unrealistically low for cattle. For these reasons, a strictly probit-based threshold was not used for cattle and sheep facilities.

In place of the method used for swine, the baseline approach for determining which cattle and sheep premises are infected by an aerosol uses the likelihood of at least one animal in a herd inhaling 1 PFU, as this value is close to the minimum dose that could be delivered by a biological aerosol and can plausibly cause an infection. Because of the low ID₅₀ and shallow probit slope of FMDv in cattle and sheep, the probability of infection at 1 PFU is predicted to be significant (35% for cattle). In the calculations, the dose entrained by each animal in a herd is summed; if the herd collectively inhales 1 PFU or more, an infection is considered to occur. For example, an infection would occur in a herd of 10 cattle if the dose received by a cow in this location was calculated to be 0.1 PFU or greater, whereas the threshold for a 500 cattle operation would be 0.002 PFU. This method relies on the assumption that the air around the herd is well mixed.

Many researchers have proposed that there is no risk of infection for doses of FMDv lower than a certain amount, called the “minimum infectious dose.” The review of this literature is presented in Appendix A6, Infectious Dose 50 (ID₅₀) and Probit Analysis: Aerosol and Intranasal Exposure. The smallest value proposed for the minimum infectious dose is presented in Table 6.1.3-2.

Animal	Minimum Infectious Dose
Cattle	9 PFU
Swine	150 PFU
Sheep (and goats)	7 PFU

These values might represent a phenomenon in which a minimum number of pathogen particles are required to overcome host defenses and establish an infection, or they could be an artifact of the use of a small number of animals in infection experiments (i.e., if five animals were used, identifying doses that cause less than a 20% probability of infection is difficult). The method based on minimum infectious dose is used in the sensitivity analysis described below to examine risk if a less aggressive threshold of infection is used for cattle and sheep (and goats). Additionally, the modification of these two thresholds by a factor of two is explored to determine if the exact values used in the thresholds significantly drive the risk that an infection will start in a premises.

Table 6.1.3-3: Probit Slope and ID₅₀ for Cattle, Swine, and Sheep/Goats Exposed to FMDv via Aerosol

Animal	Baseline Threshold Basis	Alternate Threshold Basis
Cattle	1 PFU inhaled by herd in aggregate	One minimum infectious dose inhaled by herd in aggregate
Swine	Probit analysis	Probit analysis
Sheep/goats	1 PFU inhaled by herd in aggregate	One minimum infectious dose inhaled by herd in aggregate

Data supporting this analysis can be found in Appendix A6.

Additionally, in this study, an aerosol was considered to pose two possible infection pathways for susceptible species: direct inhalation of pathogens suspended in an aerosol by an animal, or ingestion by an animal of grass or fodder contaminated by pathogens deposited by an aerosol. However, it was determined that it is very unlikely that a herd will have an animal that received an infection via ingestion of aerosol-contaminated material and not also have an animal infected directly from the aerosol. When the dose expected to be directly inhaled was compared to the amount expected to be consumed through aerosol deposition, it was found that the inhaled dose was several-fold larger. In addition, the FMDv oral ID₅₀ is several orders of magnitude greater than the FMDv inhalation ID₅₀ (Alexandersen et al., 2003). Finally, many animals in Kansas are fed processed feeds which present a much smaller surface area for aerosol contamination compared to grass-based forage. For these reasons, although infection from pathogens deposited by an aerosol was considered, it was determined that this pathway posed no additional risk over direct infection from the aerosol itself.

6.1.3.2 Transference Pathways

There exist innumerable paths from the release event to outbreak initiation via transference (the transport of infectious material in or on a person or fomite). In order to determine the most likely of these paths, employees of the Biosecurity Research Institute (BRI) at Kansas State University (K-State) were interviewed on their typical movements and behaviors both within the BRI and upon leaving the facility. The BRI is a new BSL-3E and large animal (BSL-3Ag) research facility immediately adjacent to the site on which the NBAF is being constructed. This proximity allows BRI researchers and employees to serve as valid proxies for describing the behaviors of the workers at the NBAF. These workers are drawn from the same community that will provide workers for the NBAF, thus the two groups will represent similar demographics in terms of outside activities. In addition, the similarities in activities within each facility (both provide containment research space for high consequence agricultural pathogens) ensure that behaviors within the two facilities are comparable. FMD is not studied at the BRI, however, so some assumptions had to be made to account for behaviors that some BRI employees displayed that would be prohibited when working with FMDv; these are described in Section 5.4.

Once an outbreak is predicted to occur due to the transference pathway, the outbreak starting location is determined by analyzing the interview data gathered from personnel on the K-State campus. When an interviewee mentioned that they visited a farm, that farm's location was modeled as a possible starting location. The probability that an outbreak would start at any given location is proportional to the

number of respondents who mentioned visiting farms in that location. This method therefore explicitly considers that outbreaks caused by transference may not start near the NBAF. That is, if 20% of respondents mentioned visiting farms in Topeka, the model would start 20% of the outbreaks from transference in Topeka. Because the majority of livestock premises in Kansas are cow-calf operations (and because respondents did not give consistent premises types in their responses), each outbreak was considered to start in a cow-calf operation. Rodeos and state fairs are not premises types currently modeled in NAADSM, so these locations were ignored as possible starting locations to determine the extent of an outbreak (importantly, they still contribute to the chance that an outbreak occurs as described above). To maintain privacy of the respondents, farm location data was collected at the town- or county-level only (no specific addresses were collected); therefore a median-sized cow-calf operation was selected for each location mentioned.

A total of 27 researchers and support staff at the BRI were interviewed. Both scientific and support staff were selected in order to account for all types of personnel that will be present in the NBAF; these included research scientists, laboratory technicians, a graduate student, K-State faculty, a veterinarian, lab coordinators, biosafety specialists, maintenance and building systems personnel, security personnel, and a network technician. In addition to BRI employees, 110 people selected randomly from locations on the K-State campus were interviewed. This group of people was chosen to represent the community surrounding the NBAF and determine likely points of interaction between the two communities.

Both groups of participants were asked how often they visited facilities that contain susceptible species, including farms, campus facilities with livestock, veterinarian offices, rodeos and state and county fairs. The locations and species present at these facilities were recorded. Participants were asked whether they handled animals or were simply at the location. Additionally, participants were asked the occupations of the people they live with, and whether any individuals with whom they have regular contact handle livestock.

Sixty-six of the 137 people interviewed (27 from the BRI, 110 from K-State) indicated that they visit livestock on a regular basis. These 137 interviewees described visiting 66 farms that correspond to 37 unique locations in Kansas. These sites were very evenly spread across the state of Kansas; the mean and median distances from the NBAF were 103.2 and 95.5 miles, respectively (Table 6.1.3-4). The majorities of farm locations were unique, and thus had a 2.1% chance of being the starting point of an infection each. Only five of the locations were mentioned by multiple interview participants; the most common was Manhattan, Kansas, with a probability of 10.6% to be the starting location (Table 6.1.3-5).

A few respondents mentioned that they visited susceptible species outside of Kansas (in other US states and as far away as Mexico). Because the model developed for this study calculates interstate spread only from Kansas and not all of the locations mentioned are modeled in this study (e.g., Mexico), outbreaks initiated in other states were re-assigned a probability of starting in Kansas (otherwise, outbreaks modeled as beginning in other states would be artificially small because the model does not consider that the disease can spread from any other state to another except from Kansas).

The method used captures the possibility that events at the NBAF could initiate outbreaks far from Manhattan, Kansas. As described below, because all starting locations are considered cow-calf operations (because they are the preponderance of locations in Kansas), there is relatively little variance in the results due to starting locations (section 6.2). To address this shortcoming, a method must be devised to sample a possible starting location without biasing the results to assume that an outbreak always starts in a higher-risk premises (like a large feedlot) in locations that would normally be represented by a single starting location. Potentially, the number of each type of facility in each location mentioned by an interviewee could be calculated to determine the probability of an outbreak starting in any particular facility type. This approach would greatly expand the number of model runs needed to simulate risk from transference.

Even with this shortcoming, because the probability of a start in a given location is based on the number of respondents mentioning that site was visited, this method does capture how much of the outbreak starting risk is nearby the NBAF and distant from it. This method therefore greatly informs the benefit of potential mitigation measures that are specific to regions surrounding the NBAF (active surveillance, educational programs for producers, etc.).

Table 6.1.3-4: Descriptive Statistics of Distances to Potential Infection Starting Locations (in miles from the NBAF)

Mean:	103.2
Standard Deviation:	77.8
Minimum:	2.0
5th Percentile:	13.3
Median:	95.5
95th Percentile:	281.3
Maximum:	320.0

Table 6.1.3-5: Locations of Farms Visited by Interview Subjects

Location	Number of Responses	% of Responses
Manhattan	5	10.64%
Huchinson	3	6.38%
Clay Co.	2	4.26%
Marshall Co.	2	4.26%
Riley Co.	2	4.26%
Washington Co.	2	4.26%
Wichita	2	4.26%
Allen	1	2.13%
Alma	1	2.13%
Blaine	1	2.13%
Clafin	1	2.13%

Table 6.1.3-5: Locations of Farms Visited by Interview Subjects

Location	Number of Responses	% of Responses
Dodge City	1	2.13%
El Dorado	1	2.13%
Ellsworth	1	2.13%
Emporia	1	2.13%
Green	1	2.13%
Gypsum	1	2.13%
Hays	1	2.13%
Holton	1	2.13%
Hope	1	2.13%
Jefferson Co.	1	2.13%
Kansas City	1	2.13%
Lakin	1	2.13%
Liberal	1	2.13%
McPherson	1	2.13%
Newton	1	2.13%
Pottawatomie Co.	1	2.13%
Pratt	1	2.13%
Russell Co.	1	2.13%
Scott City	1	2.13%
Seneca	1	2.13%
Spring Hill	1	2.13%
Topeka	1	2.13%
Valley Center	1	2.13%
Wamego	1	2.13%
Winfield	1	2.13%

6.1.3.3 Waste Pathways

To determine where outbreaks may start due to events that allow infectious waste to accidentally leave the NBAF, likely locations of contaminated waste were compared to the locations of susceptible species. Simply put, for each transport pathway, the closest livestock premises was identified as the starting location. For the solid waste pathway, the premises closest to the Riley County Transfer Station and to the location of the final disposition of waste, Hamm Quarry in Jefferson County, were identified. For the liquid waste pathways, the premises closest to the location of the spills were identified. If two types of livestock were present on the premises, these premises were considered as two possible starting locations (because no one has developed a straightforward mechanism to allow NAADSM to account for facilities housing multiple species of animals – see section 6.1.4.3 for more detailed discussion).

6.1.4 Estimating Extent of Outbreaks in Kansas

The extent and duration of FMD outbreaks in Kansas were estimated using the NAADSM v 3.2.18, a stochastic state-transition model that simulates outbreaks of animal disease in a geographically defined population. Disease progression, disease spread and outbreak control are parameterized by the user. This section describes the parameters used to build the baseline NAADSM event file for the state of Kansas, which was used to estimate the extent of an outbreak of FMD using outbreak starting locations identified for each potential NBAF release pathway (see section 6.1.3).

6.1.4.1 Choice of Epidemiological Model

For the 2010 SSRA, several models described in the peer-reviewed literature were evaluated for epidemiological modeling. The North American Animal Disease Spread Model (NAADSM) was selected for use in the 2010 SSRA FMD modeling [DHS, 2010] and used again in this Updated SSRA. USDA also uses NAADSM for their FMD epidemiological modeling, allowing the Updated SSRA team to leverage the parameters developed for USDA studies in this analysis.

6.1.4.2 USDA NAADSM Parameter Sets

The data used to develop NAADSM parameters came from a variety of sources including government reports, open source literature and interviews with subject matter experts (SMEs). Parameter sets developed for FMD and other epidemiological models at USDA and DHS were leveraged to ensure the Updated SSRA epidemiological model was built using the best available data. Several of these reports are not publicly available, but were used extensively for parameter development.

Two NAADSM modeling studies completed at USDA provided many of the parameters used for the Updated SSRA epidemiological model. These reports will be referenced in the upcoming text using the following abbreviations:

- “USDA 2011” will refer to: USDA. [2011]. Draft. Vaccination Against Foot-and-Mouth Disease: Epidemiologic and Economic Consequences of Production Specific Vaccination Strategies. USDA-APHIS-VS-CEAH. Fort Collins, Colorado.
- “USDA 2009” will refer to: USDA. [2009]. Draft. Model Scenario and Parameters for Estimating the Number of Foot-and--Mouth Disease Vaccine Doses Required in the Event of an Outbreak in Kansas. USDA-APHIS-VS-CEAH. Fort Collins, Colorado.

The Updated SSRA team carefully reviewed the underlying evidence basis and the logic used to create the USDA parameters and corresponded with report authors when additional information was necessary to understand parameter development; this correspondence is sometimes referenced in the parameter development section. USDA updated several parameters from the 2009 study (so the study parameters do not match the Updated SSRA parameters); these updates are noted.

6.1.4.3 NAADSM Modeling Parameter Development and Data Collection

The NAADSM modeling parameter section is organized using the order in which data is entered into NAADSM through event parameter entry prompts in order to ensure that all input parameters are

accounted for and to facilitate independent validation of results. A parameter entry guide is provided in Appendix A6 that collates all parameters and gives instructions for check box selections that are only implied in the main body of the write-up. The Appendix is intended to provide a level of detail sufficient to set up a NAADSM event file and repeat Updated SSRA experiments, while this section focuses on giving an overview of the evidence basis and parameter development methods. When a detailed discussion is required for an individual parameter, a supplemental section is referenced in the Appendix.

Subject matter experts consulted for parameter development are listed in Appendix, Subject Matter Experts (SMEs) Consulted for Parameter Development, and are sorted by parameter. Individual interviews are not referenced in the parameter development discussion because as many as 15 SMEs may have been consulted when developing a parameter.

General NAADSM Setup

General NAADSM setup, including the number of iterations run per event, can be found in Appendix A6.

Production Types

Most of the production types used for the Updated SSRA were based on USDA 2009. These production types included both sheep and goats, addressing concerns expressed by SSRA reviewers. Three additional production types were developed in response to SSRA reviewer comments to describe backyard and small-scale producer facilities. Parameters associated with these production types were developed from interview data and SME input.

In addition to domestic livestock, wildlife (including feral swine) almost certainly contribute to the spread of FMD [Mohamed et al., 2011; Ward et al., 2011]. Several susceptible wildlife species were identified in Kansas, including small populations of elk, pronghorn, feral swine and a significant deer population (see Appendix A6). At this time, no one has developed a method to quantitatively include wildlife in NAADSM. Local area spread parameters attempt to capture some of the contribution of wildlife to FMD spread during an outbreak, but this representation does not capture the full impact wildlife may have on an outbreak. Therefore, wildlife was not included in the Updated SSRA.

Updated SSRA Production Types

In NAADSM, farms are grouped by production type. All farms within a production type share characteristics due to similar livestock management practices and the presence of the same species of animal. For example, one would expect that the frequency with which a farmer observes his cattle to be similar for all dairies, so the probability of a farmer observing a sick cow is defined by one function that applies to all dairies.

Table 6.1.4-1: Production Types Used for the Updated SSRA Epidemiological Model

Updated SSRA production type	Description
Cow-Calf	<i>“Beef cow-calf farms are those which maintain female cattle for the purpose of breeding and production of calves for sale.”^a</i>
Dairy	<i>“Dairy farms maintain cows for the purpose of producing milk.”</i>

Table 6.1.4-1: Production Types Used for the Updated SSRA Epidemiological Model

Updated SSRA production type	Description
	Heifer calves produced serve as replacement heifers in a dairy herd. Bull calves produced are raised and ultimately sent to a beef feedlot for fattening and slaughter.” ^a
Feedlot (L) Feedlot (S)	<i>“Beef backgrounders and feedlots are farms that feed cattle for ultimate slaughter and consumption. They are made up of predominantly young beef animals fattening for slaughter. A small proportion of dairy steers, beef cows or heifers, and dairy cows are also fed for slaughter. The Updated SSRA team has separated feedlots into backgrounders/stockers and finish feedlots based on NASS feedlot size designations. Backgrounder/stocker types are those with less than 3,000 head of cattle and typically send cattle onto finishing feedlots. Finish feedlots are those with 3,000 or more head of cattle.”^a</i>
Swine (L) Swine (S)	<i>“Swine farms are those which maintain swine for the purposes of breeding, feeding, and production. The various types of swine operations (i.e. farrow to wean, finish, nursery, farrow to finish, and farrow to feeder) were not separated, given the absence of data. Swine operations were separated based on size designations. Small swine operations were those with 250 or fewer head of swine and large operations were those with more than 250 head of swine.”^a</i>
Goat Sheep	<i>“Sheep and goat operations are those that raise commercial sheep or goats.”^a</i>
Beef (BY-SS)	Backyard and small-scale (BY-SS) production of cattle raised for beef and dairy for personal use, 4H, show or very small-scale commercial production. For the Updated SSRA, these facilities have 10 animals or fewer. See more detail in the next section “Backyard production types.”
Swine (BY-SS)	Backyard and small-scale (BY-SS) production of swine for personal use, 4H, show or very small-scale commercial production. For the Updated SSRA, these facilities have 10 animals or fewer. See more detail in the next section “Backyard production types.”
SmRu (BY-SS)	Backyard and small-scale (BY-SS) production of small ruminants (sheep and goats) for personal use, 4H, show or very small-scale commercial production. For the Updated SSRA, these facilities have 10 animals or fewer. See more detail in the next section “Backyard production types.”

^aProduction types described in USDA 2009

Backyard Production Types

Backyard and small-scale (BY-SS) farmers were not included in the 2010 SSRA. Detailed parameters describing backyard producers were not regularly included in published FMD models, and the epidemiological modeling parameters used for SSRA were sourced from published models which prevented the inclusion of this facility type in the 2010 SSRA. NAS expressed concern over the exclusion of these producers from the 2010 SSRA. BY-SS producers were included in the Updated SSRA model as

three production types: Beef (BY-SS), Swine (BY-SS), and Small Ruminants (BY-SS). A small-scale producer (regardless of animal species), for this project, has been defined as 10 head or less. Based on SME input, BY-SS producers are a very small subset of the livestock industry, especially in terms of animal numbers.

Very little data are available on BY-SS producers. The MESA model incorporated backyard production types [Tammero et al., 2010]. MESA and NAADSM use different parameters to describe and model disease spread, so the MESA backyard parameters could not be used directly in NAADSM. Insufficient information was available on the evidence basis and parameter development for MESA to support the development of NAADSM parameters using data from MESA.

This year, BY-SS production types were developed from interviews conducted with 30 producers at state fairs in Kansas and SMEs. According to SMEs, the majority of small-scale Kansas producers are involved with 4-H and Future Farmers of America (FFA). Two of these 30 producers did not exhibit animals at county fairs, so they would represent the non-4H or FFA producer. In addition, three small-scale producers from Riley County, Kansas, were interviewed as part of the regional survey near the NBAF. These three producers also were not 4H or FFA members. The data gathered to date from personal interviews with Kansas small-scale producers indicate that a veterinarian would be called if an animal were thought to be sick and therefore would not support the conclusion that these producers would knowingly transport a sick animal to a livestock market just to get rid of it, a concern expressed during the NAS panel discussion for the Updated SSRA. Interviews are described in detail in Appendix A6, Backyard and Small-Scale (BY-SS) Producer Interviews and Data.

One major shortcoming of this dataset is the small number of producers interviewed. It was also difficult to obtain estimates of the number and location of backyard facilities. The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Agricultural Census data, the most comprehensive source of data on regional animal populations, includes only, "... any place from which \$1,000 or more of agricultural products were produced and sold, or normally would have been sold, during the census year" [USDA, 2009]. Thus, the population dataset likely underestimates the number BY-SS producers, and addressing this shortcoming is a major challenge.

Facilities with Multiple Production Types

During data collection for BY-SS facility parameter development, it became clear that a large proportion of BY-SS producers raise multiple species of animals. Additionally, there are several K-State facilities that house multiple species. Facilities housing multiple species of livestock present several modeling challenges. First of all, it is very difficult to identify these facilities. Published NASS data does not facilitate estimation of the prevalence of such facilities, and other resources, such as concentrated animal feeding operation (CAFO) permits, give a limited view. Next, NAADSM does not have a straightforward mechanism for dealing with facilities housing multiple species of animals. For the Updated SSRA, the team assigned a single production type to backyard facilities based on the most prevalent species of livestock. For a few sites on the K-State campus, such as the College of Veterinary

Medicine, the team placed multiple production types at the same latitude and longitude. While this will represent the true risk of these animals becoming the first animals infected by releases from the laboratory, it significantly underestimates the true spread of disease between animals at the same location. Co-localization of animals does not increase contact in NAADSM; for example, if goats and cattle have 0 direct contact in the model, co-localizing them will not increase that contact. This presents a real problem for locations such as the College of Veterinary Medicine and backyard facilities. One way to account for facilities with multiple species of animals in NAADSM is to develop custom production types that have increased direct and indirect contact between species at the same location, while maintaining all the other parameters for that production type. So, for example, a cow-calf facility with a couple of goats on site would have to be parameterized using different production types than a backyard facility that had both cows and goats. The number of special production types this approach necessitates quickly escalates. Furthermore, a large-scale data collection effort would be necessary to develop such a complicated system of parameters, which was not feasible for the Updated SSRA.

Susceptible Animal Populations

The number and specific location of FMD-susceptible animal populations were determined by an extensive data collection effort. This approach accounts for the specific animal populations and densities near the proposed NBAF site, and in the rest of Kansas. The specific populations in other states are described in section 6.1.6.

Farm/Facility Sizes and Locations

A population file was compiled for Kansas and uploaded to NAADSM in the format shown in Table 6.1.4-2. HerdID is a unique number assigned to each facility in the model, and was used for tracking purposes. Herd size is the number of animals in a herd. Lat and Lon are the latitude and longitude of the herd. NAADSM incorporates spatial modeling into its simulations, so it is important to identify farm locations as accurately as possible. Production type describes the species and management practices of that herd. Status indicates the disease state of that herd. S means susceptible; that status was changed to L (latent—the term used in the NAADSM model for animals incubating an infection) when a herd was infected before starting the model. Daysleftinstatus refers to the number of days the herd has left in that disease state; this may be automatically generated by NAADSM as -1 when the population file is uploaded.

Table 6.1.4-2: NAADSM Model Dataset Format

HerdID	Herd size	lat ^a	lon ^a	ProductionType	Status	daysleftinstatus
1	549	40.0000	-96.9696	Cow-Calf	S	-1
2	1477	41.1111	-98.8888	Cow-Calf	S	-1
3	785	43.3333	-102.222	Cow-Calf	S	-1

^aNotional latitude and longitude

For the 2010 SSRA, modeling files were built with data from CAFO permits, data purchased from the Dunn & Bradstreet (D&B) business database, and interviews with K-State officials and facilities identified

in the local yellow pages. While this approach accounted for almost all of the large facilities, and many medium- sized facilities in the region modeled, it underrepresented small and backyard facilities. For the Updated SSRA, the team again used CAFO permit data, D&B data, and interviews with K-State officials to build the animal population file. Additionally, the team collected high-fidelity data through on-the-ground surveys near the NBAF site in Kansas. The team accounted for smaller facilities by also incorporating locations from a dataset developed by Lawrence Livermore National Laboratory (LLNL) using the NASS Agricultural Census data from 2007 [Melius et al., 2006]. In this section the team first describes the data collection effort and then the compilation of multiple datasets into the animal population file used for modeling.

Data Collection and Standardization

Survey of All Animals within 6.2 Miles of the NBAF

Precise data were collected on all animal populations within a 6.2-mile radius of the NBAF site, including the location (lat and lon), herd size and production type of every herd in the region. A 6.2-mile (10 km) radius was selected because this is the size of a quarantine zone according to the Kansas Incident Specific Plan for high-consequence foreign animal diseases. Herds identified for the 2010 SSRA were confirmed and additional herds were identified through interviews and by on-the-ground surveys of the entire area. Producers and K-State officials were interviewed to collect information about production practices in the region. Interviews are described in detail in Appendix A6, Producer Interviews for All Private Facilities within 6.2 Miles of the NBAF and Kansas State University Data Collection.

Private Herds (Commercial, Small-Scale and Backyard)

Eleven producers were identified in Pottawatomie county and 34 producers were identified in Riley County within a 6.2-mile radius of the NBAF. An additional four pastures were identified that could potentially be used for livestock grazing, but the owners of these properties could not be contacted and the pasture uses could not be determined. Twenty-eight producers agreed to interviews (62%). Only one active swine operation was identified in the area and only one dairy with two cows was identified. The majority of livestock operations were cow-calf beef operations, with a few backgrounder operations. There are no true feedlots in this area. It is estimated that this survey accounted for between 75% and 90% of privately held livestock in this area. None of the producers interviewed were planning to change production practices or relocate as a result of the NBAF's construction (for more detail see Appendix A6, Producer Interviews for All Private Facilities within 6.2 Miles of the NBAF).

Survey of Kansas State University

K-State faculty and staff were interviewed to collect data on all university animal populations. Location data were collected for all thirteen campus-affiliated facilities housing livestock. K-State does not plan to relocate any of their operations when the NBAF opens [Odde, 2011]. While many K-State facilities could clearly be assigned a production type based on interviews, animals in campus herds are likely to have greater contact than those in other herds of the same production type due to the use of the herds for education. Furthermore, observation and reporting of disease is likely to happen faster for some of

these herds because of the level of education of the herd caretakers: many are veterinarians. In the case of the veterinary hospital and large animal research facility, backyard production types were chosen to represent animals at the veterinary clinic based on how often they came into contact with other people or animals regardless of the associated population size (high indirect contact). For detailed information please see Appendix A6, Kansas State University Data Collection.

Concentrated Animal Feeding Operation (CAFO)

Regulations set by the Environmental Protection Agency (EPA) require that large concentrated animal feeding operations (CAFOs) obtain permits for wastewater management. Permits are legally required for facilities housing 1000+ cattle or cow-calf pairs, 700+ dairy cattle, 2,500+ swine over 55 lbs, or 10,000+ swine under 55 lbs. Updated datasets for these permits were obtained from each state in the modeled region for the Updated SSRA. Generally, records contained all information necessary to model these facilities in NAADSM including: location, production type, and number of animals. As a result, CAFOs provide a comprehensive list of all large animal livestock operations in each state. A detailed description of how data from CAFO permits was interpreted to create locations for NAADSM can be found in Appendix A6, Concentrated Animal Feeding Operation (CAFO) Permit Data Collection and Standardization.

Dunn & Bradstreet (D&B)

D&B is a company that compiles information about the revenue generating activities and geographical locations of corporations and businesses. Business listings for Kansas, Oklahoma, Colorado, Nebraska, Texas, and Missouri were downloaded from D&B's database as Microsoft Excel spreadsheets, allowing data to be easily sorted by type or searched by keyword. D&B records provide location and production type information, but number of animals had to be extrapolated. Obtaining the D&B data for Iowa would have incurred additional cost and the extent of the CAFO records in Iowa enabled the Updated SSRA team to capture almost all premises that would have been listed in the D&B database for this state.

To assign a production type to each facility, the Updated SSRA team used the Standard Industrial Classification (SIC) code, a government classification for businesses based on their primary revenue generating activity, provided with each record. Additionally, targeted word searches were used when SIC codes failed to provide a translatable production type. SIC codes provided by D&B were used as the basis for classifying facilities as dairies, feedlots, cow-calf facilities, swine producers, or goat and sheep producers. Facilities with non-livestock SIC codes, but with livestock mentioned in their business descriptions were identified through targeted word searches, and classified as backyard operations for the purpose of the modeling. Backyard operations were further classified as beef operations, swine operations, or as small ruminant operations raising sheep and goats. Further detail on this processing of data from D&B can be found in Appendix A6, Dunn & Bradstreet Data Collection and Standardization. The process of assigning a number of animals to each facility is described below, in the Population file creation section.

LLNL Animal Population Dataset

In 2007, LLNL developed a dataset of farms (including production type, size and location) computed from data in the NASS 2007 Agricultural Survey. This dataset improved upon a previous dataset created with 2002 NASS data by taking into account geographic features when simulating farm locations [Melius et al., 2006]. “LLNL 2007” will refer to this dataset, which was used to fill in gaps in the animal population files. This dataset was used to help account for all the small and medium sized facilities not identified through CAFO permit datasets, D&B datasets, and surveys. Twenty-eight separate production types were included in the original LLNL 2007 dataset; these were translated into the Updated SSRA production types (see Appendix A6, LLNL Dataset Standardization).

Prior to using LLNL 2007 for the Updated SSRA, the team evaluated how closely the simulated dataset matched the NASS 2007 data on which it was based. This was achieved by comparing the total animals and facilities in the NASS and LLNL datasets for three counties in four of the states modeled. In most cases, the LLNL dataset matched the NASS results within 95% of the NASS totals. The team determined it was sufficiently accurate, and probably the best available dataset of its type, so it was used to provide supplementary locations for the Updated SSRA modeling files. The full analysis of the LLNL dataset can be found in Appendix A6, LLNL Dataset Assessment.

Population file creation

The LLNL, CAFO, D&B, and survey data were ultimately merged into a single population file. A detailed description of the creation of the NAADSM modeling population file for Kansas can be found in Appendix A6, Modeling File Compilation. The datasets were merged as follows:

1. The D&B and CAFO datasets were compared based on geographical coordinates and duplicate facilities were removed from the D&B dataset.
2. D&B facilities and CAFO facilities were removed from within the dense downtown areas of the top ten most populous cities using R [Team, 2011b] to account for facilities with offices, not animals at these locations.
3. The D&B and LLNL Kansas datasets were divided into 12 regions using a 3 × 4 grid covering the state. Within each region and for each production type, D&B facilities were rank-ordered by revenue. Similarly, LLNL facilities were rank-ordered by herd size. Each facility was assigned a corresponding percentile based on revenue and herd size, respectively. Each D&B facility was matched with the LLNL facility of the same percentile. The locations (latitude and longitude) of the LLNL facilities were replaced with the matching D&B locations so that the largest LLNL facility's location was replaced with that of the D&B facility with the highest revenue. BY-SS facilities for both LLNL and D&B were handled separately.
4. BY-SS facilities in the D&B dataset were designated based on SIC code; word searches identified those facilities whose primary SIC code was designated as a plant crop but whose description included livestock production. Because the revenues associated with these facilities were not generated as a direct product of animal sales, the use of revenue was considered an inappropriate means of LLNL coordinate replacement. Thus, LLNL and D&B BY-SS facilities were geographically separated into 12 regions and LLNL facility coordinates

- were randomly replaced with D&B coordinates within the same region. This process maintained the production type and population count in a geographical area, while replacing simulated geographical coordinates with verified geographical locations.
5. CAFO operations were divided into two subsets: small CAFOs and large CAFOs. Small CAFOs were permitted facilities that fell below the legal cutoff for that operation type; all large CAFOs were at or above the permitted population. For example, if all dairies over 700 head are required to obtain a CAFO, a dairy with 600 cows that obtained a CAFO permit would be in the small CAFO subset. A dairy with 750 cows would be in the large CAFO subset.
 6. For production types with CAFO requirements (this excluded BY-SS production types by definition), all facilities that were above the specified size requiring a permit were removed from the interim LLNL-D&B merged dataset and replaced with the CAFO large dataset. For example, all dairies with 700 cows or more were removed from the LLNL dataset and replaced with the Dairy CAFO large subset. Every dairy in Kansas over 700 head is legally required to obtain a CAFO permit, so the Dairy CAFO large subset should include every dairy in the state of Kansas with 700 cows or more.
 7. For the small CAFO subset, the small CAFO subset and the merged file were each divided into 12 regions formed roughly from a 3 × 4 grid covering the state. Within each region, a LLNL facility was removed and replaced by a CAFO facility with the same production type and herd size from that region. If there were no exact matches, the size requirement for facilities larger than 85 animals was relaxed from an exact match to a ± 1% range, ± 5% range, ± 10% range, and finally a ± 20% range, if needed. The size requirement for facilities smaller than 85 animals was relaxed from an exact match to a ±1 range, ±5 range, ±10 range, and finally a ±20 range. The size ranges of specific production types were ignored so that, for example, a CAFO Feedlot(S) facility with a herd size close to the Feedlot(L) cutoff could be matched with either a Feedlot(S) or Feedlot(L) LLNL facility. Any CAFO facilities not able to be matched even at a ±20 or ±20% size range were allowed to remain in the final dataset without a match.
 8. The location (latitude and longitude) of LLNL facilities that overlapped with CAFO and D&B facilities were shifted. An area was approximated for each CAFO and D&B facility based on the NASS 2007 Census State Data. Any LLNL facilities falling within these areas were moved a distance equivalent to the diameter of the typical farm of that production type. The LLNL facilities were moved in a direction towards the center of the state to prevent facilities being moved into adjacent states.
 9. All facilities within 6.2 miles of the proposed NBAF site were removed and replaced with the facilities identified by surveys and K-State interviews.

Results

The number of livestock facilities and animals identified across the modeled region through evaluation and reconciliation of all the datasets are provided in Table 6.1.4-3. The analysis of this population file is discussed in Appendix A6, Analysis of Final Population Files vs. NASS and LLNL Files. The analysis includes a comparison of animal and facility totals versus LLNL and NASS census.

Disease Progression

Disease progression in NAADSM is represented by five distinct periods that each herd in the model may pass through: susceptible, latent (a term in NAADSM used to describe animals incubating the illness), infectious subclinical, infectious clinical, and immune. Each period is defined by a probability function that specifies the probability that a herd will spend a length of time (in days) in that disease state. For example, a triangular distribution for the latent period of (1,2,3) would indicate that a herd could spend between 1 and 3 days latently infected, with the most likely period in this disease state being two days.

Table 6.1.4-3. Number of Facilities and Animals in the Final Kansas Population File		
	Facilities	Animals
CATTLE		
Cow-Calf	22,977	3,772,864
Dairy	1,061	345,191
Feedlot (S)	2,485	952,305
Feedlot (L)	221	3,360,890
Beef (BY-SS)	3,723	27,154
SWINE		
Swine(S)	529	47,308
Swine(L)	722	168,480
Swine(BY-SS)	526	2,915
SMALL RUMINANT		
Goats	1,377	47,320
Sheep	766	103,815
Small Ruminants (BY-SS)	969	5,500
Total	35,356	8,833,742

The actual length of each disease period for each infected herd is determined stochastically. Animals die in NAADSM only as defined by user-specified destruction-based control strategies. Although an entire herd is characterized by a single disease state, a function is available that defines the prevalence of infection within a herd on any given day (the percent of the herd that is infected).

Herd-Level Disease Periods

Animal-level disease distributions were obtained from Mardones [2010] for latent, subclinical, and clinical disease periods. The clinical period was extrapolated from these data (see Appendix A6, Extrapolation of Clinical Period from Mardones Disease Phase Durations, for detailed method). The immune period was obtained from USDA 2011, who provided the following evidence basis:

“Eighty percent of the cattle reported by Cunliffe (1963) [Cunliffe & Graves, 1963] retained immunity over a period of four and one-half years. Sixty percent of the cattle reported by Moonen et al. [2004] retained immunity for 609 days following inoculation with FMD virus.

Swine have shorter immune periods [Bachrach, 1968], [Cunliffe, 1962] than cattle; however, unlike the studies reported for cattle, there are no long-term studies available in the peer-reviewed literature that define the duration of the immune period for swine. Given this limitation, the Weibull distribution was chosen as an approximation of the duration of the immune period in swine in order to account for their shorter immune period as compared to cattle. There are no long-term studies available in the peer-reviewed literature that define the duration of the immune period for small ruminants. Given this limitation, it was assumed that the duration of the immune period in small ruminants is roughly equivalent to that of swine. Additionally, in order to account for an increase in the quantity of antibodies detected in sheep after vaccination [Patil et al., 2002] a Gaussian distribution was chosen as an approximation of the duration of the immune period in small ruminants” [USDA 2011].

Herd-level disease phases were estimated using the within-herd model (version 0.9.6), a model that captures animal-level variation and within-herd dynamics developed by Colorado State University’s Animal Population Health Institute [Reeves, 2011]. The probability distributions for cattle (Figures 6.1.4-1 through 6.1.4-4), swine (Figures 6.1.4-5 through 6.1.4-8), and small ruminants (Figures 6.1.4-9 through 6.1.4-12) are plotted to show herd level distributions. These figures demonstrate the importance of developing herd-level parameters. Herd size can change disease phase duration significantly, especially for large feedlots. The within-herd model, input parameters, and methods used to develop herd-level disease phases are described in Appendix A6, Within-Herd Model Generated Parameters. The herd-level disease phase distributions can also be found in this appendix.

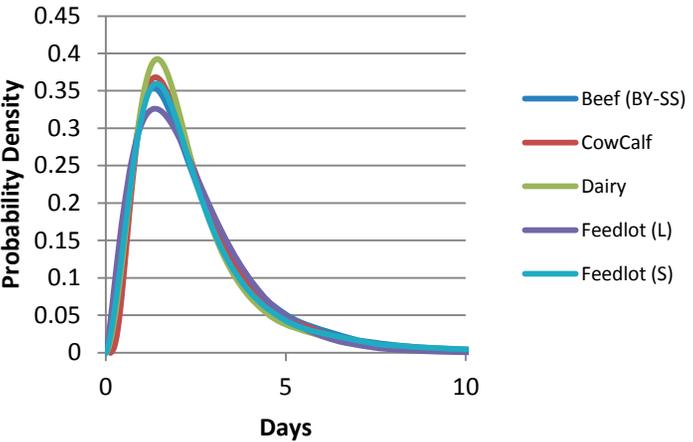


Figure 6.1.4-1: Kansas Cattle Latent Disease Phase

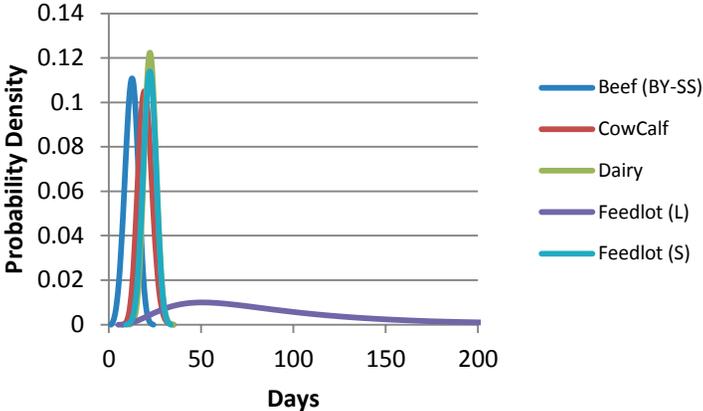


Figure 6.1.4-3: Kansas Cattle Clinical Disease Phase

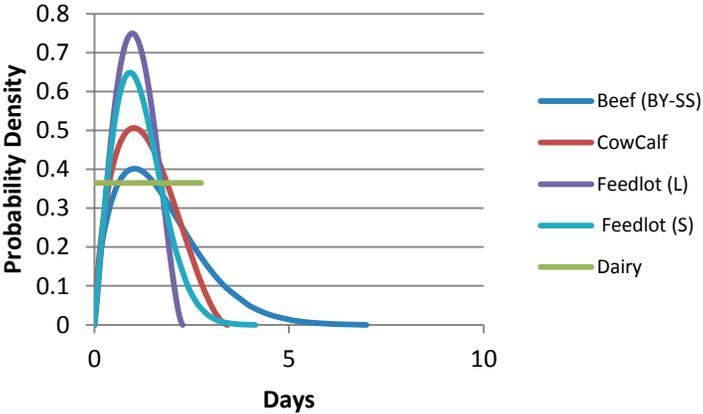


Figure 6.1.4-2: Kansas Cattle Subclinical Disease Phase

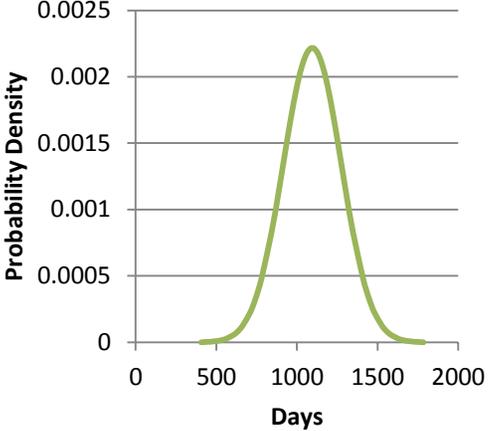


Figure 6.1.4-4: Kansas Cattle Immune Period

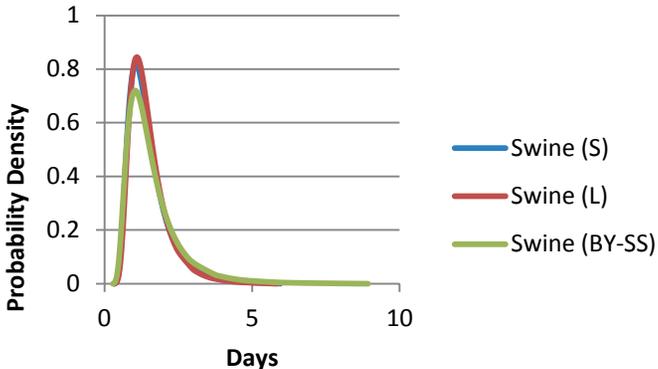


Figure 6.1.4-5: Kansas Swine Latent Disease Phase

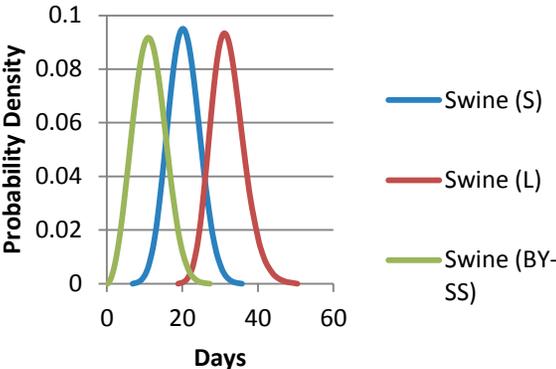


Figure 6.1.4-7: Kansas Swine Clinical Disease Phase

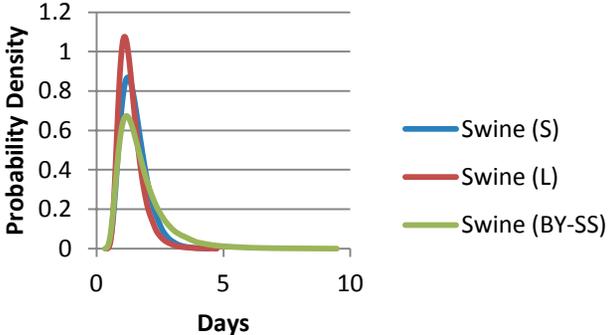


Figure 6.1.4-6: Kansas Swine Subclinical Disease Phase

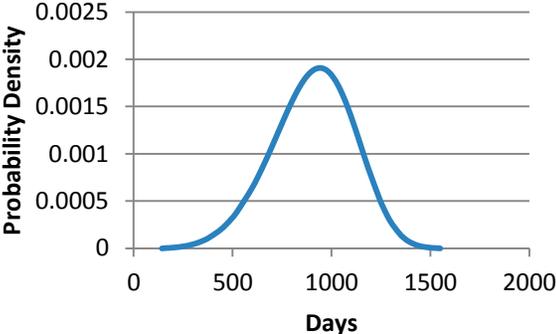


Figure 6.1.4-8: Kansas Swine Immune Disease Phase

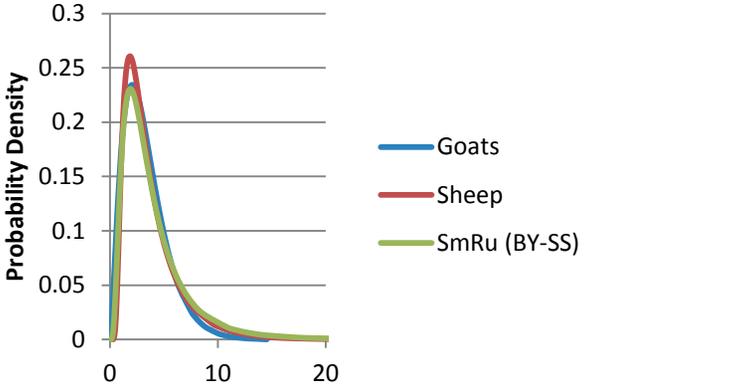


Figure 6.1.4-9: Kansas Small Ruminants Latent Disease Phase

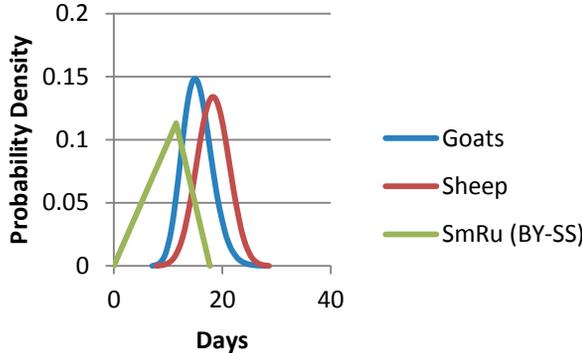


Figure 6.1.4-11: Kansas Small Ruminants Clinical Disease Phase

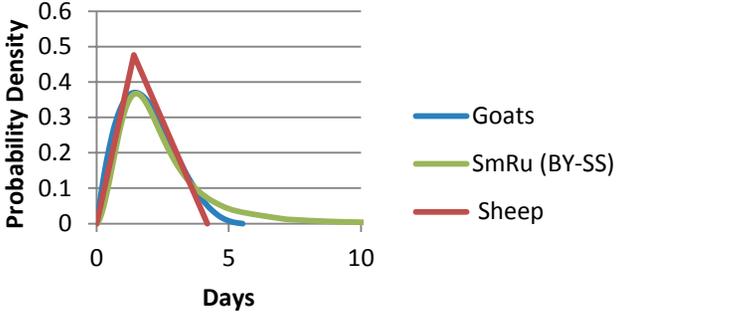


Figure 6.1.4-10: Kansas Small Ruminants Subclinical Disease Phase

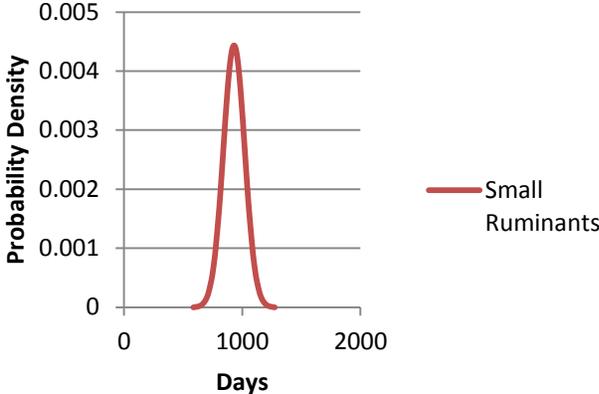


Figure 6.1.4-12: Kansas Small Ruminants Immune Disease Phase

Within-Unit Prevalence

The proportion of animals infected in a herd is expressed by the within-unit prevalence function. This function is used by NAADSM when determining if an infected animal is shipped from an infected herd to a susceptible herd. Within-unit prevalence functions were calculated for each production type using output from the within-herd model (Figures 6.1.4-13 through 6.1.4-15). Calculation details and complete functions are found in Appendix A6, Within-Herd Model Generated Parameters.

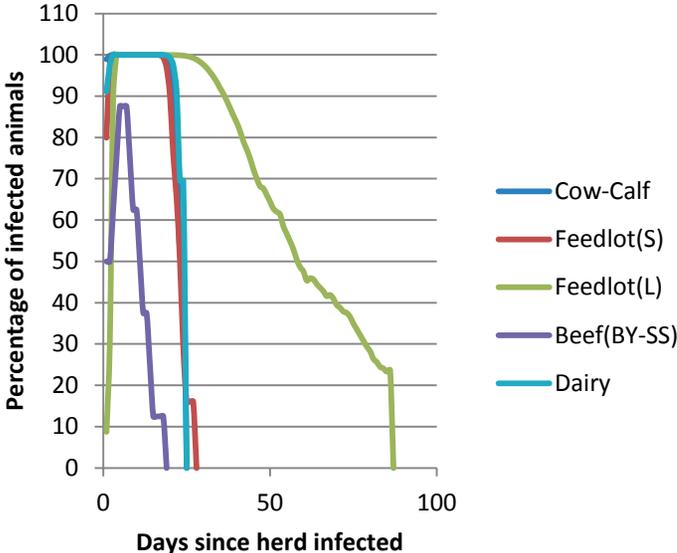


Figure 6.1.4-13: Kansas Cattle Within-Herd Prevalence

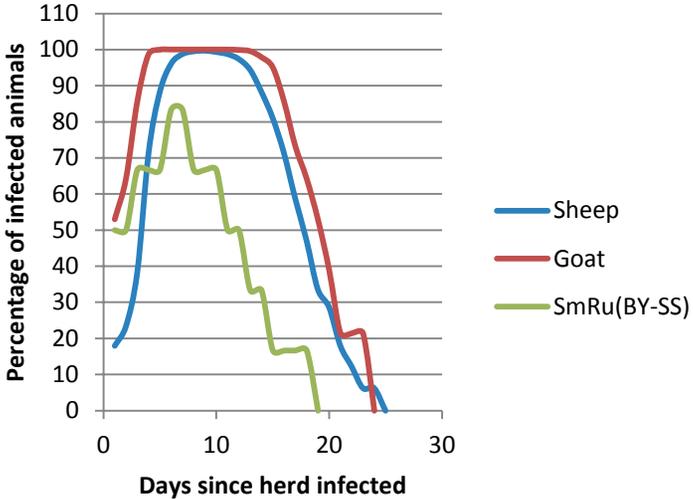


Figure 6.1.4-14: Kansas Small Ruminants Within-Herd Prevalence

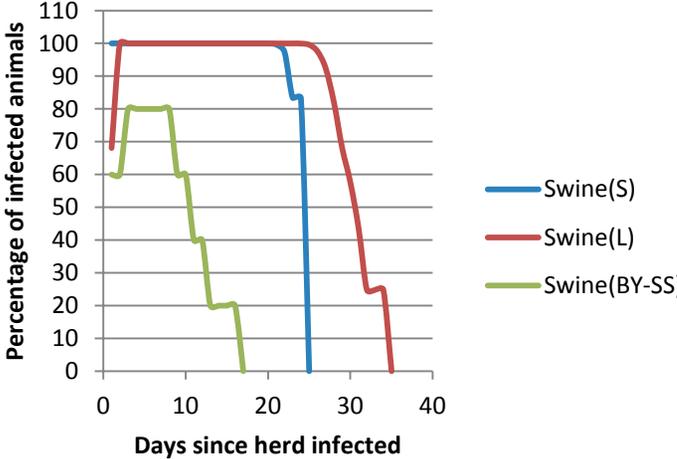


Figure 6.1.4-15: Kansas Swine Within-Herd Prevalence

Disease Spread

Disease spread in NAADSM occurs through three pathways: direct contact, indirect contact, and airborne/local area spread. Direct contact accounts for spread that occurs through shipments of animals from one facility to another. Indirect contact accounts for humans and equipment that come in contact with an infected herd and then move to an uninfected herd, where they may spread disease. Airborne and local area spread account for airborne spread and mechanical transmission through fomites that cannot be controlled by quarantine.

Direct Contact Rate

For direct contact, the user defines which production types have contact with each other and what disease states are capable of spreading disease by direct contact. For each production type combination, a movement rate is selected by sampling the number of shipments from a poisson distribution with the mean defined by the direct contact rate. The direct contact rate reflects the mean number of shipments that occur between each pair of production types. Additionally, a distance distribution defines the range of distances traveled by shipments moving between each production type pairing.

USDA 2009 parameters served as the basis for the Updated SSRA direct contact parameters, however some parameters were modified to best reflect available data and to account for differences in the modeling approaches used by the Updated SSRA and USDA 2009. Additionally, contact parameters were developed to describe BY-SS producer contact.

Direct Contact Increase for Movement Through Sales Barns

Direct contact simulates the direct movement of animals between farms as shipments. When the parameters were originally developed, it was assumed that one shipment out of a facility was equivalent to one shipment into another. This would be true if farmers sold their shipments directly to the next facility, or if they sold through sales barns in single lots. According to SMEs, in Kansas about 90% of cow-calf sales occur through sales barns, and some producers sell multiple lots in a single sale. The Updated SSRA team analyzed the records of 500 sales from two markets that listed the producer for individual lots to determine the number of lots typically sold by a single producer at a sale. A single cow-calf operation sells between one and seven lots at a sales barn at a time. According to SME interviews, at most sales these lots would go to multiple buyers. Around 65% of cow-calf operations sell in a single lot, 25% sell in two lots and the percent of producers selling three to seven lots is evenly distributed. Parameters which were modified to account for increased shipments through sales barns are noted with a superscript B in the following parameter tables. Here is an example of the calculation the team applied to cow-calf operations:

$$\begin{array}{ccc} \text{direct sales} & \text{sales through markets} & \text{65\% sell single lot} \\ \downarrow & \downarrow & \downarrow \\ \text{New contact rate} = & (10\% * \text{old contact rate}) + & ([90\% * \text{old contact rate}] * [(1 \text{ lot} * 65\%) + (2 \text{ lots} * 25\%) \dots (7 \\ & & \text{lots} * 2\%)]) \end{array}$$

The small sample size of market sales records is a weakness of this approach.

Direct Contact Reduction for Out-of-State Movement

The Updated SSRA models each state individually and accounts for movements between states using an approach described in Section 6.1.5, while USDA 2009 modeled a multi-state region using a single parameter set and a single population file. Contact rates were based on shipment from a facility to other facilities, regardless of the state in which the destination facility fell. The Updated SSRA models each state individually and accounts for movements between states using a separate approach (see section 6.1.5). To avoid inflating contact by double counting out-of-state contacts, the Updated SSRA team reduced the USDA's contact rate so that it only reflects in-state animal shipments using data from certificates of veterinary inspection (see Appendix A6, Direct Contact Reduction for Out-of-State Movement).

The final direct contact parameters for USDA 2009 production types are listed in Appendix A6, Direct Contact Parameters. An example is provided below describing cow-calf direct contact parameters. Direct contact parameters for BY-SS facilities were developed for the Updated SSRA and parameter development is described using the Beef BY-SS production type as an example. The BY-SS production type direct contact rates are also provided in Appendix A6, Backyard Small-Scale Production Type Direct Contact Parameters, following USDA production type parameters.

Example: Cow-Calf

Direct contact parameters for cow-calf facilities were developed for USDA 2009 through SME interviews and literature reviews (see Appendix A6, Direct Contact Rate and Distance Distribution Parameters for more detail).

Parameters describing direct contact between cow-calf and BY-SS facilities were developed from BY-SS producer interviews (described in Appendix A6, Direct Contact Rate and Distance Distribution Parameters). Producers were asked how often they purchased new animals and from where they obtained those animals. Animals were often directly purchased from another facility, but in the event that animals (typically calves) were purchased at market, they were assumed to originate from a cow-calf facility. Almost all animals originated from within the state. The mean number of purchases per year per producer was calculated and then multiplied by the total number of each type of backyard facility and divided by the total number of cow-calf facilities. For example, there were 14 shipments sold from cow-calf operations to the 18 beef backyard producers interviewed, which averaged to 0.78 shipments to each of those 18 beef backyard facilities. This value was then adjusted for the total number of backyard beef (3,724) and cow-calf (22,929) producers in Kansas and converted, by dividing by 365, from a yearly value to a daily value of 0.00035 shipments per day (Table 6.1.4-4).

Table 6.1.4-4: Direct Contact Originating from Cow-Calf Operations

Production Types	Kansas mean baseline direct contact rate	Shipments per year	Parameter source
Cow Calf to Cow Calf	0.0099 ^{a,b,c}	3.6	USDA 2009 modified by Updated SSRA team
Cow Calf to Dairy	7.0E-06 ^{a,b,c}	.0026	USDA 2009 modified by Updated SSRA team
Cow Calf to Feedlot (S)	0.0051 ^{a,b,c}	1.9	USDA 2009 modified by Updated SSRA team
Cow Calf to Feedlot (L)	0.0076 ^{a,b,c}	2.8	USDA 2009 modified by Updated SSRA team
Cow Calf to Sheep	0	0	USDA 2009
Cow Calf to Goats	0	0	USDA 2009
Cow Calf to Swine (S)	0	0	USDA 2009
Cow Calf to Swine (L)	0	0	USDA 2009
Cow Calf to Beef (BY SS)	0.00035	.13	Updated SSRA team
Cow Calf to Small Ruminants (BY SS)	0	0	Updated SSRA team
Cow Calf to Swine (BY SS)	0	0	Updated SSRA team

^aUSDA 2009 contact rates were modified by K-State SME

^bContact rates were increased to account for the fact that many cow-calf operations will send one shipment of animals to a sales barn that will then be sold in multiple lots to multiple buyers (described in direct contact introduction)

^cContact rates were modified to account for interstate movement

Example 2: Beef (Backyard-Small-Scale)

Parameters describing direct contact originating from BY-SS were developed from producer interviews (interviews are described in Appendix A6, Direct Contact Rate and Distance Distribution Parameters). For BY-SS producers each animal sold or purchased was considered a single shipment. When answers were provided in number ranges, the mean value of the range was used. For example, if a producer purchased two to four animals per year, he was considered to have purchased three shipments of animals. Producers were asked how often they sold animals and to whom they sold their animals. Animals were sometimes sent to slaughter and sometimes sold through markets. Animals sold straight to slaughter were excluded. Most producers were able to indicate whether animals sold through market went to slaughter or finishing. The destination was assumed to be feedlots for most cattle sold through markets. If the producer specified other destinations through markets, such as 4-H operations or other small farms, beef BY-SS facilities were selected as the receiving production type. Shipments that went

to unspecified feedlots were divided between small and large feedlots according to the ratio of small to large feedlots in Kansas. The same method was used when the destination of backyard swine or small ruminants was not specified between the various small and large swine or goat and sheep locations. All producers surveyed were from Kansas and shipments from these farms were assumed to stay within the state, because insufficient data was available.

The mean number of sales per year per producer was calculated. This mean was then multiplied by the total number of beef BY-SS facilities and divided by the total number of each production type. For example, there were 25.25 shipments sold from the 18 beef BY-SS producers interviewed to small feedlots, which averaged to 1.4 shipments sold by each of the 18 beef BY-SS facilities. This value was then adjusted for the total number of beef BY-SS facilities (3,724) and small feedlot facilities (2,485) in Kansas and converted, by dividing by 365, from a yearly value to a daily value of 0.00576 shipments per day. These contact values were not adjusted for backyard facilities in other states, nor were they adjusted for the complications of market sales because shipment sizes were likely to be so small that they would only be sold as single lots.

Table 6.1.4-5: Direct Contact Originating from Beef (BY-SS) Operations

Production Types	Kansas mean baseline direct contact rate (shipments/day)	Shipments per year	Parameter source
Beef (BY-SS) to Cow-Calf	0	0	Updated SSRA team
Beef (BY-SS) to Dairy	0	0	Updated SSRA team
Beef (BY-SS) to Feedlot(L)	0.0058	2.1	Updated SSRA team
Beef (BY-SS) to Feedlot(S)	0.0058	2.1	Updated SSRA team
Beef (BY-SS) to Goats	0	0	Updated SSRA team
Beef (BY-SS) to Sheep	0	0	Updated SSRA team
Beef (BY-SS) to Small Ruminant (BY-SS)	0	0	Updated SSRA team
Beef (BY-SS) to Swine (S)	0	0	Updated SSRA team
Beef (BY-SS) to Swine (L)	0	0	Updated SSRA team
Beef(BY-SS) to Beef (BY-SS)	0.0018	0.64	Updated SSRA team
Beef(BY-SS) to Swine (BY-SS)	0	0	Updated SSRA team

Distance Distribution

The distance distribution function defines the distance that animals are shipped, once NAADSM determines that a shipment should be made based on the contact rate. This parameter is a probability distribution of shipping distances. USDA 2009 functions are all BetaPERT functions, which are defined by a minimum, mode and maximum distance that a shipment can travel (Table 6.1.4-6). Distance distributions for USDA 2009 were established using the same sources as the direct contact parameters described in the previous section. For the Updated SSRA, all USDA 2009 distance distribution functions were modified to increase the maximum distance traveled. This change was made based on sales barn records that indicated that animals were shipped farther than the original distance described by USDA

2009 parameters. For example, many cow-calf operations in the northeast corner of Kansas near the NBAF ship animals diagonally across the longest part of the state to the southwest corner of Kansas. A new maximum distance, 752 km, was chosen because it allows all farms in Kansas to contact each other.

Table 6.1.4-6: Distance Distribution of Recipient Parameters for all USDA 2009 Production Type Pairs with a Direct Contact Greater than Zero	
Production Type	Distance Distribution Function (km)
Cow-Calf to Cow-Calf	BetaPERT (1.6, 32.2, 752)
Cow-Calf to Dairy	BetaPERT (1.6, 80.5, 752)
Cow-Calf to Feedlot (L)	BetaPERT (1.6, 193.1, 752)
Cow-Calf to Feedlot (S)	BetaPERT (1.6, 96.5, 752)
Dairy to Cow-Calf	BetaPERT (1.6, 80.5, 752)
Dairy to Dairy	BetaPERT (1.6, 80.5, 752)
Dairy to Feedlot (L)	BetaPERT (1.6, 80.5, 752)
Feedlot (L) to Cow-Calf	BetaPERT (1.6, 80.5, 752)
Feedlot (L) to Dairy	BetaPERT (1.6, 80.5, 752)
Feedlot (S) to Cow-Calf	BetaPERT (1.6, 80.5, 752)
Feedlot (S) to Dairy	BetaPERT (1.6, 80.5, 752)
Feedlot (S) to Feedlot (L)	BetaPERT (1.6, 160.9, 752)
Goats to Goats	BetaPERT (1.6, 80.5, 752)
Sheep to Sheep	BetaPERT (1.6, 80.5, 752)
Swine (L) to Swine (L)	BetaPERT (0, 20, 752)
Swine (S) to Swine (S)	BetaPERT (0, 20, 752)

Development of backyard and Small-Scale Distance Distributions

Data used to calculate BY-SS distance distributions were obtained from interviews (see Appendix A6, Backyard and Small-Scale Distance Distributions). Producers were asked the distance animals traveled from purchase location and how far their animals traveled to their destination farm when they were sold. Producers typically answered with a range or a single point location, although some provided a range and a most common distance. Distance estimates were grouped by production type pair-assigned for the purpose of calculating the mean direct contract rate (for example, all shipments from Beef BY-SS to Feedlot (L)). Each distance estimated was weighted depending on how many shipments a year of that type that producer pair sent or received, and then they were used to estimate a distance function to represent all shipments for that combination as described in Appendix A6, Backyard and Small-Scale Distance Distributions. Distance distributions are also provided in this appendix.

Shipping Delays

USDA advised that the shipping delay used in all current versions of NAADSM (NAADSM 3.2 and prior) should be set to a fixed value of "0". Shipping delays are a deprecated feature that will not exist in newer versions of NAADSM [Forde-Folle, 2011].

Indirect contact rate

The indirect contact rate in NAADSM is used to indicate the average number of contacts that are generated from each source herd to each recipient herd, each day. As described by the NAADSM user's guide, indirect contact occurs through the simulation of "movement of people, materials, vehicles, equipment, animal products, etc." between an infectious herd and a susceptible herd. Unlike direct contact, only subclinical and clinical herds can be a source of infection. For simplicity sake, in this section "people, materials, vehicles, equipment, animal products, etc" are referred to as fomites.

Indirect contact data

Indirect contact rates for all production types except BY-SS were from USDA 2009. An example of indirect contact rates for cow-calf operation is provided in Table 6.1.4-7. A full list of indirect contact rates and the evidence basis provided by USDA 2009 for each of the livestock species can be found in Appendix section A6.2.18. Updated versions of the data and templates used to develop indirect contact parameters for USDA 2009 were provided by Dr. Mike Sanderson, Professor of Epidemiology and Beef Production, K-State. These templates were used in developing BY-SS indirect contact parameters to insure consistency in parameter development.

Table 6.1.4-7: Example Indirect Contact Values for Contacts Originating at Cow-Calf Operations From USDA 2009	
Production Type	Indirect Contact Rate (contacts/day)
Cow-calf to Cow-Calf	0.02
Cow-Calf to Dairy	0.104
Cow-Calf to Feedlot (S)	0.147
Cow-Calf to Feedlot (L)	1.152
Cow-Calf to Swine (S)	0.004
Cow-Calf to Swine (L)	0.035
Cow-Calf to Sheep	0.005
Cow-Calf to Goats	0.005

Backyard and Small-Scale Indirect Contact

BY-SS indirect contact values were developed by the USSRA team. Data on indirect contact was obtained through producer interviews, which included questions about contact with indirect fomites such as veterinarians, and neighbors (see Appendix section A6.2.18.4 for details on backyard producer interviews). Producers responded with how many times a year they may have had a visit from a particular fomite (Table 6.1.4-8).

Table 6.1.4-8: Average Visits Per Year Between Backyard Facilities and Each Professional Service Provider (Indirect Fomite)			
Fomite	Beef (BY-SS)	Swine(BY-SS)	SR (BY-SS)
Veterinarian	1.07	0.88	1.21
Feed Truck	1.83	0.5	0.86
Drug Sales	2.5	0	0
Neighbors	23.68	0	142.5
Total Visits/Year	29.08	1.38	144.57

The approach used to calculate the BY-SS indirect contact parameters was based on the approach used to calculate the USDA 2009 parameters. The backyard producers' data was integrated into the weighted matrix used by the USDA 2009 team. According to the original matrix, values were estimated for the percent of visits each fomite made to the respective production type, (e.g. veterinarians in Kansas make 68% of visits to cow-calf ops.). In other words, if a veterinarian made 100 visits in a year to various operations, 68 of those visits were to cow-calf operations. These values, based on expert opinion, were intended to account for the fact that some indirect fomites may be more likely to visit some production types than others. Similar values were not obtained from the backyard producers interviewed. However, since backyard facilities were substantially smaller than other production type facilities, we assumed that the fomites would most likely spend the least amount of time there. Table 6.1.4-9 provides the estimated percentages of visits by each fomite to each backyard production type. The backyard values were selected according to the assumption of minimal contact. It should be noted that these values were only modified in the calculations for purposes of adapting the indirect contact method for use with backyard facilities. These modifications were not applied to the existing USDA 2009 indirect contact rates used for all other production types because insufficient information was available to redevelop indirect contact rates for all production types. With the exception of two values, 1% of all fomite visits was assumed for any contact numbers greater than zero. Since the total percent of veterinary visits to goats and sheep was 2% according to the data provided in the template, the value for the three ruminant categories was divided equally yielding 0.66% for each of these categories. Another value inconsistent with the 1% rule was the percent of neighbor visits to Beef BY-SS operations. Since the number of neighbor visits according to backyard producers was higher than the number of visits to cow-calf and dairy operations in the template, the percentage of visits from neighbors was matched to the percentage values selected for the other cattle production types (cow-calf & dairy) since the percentage across neighbor visits did not add to 100% indicating that neighbors that visit a backyard operations may be different than those neighbors that would visit large-scale operations.

Table 6.1.4-9: Estimated Percent of Visits of Each Fomite Type to the Backyard Facility*

Fomite	Beef BY-SS	Swine (BY-SS)	SR (BY-SS)
Veterinarian	1	1	0.67
Feed Truck	1	1	1
Drug Sales	1	-	-
Neighbor	50	-	-
Average % of Visits	13	1	.8
Normalized % of Visits	8.5	.65	0.54

* These values were subtracted from the largest of the percentage within fomite type across production types. A dash indicates that information was not available.

All fomite visits were summed, yielding a total number of visits for each production type (Table 6.1.4-8). Similar to the original indirect contact method, the percent visits spent by fomites at each backyard facility was averaged and normalized to one across all the production types. The sum of all indirect visits for the destination production type was multiplied by the visit proportions for the origin production type and converted to a daily contact rate. For example, the number of indirect contacts per year from a beef BY-SS to Swine BY-SS would be the total fomite visits/year for the swine BY-SS (1.38) multiplied by the normalized proportion of all fomite visits to beef BY-SS (0.085). The yearly indirect contact rate (0.1178) would then be converted to a daily indirect contact rate (0.000323). A connectivity matrix was not used for backyard facilities because evidence was unavailable. An example of indirect contact rates developed for Beef (BY-SS) production types is provided in Table 6.1.4-10; a full table of BY-SS indirect contact rates is provided in Appendix section A6.2.18.4.

Table 6.1.4-10: Example of BY-SS Indirect Contact Rates (Contacts/Day)

Production Type	Indirect Contact Rate (contacts/day)
Beef (BY-SS) to Cow-Calf	0.00982
Beef (BY-SS) to Dairy	0.0552
Beef (BY-SS) to Feedlot (L)	0.540
Beef (BY-SS) to Feedlot (S)	0.0737
Beef (BY-SS) to Goats	0.00246
Beef (BY-SS) to Sheep	0.00222
Beef (BY-SS) to Small Ruminant (BY-SS)	0.0338
Beef (BY-SS) to Swine (L)	0.0262
Beef (BY-SS) to Swine (S)	0.00374
Beef(BY-SS) to Beef (BY-SS)	0.00680
Beef(BY-SS) to Swine (BY-SS)	0.000323

Indirect distance distribution

The indirect contact distance distribution provided in USDA 2009 was used for all indirect contact in the USSRA, including BY-SS facilities, because we were unable to collect sufficient data to calculate this parameter. The function used is: **BetaPERT (1.6, 40.2, 160.9)**, where 1.6 km is the minimum distance traveled, 40.2 km is the mode and 160.9 km is the maximum.

Probability of Infection Given Exposure for Indirect Contact for All States

The parameters describing the probability of animal infection given indirect contact with a contaminated fomite were taken from USDA 2011. The following excerpt describes parameter development:

“Laboratory transmission data were obtained from published studies involving experimental infection with FMD. In cases where no empirical disease transmission data were published, the probability of disease transmission was assumed to be 1.0 (100%). The data collected from the literature were used to calculate the probability of infection given exposure for each production type combination. To account for a variety of biosecurity measures implemented by various livestock sectors, an average reduction factor was calculated using published National Animal Health Monitoring Systems (NAHMS) data. This reduction factor was then multiplied to the probability of indirect disease transmission for each livestock sector (cattle, swine, & small ruminants).”

USDA 2011 parameters were developed using a different set of production types than the production types used for the Updated SSRA model. It was generally obvious which USDA 2011 pairing was equivalent to the Updated SSRA production type pairing. In some cases, multiple USDA 2011 production type combinations had the same probability of infection given exposure; this simplified identification of an appropriate match to an Updated SSRA production type combination. Table 6.1.4-11 shows a few examples of probability of infection given exposure for indirect contacts. A full table can be found in Appendix A6, Probability of Infection Given Exposure for Indirect Contact. In this table, both production type combinations have been provided along with the “probability of infection given exposure by indirect contact” parameter used for the Updated SSRA model.

Table 6.1.4-11: Example Probability of Infection Given Exposure, Given Indirect Contact

Updated SSRA Production Type Pair	USDA 2011 Production Type Pair	Indirect Contact: Probability of Infection Given Exposure
Cow-Calf to Cow-Calf	All Cow-Calf to all Cow-Calf	0.1263
Cow-Calf to Dairy	All Cow-Calf to all Dairy	0.2795
Dairy to Goats	Dairy to Small Ruminant	0.4286
Feedlot (L) to Feedlot (S)	Feedlot (all, except company feedlot) to Feedlot (all, except company feedlot)	0.1384
Feedlot (L) to Goats	Feedlot (all) to Small Ruminant	0.4286
Goats to Goats	Small Ruminant to Small Ruminant	0.2143

Shipping Delays

USDA advised that the shipping delay used in all current versions of NAADSM (NAADSM 3.2 and prior) should be set to a fixed value of “0.” Shipping delays are a deprecated feature that will not exist in newer versions of NAADSM [Forde-Folle, 2011].

Effect of Movement Control on Both Direct and Indirect Contact

Universal movement control was used for epidemiological modeling because no group has developed a modification to NAADSM that enables zones to reflect the manner in which they would be implemented as described by various SMEs contacted for this assessment. While all experts consulted agreed that zoned movement control would be used during an FMD outbreak, no group has developed a modification to NAADSM that enables the modeling of zones that reflect how they will be implemented in reality. The universal movement control parameters are estimated based upon several lines of evidence. In the 2010 SSRA, movement control was considered to be perfect in the baseline studies (no contact with infected premises any time after the outbreak was announced). The 2010 SSRA examined, through sensitivity analysis, the effect of imperfect movement controls that allowed a few percent of the movement to proceed before the outbreak was detected. Even though imperfect movement control was explored in sensitivity analysis, the 2010 SSRA was strongly urged to consider movement control strategies that are imperfect due to the difficulty of controlling movement after an outbreak. A stronger evidence basis supports the Updated SSRA movement control parameters.

Phone interviews were conducted with representatives of the Departments of Agriculture of Kansas, Nebraska, Missouri, and Iowa. For both direct and indirect movement, the representatives were asked to estimate the ability of the state to control movement of direct contacts (animals) and indirect contacts (fomites, i.e., people and inanimate objects that could spread FMD) over time. In particular, the representatives were asked to provide estimates of percent movement reduction versus ‘normal’ movement over time after the declaration of an FMD outbreak. It was assumed that movement would be controlled through the use of zones, so estimates describe the restriction of travel from within to outside of a 10 km zone around an infected farm. Most states would be able to set up control zones around only a few infected premises using their own resources (up to five premises according to one state); these resources will be supplemented with federal resources from the very beginning of the outbreak. For some of the larger outbreaks modeled, due to the number of premises infected when the outbreak is detected, even with federal resources, the control of zones around all infected premises would be challenging. It was suggested by at least one expert that responders would need to get creative with road blockades, using whatever they could find (e.g., semi trucks, farm equipment, hay bales). Individual state responses are not provided because this information is considered sensitive as it reveals strong and weak points in the nation’s preparedness for an agricultural emergency. The average zoned movement control estimates are plotted in Figure 6.1.4-16.

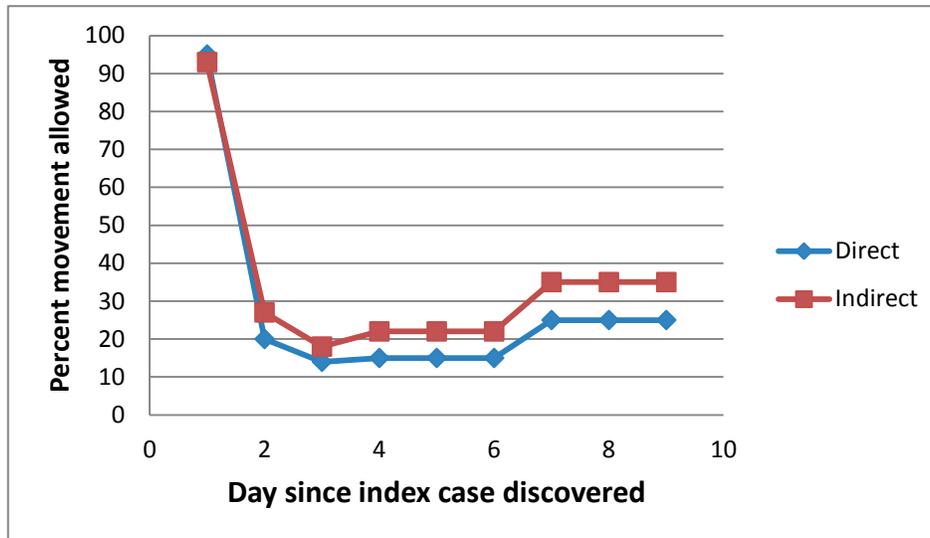


Figure 6.1.4-16: Average Estimated Reduction in Direct Contact and Indirect Contact for One 10-km Zone Around an FMD Infected Farm According to Interviews with State Officials

In addition to any enforced stop movement put into effect, there will likely be a de facto secondary level of stop movement. There is a widespread belief amongst the experts the Updated SSRA team interviewed that there will be self-enforcement within the producer community of any stop movement request. Farmers will understand the danger an FMD outbreak presents to their livelihood and follow any publicized recommendation to mitigate an outbreak. Furthermore, many experts believe producers will report their neighbors if they witness non-compliance. Next, direct contact will be significantly reduced because there will be nowhere to send the animals. Sales barns and slaughter yards will likely be shut down as part of a response, and purchasers probably won't accept shipments of animals, especially from impacted areas. The contribution of these efforts is difficult to quantify.

Given these data sources, movement control parameters had to be estimated that were applicable not just to zones but to all locations in the state. Once disease is detected in any production type, if the movement control variables in NAADSM are parameterized in a similar manner for all production type combinations, movement of all livestock (no matter their production type) will be restricted according to the relational function (reduction in contact rate over time) entered by the user. So, the Updated SSRA team had to develop a movement control parameter that accounted for localized, enforced zones and less effective, voluntary movement restriction. For this reason, the time required to drop the amount of contact to a minimum was extended by approximately two fold over the state estimate for zones (in Figure 6.1.4-17, the minimum indirect contact rate is reached in 20 days whereas the minimum indirect contact rate is reached in only five). This modest level of universal direct movement control is only possible because of the extent of self-policing predicted, with producers acting in their own self-interest. The day-to-day activity surrounding a premises will not simply cease just because an infection is found elsewhere in the state. For these reasons, the low-point of indirect movement projected for zones by

state officials was increased by half and the time to get to this point was dropped by a factor of 10 to create the universal indirect contact movement control function.

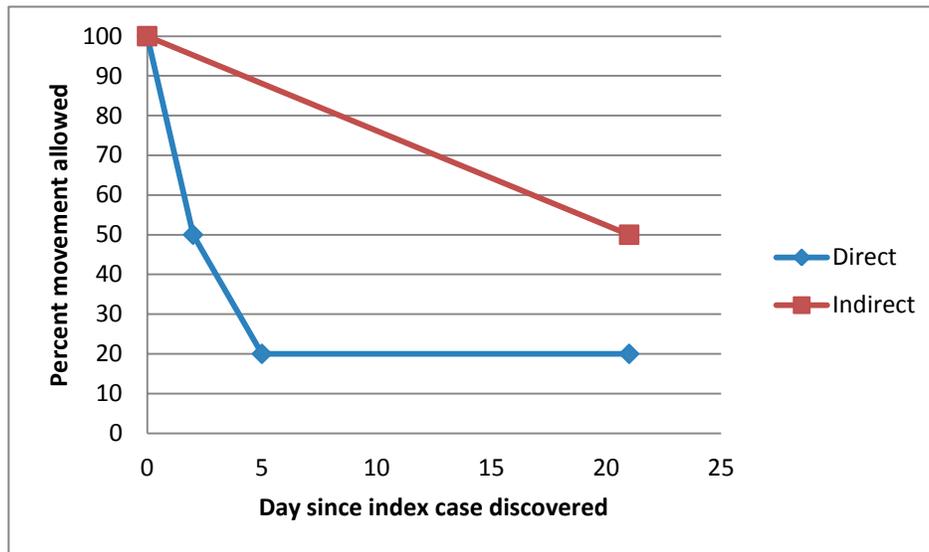


Figure 6.1.4-17: Universal Movement Control Functions Entered in NAADSM

In summary, the universal movement control parameters aimed to account for the fact that the majority of farms in the model would not be placed on mandatory movement restriction during an outbreak. Balancing this effect is the fact that there is an awareness of the seriousness of FMD in areas where livestock production is the primary industry and self-policing and control will be the primary force in preventing indirect and direct contacts. The exact effectiveness of movement control in a large FMD outbreak in the US is impossible to predict, and for this reason the Updated SSRA team explored the effect of different assumptions in the cost-benefit analysis (section 6.3). The team used values for movement control that are likely conservative because of the incentive of the community itself to prevent the movement of infected animals and vehicles. This uncertainty is yet another factor undermining the interpretation of epidemiological modeling results as part of an absolute estimate of the impact and extent of FMD outbreaks. Instead, because of this uncertainty, a more robust use of the modeling data is to understand the relative impact and extent of outbreaks compared across various starting locations, or in the presence/absence of a control measure.

Airborne and Local Spread

Airborne and local area spread parameters were taken from USDA 2011 (Table 6.1.4-12). These parameters describe airborne spread of FMD virus, a phenomena which has been documented to play a role in previous outbreaks. Additionally, these parameters aim to capture some of the local area spread that cannot be controlled through quarantine, for example spread across fence lines or spread of fomites farm-to-farm by rodents. This evidence was provided by USDA:

“After movement controls had been imposed in Cumbria, U.K. during the 2001 outbreak, disease spread continued. This continued spread may have been due to direct fence line contact between contiguous premises, spread by fomites or illegal movements of animals, or close proximity aerosol spread. Disease spread that occurred over short distances (< 3km) where no source was identified was referred to as local spread. A study using data from the 2001 Cumbria outbreak estimated the cumulative 17-day risk of infection to be 14% at a distance of 1.5km and 3% at a distance of 3km after movement controls had been imposed [Taylor et al., 2004]. Therefore the daily risk of local spread for all other production type combinations was estimated to be 0.008 (0.14/17 = 0.008).” [USDA 2011]

Table 6.1.4-12: Airborne and Local Area Spread Parameters from USDA 2011			
Production type combination	Probability of spread between two herds of average size located 1 km apart	Range of direction	Airborne transport delay in days
All swine to all cattle production types	0.1	0-360°	0
Swine to small ruminants	0.01	0-360°	0
All other production type combinations	0.008	0-360°	0

Using a database of thousands of real weather conditions from Manhattan, Kansas, the Updated SSRA team modeled the downwind uptake of FMDv by cows from a release at the NBAF. These data show that downwind concentration (and therefore risk) is not biased in any particular direction which corroborates USDA’s range of direction parameters (Figure 6.1.4-18).

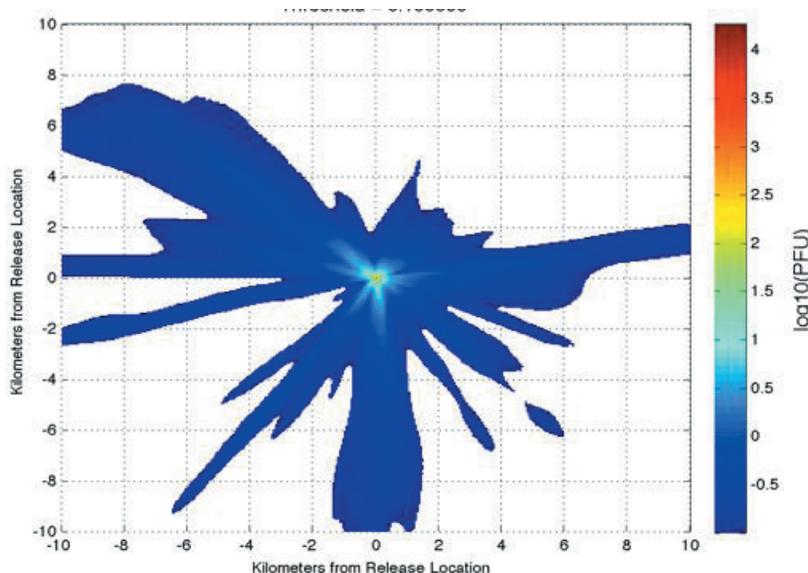


Figure 6.1.4-18: Distribution of Virus from a Location Near Manhattan, Kansas, Using Local Weather Conditions

The Updated SSRA team departed from USDA 2011 parameters in that the team modeled an exponential decline in disease transfer rate moving away from the source. Sorensen et al.'s FMD transport model shows that the downwind concentration of infection decreases by an order of magnitude for each doubling of distance [Sorensen et al., 2000]. Garner and Cannon's FMD transport model shows that downwind risk of infection decreases exponentially if the atmosphere is unstable or the source is several animals and linearly for relatively stable point sources (non-point sources will be the greater contributor to risk of disease spread from sources around the NBAF) [Garner & Cannon, 1995]. Lastly, transport modeling by the Updated SSRA at the NBAF shows that uptake (by livestock) of FMDv, irrespective of wind direction, drops exponentially with distance given real weather conditions in Manhattan, Kansas (Figure 6.1.4-19).

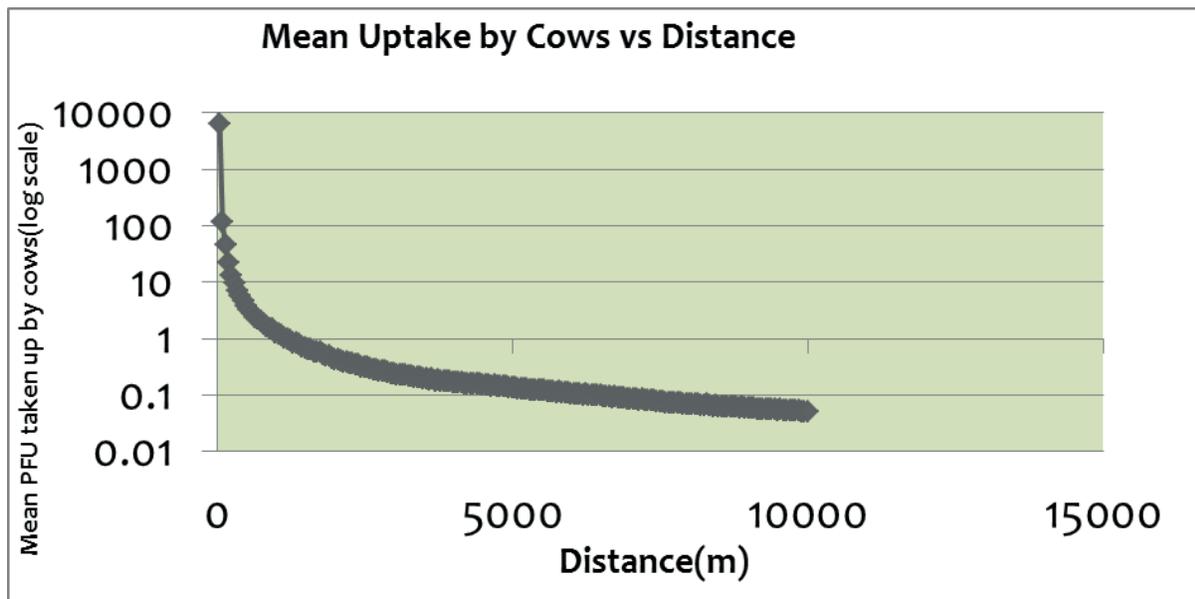


Figure 6.1.4-19: The Mean PFU Uptake by Cows Decreases Exponentially with Distance Irrespective of Wind Directions

This phenomenon is due to the fact that the chance that a particular location is hit with the aerosol decreases as a function of the square of the distance.

A potential criticism of utilizing an exponentially decreasing aerosol risk curve comes from probit susceptibility analysis. Conventional probit analysis suggests that as the dose decreases much lower than the ID_{50} , the probability of infection drops more slowly as a function of dose. This phenomenon may partially counteract the exponential decrease in concentration and probability of uptake. However, doses less than one virus particle will pose no risk of infection in reality. Furthermore, the probability of infection will determine the probability of inhaling at least one infectious particle. Therefore, doses much lower than the ID_{50} are not significant contributors to risk; this fact mitigates the aforementioned counteractive effects of susceptibility enabling the maintenance of the exponential shape of the aerosol risk curve.

The evidence basis for all other airborne and local area spread parameters was provided by USDA 2011:

“Studies that have estimated the maximum distance of spread of airborne virus from different source species have yielded varying results ([Donaldson et al., 2001]; [Garner & Cannon, 1995]; [Sansom, 2000]; [Sorenson et al., 2000]; [Donaldson & Alexanderson, 2002]). This variation is largely due to differences in excretion rates among virus strains. Studies that based their estimates on type O strains have found that the maximum distance of spread was less than 10km with swine as the source, and less than 1km when other species were the source [Donaldson et al., 2001]; [Sansom, 2000]. Cattle and sheep were the only recipient species that were at risk of airborne infection with type O strains at a distance beyond 1km. Studies using the C Noville strain estimated that the maximum distance of airborne spread was up to 300km with swine as the source and that large cattle herds or sheep herds (>1000 head) were capable of infecting cattle at distances up to 3km [Sorenson, 2000]. Because type O strains are more prevalent worldwide than type C strains, the estimates based on the type O strains were used to inform parameters for this study [USDA, 2007].

The minimum virus concentration threshold needed for airborne infection of cattle is approximately 10 times higher than for sheep resulting in a probability of airborne infection parameter that is 10 times higher for cattle production types [Donaldson et al., 2001]. In the absence of geographically specific wind data the risk of airborne spread is assumed to be equal in all directions.”

Given these studies and inputs, the Updated SSRA team used an exponential decline but took all other values from USDA 2011.

Detection

The probability of detection is defined by the product of two functions: “probability of observing clinical signs, given the number of days that a unit is clinically infectious” and “probability of reporting an observed clinical unit, given the number of days since the disease was first detected in any unit.”

Notably, these two functions operate on different time scales. The observation function changes as a function of the number of days an individual herd has been showing clinical signs, while the reporting function changes as a function of the number of days since the first infected herd in the population was detected. The problem with this approach is that both observation and reporting behavior change after the first infected herd is detected in the population. If the same observation function is used to represent observation behavior before and after an outbreak is declared, the function will either under-represent or over-represent the observation. This will have a significant effect on the initial detection of outbreak or the detection as the outbreak progresses, which in turn will have a serious impact on outbreak severity.

The approach was to use the “probability of observing” function to describe both observation and reporting in the model, prior to the declaration of an FMD outbreak. To avoid confusion, this function will be called “obs and rep fx” from this point forward. The obs and rep fx takes into account:

- The estimated prevalence of symptomatic disease over time in an average herd, determined with the within herd model, a function of the state-specific herd size population distribution and production type specific disease characteristics (see Appendix A6, Within-Herd Model Data and Herd-Level Parameter Development);
- The frequency with which producers observe their animals, from SME interviews;
- The number of animals a producer observes at a time, from SME interviews;
- The likelihood that an observer would notice a cow was ill, based on foreign animal disease diagnostician (FADD) interviews (see Appendix A6, Kansas Foreign Animal Disease Diagnostician (FADD) Interviews on Time to Observable Symptoms); and
- The probability that a producer would call a veterinarian after observing symptoms, based on a survey of Kansas veterinarians about producer behavior (see Appendix A6, Backyard and Small-Scale (BY-SS) Producer Interviews and Data).

The development of this function is described in detail in Appendix A6, Within-Herd Model Data and Herd-Level Parameter Development, and obs and rep functions (fxs) are given in Figures 6.1.4-20 to 6.1.4-22. Since this function describes normal producer behavior (not behavior during an outbreak), all production types have a significant delay in observing symptoms and contacting veterinarians (which would lead to reporting). This delay is most significant for goats and sheep because not all animals show discernible symptoms (even to a veterinarian) and profit margins are such that producers would be unlikely to contact a veterinarian unless a significant portion of his/her flock was symptomatic.

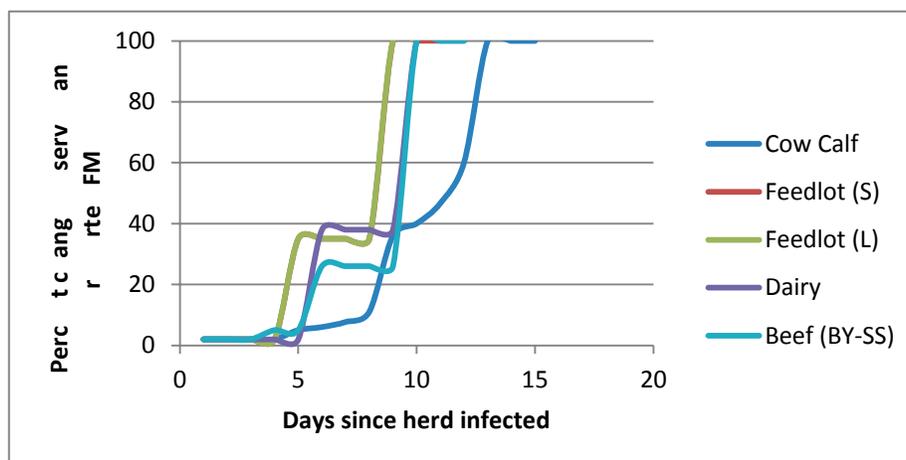


Figure 6.1.4-20: Kansas Cattle Production Type “obs and rep fxs” (NAADSM observation functions)

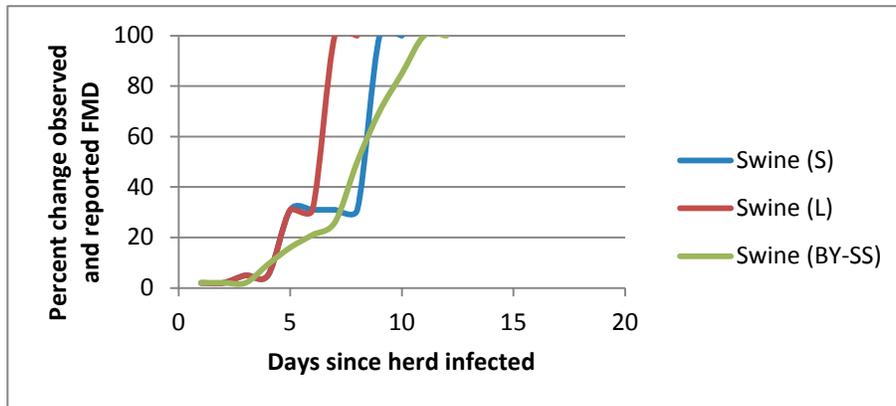


Figure 6.1.4-21 Kansas Swine Production Type “obs and rep fxs” (NAADSM observation functions)

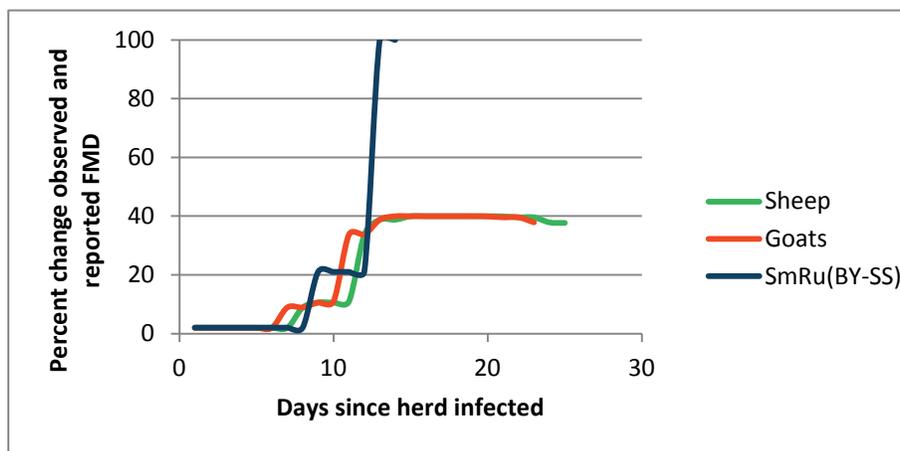


Figure 6.1.4-22 Kansas Small Ruminants Production Type “obs and rep fxs” (NAADSM observation functions)

The “probability of reporting” function was used as a multiplier to shift the “obs and rep fx” to reflect the increase in both observation and reporting after an outbreak is declared. This function will be called the “multiplier fx” going forward. An observation and reporting function was calculated assuming that producers look at their entire herd every day and contact a veterinarian at the first sign of disease after an outbreak has been declared. The multiplier was designed to shift the pre-outbreak obs and rep fx to approximately match this new curve that describes observation and reporting after an outbreak. The multiplier remains at 100% or “1” before the outbreak is declared (day 0) and for the first two days while the outbreak is publicized (Table 6.1.4-13). A multiplier of 100% will have no effect on the observation function, so observation and reporting is exactly as shown in the figures above. Once an outbreak is declared, the multiplier function increases, increasing the likelihood of observation and reporting that would result from publicity and producer education associated with an outbreak. The multiplier can be any value that is greater than 100% because it is intended to increase the likelihood of detecting an infected herd. As shown in Table 6.1.4-13, the multiplier values can be very high because it is anticipated that the public declaration of an FMD outbreak will significantly alter producer behavior.

Table 6.1.4-13: Multiplier Functions for all Production Types (NAADSM Reporting Functions)

Day	Cow-Calf	Feedlot (S)	Feedlot (L)	Dairy	Swine (S)	Swine (L)	Sheep	Goats	Beef (BY-SS)	Swine (BY-SS)	Small Ruminants (BY-SS)
0	100	100	100	100	100	100	100	100	100	100	100
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	1300	5000	5000	5000	2000	2000	5000	4000	2000	3000	5000
4	1300	5000	5000	5000	2000	2000	5000	4000	2000	3000	5000
5	1300	5000	5000	5000	2000	2000	5000	4000	2000	3000	5000
6	1300	5000	5000	5000	2000	2000	5000	4000	2000	3000	5000

Pre-Emptive Control Measures

In a typical use of NAADSM, once disease has been officially detected, response efforts begin including increased surveillance, stop movements, destruction, and vaccination. In this study, several release events are caused by natural disasters that obviously affect containment (for example, a tornado hitting the NBAF). In the case of a natural disaster, mitigation efforts will likely be initiated immediately in anticipation of an outbreak. Until this study, there were no methods developed to use NAADSM to model the implementation of control measures prior to the detection of an infected herd. This presents a complication because when disease is detected in a production type, stop movement measures are applied to all herds in that production type. In a disaster event, the initial response will not be production type specific, so the infected herd detected in disaster events needed to be a unique production type. Therefore, a “unicorn” herd was created that could trigger first detection in the model, without interacting with the larger livestock industry in any other way (described in Table 6.1.4-14).

Table 6.1.4-14: Parameter Values for “Unicorn” Premises

Initial state	Clinical
Geographic coordinates	(37, -95)
Latent	Fixed (0)
Subclinical	Fixed (0)
Clinical	Fixed (1)
Immune	Fixed (0)
Within-unit prevalence	0
Contact Spread OFF	-
Probability of observing clinical signs	100%
Probability of reporting once observed	100%
Tracing OFF	-
Zones OFF	-
Destruction OFF	-
Vaccination OFF	-

Events that used the unicorn production type included self-announcing situations such as tornados and earthquakes where significant and obvious damage to the NBAF may have caused possible FMD release.

In these situations, it was assumed that the community would initiate preemptive response measures prior to an actual detection of disease in any of the monitored production types. Additionally, preemptive control measures were needed to model the potential benefit of systems that could detect the release of FMDv from the NBAF prior to the first infected animal (such as environmental monitoring systems) as described in the cost-benefit analysis.

Tracing

Once an infected unit has been detected in NAADSM, a tracing investigation can be triggered that will identify recipients of direct or indirect contact from the infected, detected herd (trace forward). Additionally, units that were sources of contact for the infected herd can be identified through tracing (trace-back). Tracing investigations are a standard part of FMD response plans, so they were incorporated in the Updated SSRA epidemiological modeling. Tracing parameters were sourced from USDA 2011, and so the evidence basis provided by USDA is provided with the parameters.

Trace parameters

USDA 2011 provides the following evidence basis for their parameters:

“Federal and state FMD response plans dictate that trace-forward and trace-back investigations should be conducted for premises where FMD infection is detected. A survey of 19 federal animal health managers, evaluating traceability of slaughter cattle and swine to the last farm of ownership under different animal identification scenarios, reported probabilities of trace success and delay in obtaining trace results [Disney et al., 2001]. The probabilities of success and delays in obtaining results varied by species and by animal identification method. Results reported from that survey and estimates of percentages of operations that use individual animal identification (or group/lot ID for swine) were used to calculate weighted averages of the probability of direct contact trace success and the delay in obtaining trace results. Percentages of operations that use individual animal identification were obtained from NAHMS reports, a National Scrapie Eradication Program report, the National Pork Board, and the American Sheep Industry Association. The results reported in the [Disney et al., 2001] study for the delay in obtaining trace results were reported as averages. To reflect variability in the delay in obtaining trace results, these parameters follow BetaPERT distributions with minimums of 0 days, maximums of 28 days and modes equal to the weighted average delay for each production type.

A minimum of 0 days was used to allow the possibility that some direct contacts could be identified the same day that an infected herd is detected and reported. A survey of 11 traceability experts in California found that the maximum delay in obtaining trace results from dairies during a bovine TB investigation was 28 days (unpublished data). Therefore, this value was chosen as the maximum delay.

Information on the probability of trace success of indirect contacts was not available in the published literature but was assumed to be lower than the probability of success of direct traces. Based on NAHMS data of record keeping practices, small ruminants were given a lower probability of indirect trace success than all cattle and swine production types. Parameters for the delay in obtaining indirect trace results were assumed to be the same as the delay in obtaining direct trace results. The number of days prior to detection that trace investigations were to be conducted reflects two times the incubation period, as stated in federal and state FMD response plans.”

Production Type	Probability of direct contact trace in/out investigations succeeding	Probability of indirect contact trace in/out investigations succeeding	Delay in obtaining direct and indirect trace results in days (min, mode, max)	Period of interest (in days)
Cow-Calf	0.86	0.7	BetaPERT (0, 5.97, 28)	28
Dairy	0.93	0.7	BetaPERT (0, 3.63, 28)	28
Feedlot(S) and Feedlot(L)	0.86	0.7	BetaPERT (0, 7.38, 28)	28
Sheep	0.87	0.5	BetaPERT (0, 5.57, 28)	28
Goats	0.87	0.5	BetaPERT (0, 5.57, 28)	28
Swine(L)	0.91	0.7	BetaPERT (0, 3.72, 28)	28
Swine(S)	0.91	0.7	BetaPERT (0, 3.72, 28)	28
Beef(BY-SS)	0.93	0.7	BetaPERT (0, 3.63, 28)	28
Swine(BY-SS)	0.93	0.7	BetaPERT (0, 3.63, 28)	28
Sm Ru(BY-SS)	0.93	0.7	BetaPERT (0, 3.63, 28)	28

When an infected unit is examined because of a trace, the observation function (see Detection section above) is multiplied by the unit examination multiplier and the reporting function is assumed to be 100%. The Updated SSRA team used an alternate approach for these two functions, which more accurately models producer behavior during an outbreak. The alternate approach uses the reporting function as a multiplier, and so the 100% reporting used in the NAADSM tracing calculations would yield an incorrect detection rate. As a result, the team applied the maximum multiplier from the reporting function as the unit examination multiplier (Table 6.1.4-16); this results in a rate of identification of disease above 76%, in keeping with the approach described in USDA 2011, and corrects for the automatic use of 100% reporting in the NAADSM tracing calculations.

Production Type	Value
Cow-Calf	13
Feedlot(S)	50
Feedlot(L)	50
Dairy	50
Swine(S)	20
Swine(L)	20
Sheep	50
Goats	40
Beef(BY-SS)	20
Swine(BY-SS)	30
SmRu(BY-SS)	50

In addition to performing examinations for clinical signs, diagnostic testing will be performed as part of a tracing investigation. USDA 2011 parameters were used:

“FMD infection can be confirmed by ELISA, virus isolation, or RT-PCR [OIE, 2009]. The NVS Countermeasures Working Group [2007] recommended that commercial AG-ELISA tests be stockpiled for detection of FMD during an outbreak with no vaccination and the 3ABC commercial test kits (Cedi-diagnostics) be stockpiled to detect cases during an outbreak with vaccination. Because all scenarios, with the exception of the baseline scenario, will simulate outbreaks with vaccination, the parameters for diagnostic testing are based on the 3ABC commercial test kit. A comparative study of 6 ELISA tests [Brocchi et al., 2006] using cattle, swine, and sheep sera found the Cedi-diagnostic test to have a specificity of 98.1%. Sensitivity varied by vaccination status, experimental exposure status, and number of days post infection but generally approached 90%. Results were similar across species. Therefore sensitivity and specificity parameters are assumed to be the same for all species. ELISA assay results can be obtained within hours of sample delivery. However there may be a delay depending on herd distance from the nearest testing facility, time of day, or day of the week that samples are collected. Therefore, it is assumed that the delay in obtaining results follows a BetaPERT distribution with a minimum of 0 days, a mode of 1 day and a maximum of 2 days.”

Table 6.1.4-17: Diagnostic Testing: Sensitivity, Specificity, and Delay in Obtaining Test Results for All Production Types in All States

Diagnostic Parameter	Value
Sensitivity	0.9
Specificity	0.98
Delay in Obtaining Results	BetaPERT (0, 1, 2)

Zones

Zoned movement control was not used for the Updated SSRA (universal movement control was used as described above). NAADSM does not model zone-based movement control in a manner consistent with the way zones will be controlled in an outbreak according to SME interviews. When a zone is triggered in NAADSM:

- Direct or indirect contracts are not permitted from facilities inside a zone (control or surveillance) to facilities outside the zone that are at a lower level of surveillance or control. So, for example, it is possible to ship animals into a control zone from a surveillance zone or from a zone with no control/surveillance in place. Another example is that no infected animals or fomite could leave a surveillance zone to contact a farm in an area that was not in a zone.
- Movement within a zone may be allowed, if units are not quarantined. Direct and indirect contact between units is not allowed if the source unit and receiving unit are in physically separated foci of the same zone or if the source unit is in a zone of a higher surveillance level than the receiving unit.

Based on conversations with USDA and state and local officials in multiple states, human traffic will be allowed into and out of control zones with biosecurity measures in place that can significantly reduce disease transfer by indirect contact. Animals would be allowed to move under permit after inspection for disease as soon as several days after the control zone is established. Without the development of new diagnostic technology, some latent animals could potentially be released as a result (a very small but potentially significant source of direct contact out of zones that cannot be captured in NAADSM). In an actual outbreak, movement restriction would be less severe in a surveillance zone, but these zones are subject to the same NAADSM rules, so no direct or indirect contacts would be permitted to areas with less control. The use of zones unrealistically limits indirect and direct contacts from zones, as it does not allow for the small but significant failure of control measures, so zones were not used for the Updated SSRA. These conclusions are mirrored by a criticism of the approach used in the 2010 SSRA in which the reviewers stated that it was overly optimistic to assume that absolutely no movement would occur from inside an infected zone to an uninfected area.

Even if zones allowed user specified levels of control in NAADSM, more research needs to be done to understand if sufficient resources would be available during an outbreak to control movement around all infected premises. Individual states only have the resources to control a few zones before they run out of manpower and equipment, they therefore rely heavily on federal resources to make up this shortfall. In most cases modeled, more premises are infected by the time the outbreak is announced and more control measures are implemented than can be controlled by state-organized teams; however, federal resources will be immediately available. During a multi-state outbreak, the resources that would be required from the federal government would be substantial in all parts of the outbreak, but especially in movement control. It might not be possible to control the movement of animals and people around all infected premises. It is likely that, even if a modified version of NAADSM were developed that allowed some reduced level of contact out of a zone, the number of zones (and the stringent movement control they enable) should be capped to reflect that unlimited resources are not available. Zones should be used together with less stringent universal movement control based largely on self-enforcement in the community (described in the universal movement control section).

Herd Destruction

First Day of Destruction

Herd destruction begins a user-specified number of days after the outbreak is detected. Destruction starts two days after the outbreak is detected in the Updated SSRA model to allow time to organize the response based on USDA 2009 parameters.

Destruction Capacity

Destruction capacity is a function expressing the number of herds that can be destroyed each day, with capacity varying over time. The 2010 NAS SSRA Committee suggested that the destruction rate used was poorly explained and overly optimistic. For the Updated SSRA, an extensive data collection effort was performed and led to a new approach to calculating destruction capacity. Culling rate calculations

include the time needed to deploy and set up for depopulation, time to depopulate, and time to tear down the equipment.

Modeling of destruction capacity is limited because no one has developed a modification to NAADSM that enables the consideration of factors that would affect how quickly premises can be destroyed. Currently, destruction capacity must be entered into NAADSM as a single function that applies to all herds, regardless of herd size or production type differences that significantly impact the daily destruction capacity. In the version of NAADSM currently available, the time needed to cull a backyard facility with five animals is the same as the time needed to cull a swine farm with 5,000 animals.

Given these limitations, the Updated SSRA team chose a conservative destruction rate for the Updated SSRA. To calculate the destruction rate, the time needed for one team to destroy each herd in the Kansas model was calculated and included: deployment of equipment and personnel, set-up of depopulation apparatus, round-up of animals, depopulation of animals, and tear-down of depopulation apparatus. Disposal of animals was not included separately in the calculation because the culling rate accounts for the time to remove the carcass from the site of destruction. SME interviews indicate that disposal is likely to occur simultaneously with destruction, and some SMEs believe that, if necessary, disposal can continue with a less skilled team while the culling team moves on to a new facility.

Setup of depopulation apparatus and round up of animals were estimated by SMEs (Table 6.1.4-18). Production types divide into two general categories. 'Lot type' premises need less setup/tear-down time because they have animal handling equipment (pens/chutes) in place. 'Non-lot type' facilities need greater setup/tear-down time, because they do not have the same infrastructure. Feedlots, dairies, swine (S), and swine (L) facilities were classified as 'lot-type' facilities. Cow-calf, sheep, and goat facilities were classified as 'non-lot (large)' or as 'lot-type,' depending on the number animals in the herd. All backyard facilities were classified as non-lot (small).

Table 6.1.4-18: Time Estimates for Each Stage of Herd Depopulation

Herd Type	Deploy (h)	Setup (h)	Round up (h)	Baseline Kill Rate (head/hour)	Tear Down (h)
Lot	0	6	0	20(cattle) 150(swine/small ruminants)	0
Non-Lot(Small)	12	6	0	20(cattle) 150(swine/small ruminants)	6
Non-Lot(Large)	12	6	6	20(cattle) 150(swine/small ruminants)	6

The number of hours to depopulate each facility was calculated by multiplying the appropriate baseline kill rate by the number of head of animals in that herd and then adding time for setup and tear-down based on the herd production type. So, a dairy with 100 animals would take five hours to cull the total

herd plus another six hours for setup. Given 12-hours shifts in a sustained emergency response, all but the largest 15% of premises of all types require three days (36 h) or less to cull for a single team (Table 6.1.4-19). Unfortunately, when the largest 5% or 1% of premises is included, the time to cull all premises increases significantly. Data could not be found to support whether a user has modified NAADSM to accommodate this variability, so a destruction rate was selected that aims to capture the vast majority of premises sizes (85%). Basing a rate on the largest 1% of premises, would ignore the fact that the vast majority of premises can be destroyed more quickly.

Table 6.1.4-19: Total Time to Herd Depopulation for the Largest Facilities of Each Production Type			
Facility	Hours to destroy 85 th percentile premises	Hours to destroy 95 th percentile premises	Hours to destroy 99 th percentile premises
Feedlot	36	116	750
Dairy	17	18	316
Swine	9	61	130
Cow-Calf	36	40	66

The Updated SSRA team used the time required to cull herds in the 85th percentile for herd size to calculate destruction capacity; this translates to a third of a premises culled per day per team. Not only does this approach capture the vast majority of premises, it also minimizes premises type differences (Figure 6.1.4-23). This rate is conservative because most premises will require less time to depopulate. On the other hand, the largest 1% of premises may require weeks to depopulate and may drive the overall culling rate if the outbreaks reach very large swine and feedlot facilities that are geographically clustered.

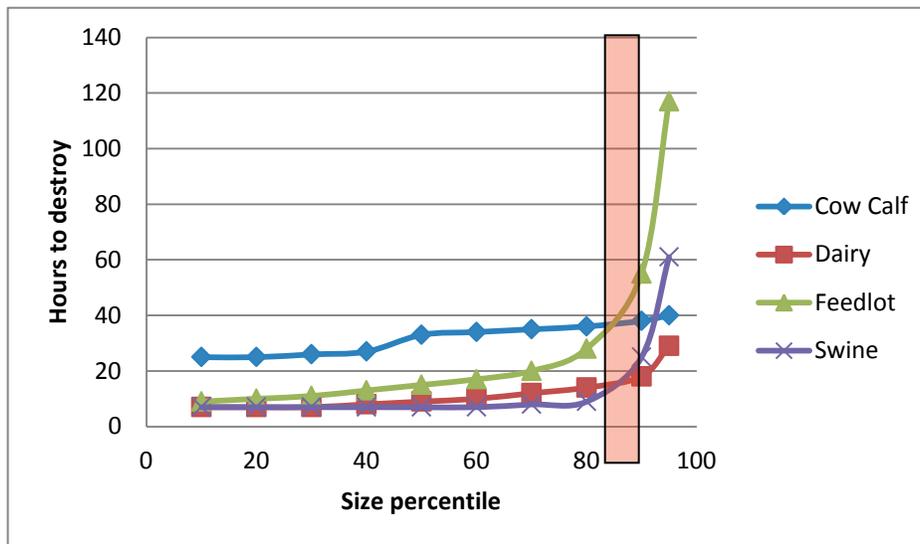


Figure 6.1.4-23: Total Time to Herd Depopulation for the Facilities of the Most Prevalent Production Types

The orange bar indicates the premises size used to set the culling rate in the Updated SSRA.

Information was collected on each state's destruction capacity through a series of interviews with state veterinarians, emergency coordinators, and health commissioners on resources available at the state level. The directors of the National Veterinary Stockpile and National Animal Health Emergency Response Corps (NAHERC) were consulted on the availability of federal resources. The state representatives were asked to identify the number of depopulation teams that would be available over the course of 60 days. Table 6.1.4-20 shows the range of responses of state representatives from four states in the modeled region. These states estimate that it will take at least ten days to deploy the maximum number of depopulation teams. Individual state destruction capacities are not provided because this information is considered sensitive because it reveals strong and weak points in the nation's preparedness for an agricultural emergency.

Table 6.1.4-20: Range of Depopulation Teams Available from States in the Modeled Region

Days into outbreak	1	10	20	30	40	50	60
Maximum	5	10	15	20	25	30	35
Mean	2	7	12	12	12	13	13
Minimum	2	4	4	4	4	4	4

Based on the number of teams available and a destruction rate of 1/3 per team per day, a destruction capacity for each state was estimated. When a state provided a destruction estimate, that estimate was used to calculate a state-specific destruction rate. For those states that did not respond to the survey, the mean number of destruction teams was used for modeling. The number of culling teams was provided in 10-day intervals and was interpolated linearly to determine the number of teams available on every day in the 60-day period. During an outbreak involving all seven states, 90 teams would be deployed.

This function was interpreted as a representation of distinct deployment groups, each of which begins culling on their respective deployment date. Because three days are required for a team to destroy a herd, each team only contributes one herd to the total destruction capacity every third day. This creates an oscillatory pattern which is a function of the deployment timing of teams (Figure 6.1.4-24). It was assumed that withdrawals are made in the order of which teams were deployed (i.e. the first team deployed is the first team to be relieved). Withdrawals were only modeled in a single state, as reported for that state's destruction capacity. Table 6.1.4-21 shows an example calculation for a notional event. The mean destruction capacity, which was used for those states where data was not collected on destruction capacity, can be found in Figure 6.1.4-24.

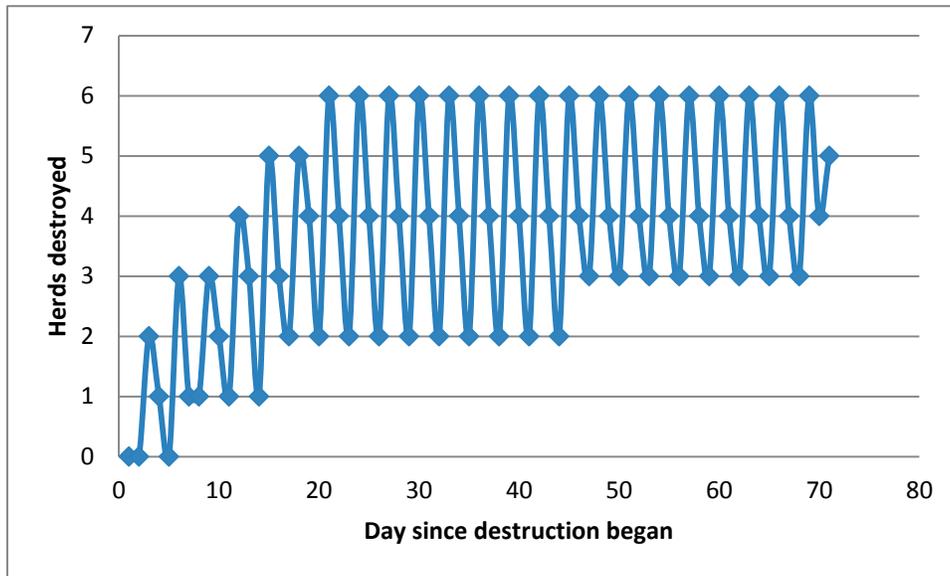


Figure 6.1.4-24: Mean Destruction Capacity Function (herds/day)

In Table 6.1.4-21, a notional destruction capacity calculation shows multiple deployments and withdrawals (please note withdrawals were only modeled in a single state, because that state indicated that teams are likely to withdraw as veterinarians need to return to their practices). Note that only the withdrawal made on day 7 has an impact within the time frame shown here and that it detracts from the culling cycle of deployment group 1; group 1 and group 3 have the same culling cycle by pure coincidence. The impact of withdrawals made on days 8 and 9 is not realized until day 12 which is not shown here. In order to be consistent, if a withdrawal is made on day 1 of a certain group’s culling cycle then the impact is realized within that culling cycle. The withdrawals on day 7 and 8 do not impact groups 3 and 4 because the entireties of groups 1 and 2 have yet to be withdrawn.

Table 6.1.4-21: Notional Destruction Capacity Calculation								
Day	Teams Available	Deployed or Withdrawn	Group 1	Group 2	Group 3	Group 4	Withdrawal 1	Total Destruction Capacity (Herds/day)
1	2	2	0					0
2	2	0	0					0
3	2	0	2					2
4	5	3	0	0				0
5	6	1	0	0	0			0
6	7	1	2	3	0	0		5
7	6	-1	0	0	1	0	0	1
8	5	-1	0	0	0	1	0	1
9	3	-2	2	3	0	0	-1	4
10	3	0	0	0	1	0	0	1

Destruction Priorities

Destruction priorities were based on USDA 2011 parameters, but adapted for Updated SSRA production types (Table 6.1.4-22). The following evidence basis was provided in USDA 2011:

“If a unit is marked for destruction but cannot be destroyed immediately, it is quarantined and goes onto the following prioritized waiting list:

Reason for destruction (*Detection of disease > identification of a direct contact with a detected unit by trace investigation > identification of an indirect contact with a detected unit by trace investigation > Production type* (Following the order in the table above) > **Days holding** *Justification for assumptions*

The destruction priorities ensure that all detected units will be destroyed before traced units. Detected high priority production types will be destroyed before detected low priority production types regardless of time that units have been waiting for destruction. This setting follows from the assumption that the highest priority production types are at risk of causing airborne spread after quarantine has been imposed and should be destroyed before lower risk production types that have been waiting longer but are at lower risk of causing airborne spread.” [USDA, 2011]

Priority	Production type
1	Swine (L)
2	Swine(S)
3	Swine (BY-SS)
4	Feedlot(L)
5	Feedlot(S)
6	Dairy
7	Cow-Calf
8	Beef (BY-SS)
9	Sheep
10	Goat
11	Small Ruminants (BY-SS)

Other Destruction Parameters

In addition to destruction capacity and destruction priority several other parameters define destruction in NAADSM. These parameters are described in the follow excerpt from USDA 2011:

“All detected units are marked for destruction. Units that have had contact with diseased units within a given number of days prior to detection of the diseased unit (found through trace investigations) and units within a given distance of diseased units may also be marked for destruction. The destruction of these units associated by trace or distance is called preemptive destruction.

According to the USDA foot-and-mouth disease response plan (the red book, 2010), four control strategies will be considered in the event of the outbreak. Three of these four strategies involve slaughter of all clinically affected units and units that have had direct or indirect contact with detected premises. The fourth strategy is a vaccination to live policy without stamping out where no slaughter takes place. Following the three strategies that involve slaughter, all detected and traced units will be destroyed and ring destruction will not be implemented.” [USDA 2011]

Vaccination

Vaccination was not considered as part of the 2010 SSRA. For the Updated SSRA, the team incorporated a plausible vaccination response into epidemiological modeling because vaccination will almost certainly be employed as a mitigation strategy in the face of a large FMD outbreak. FMD vaccination policy is still an active area of study in this country and the Updated SSRA is not designed or intended to investigate FMD vaccination strategy, which deserves careful analysis focused just on aspects of the strategy. The approach aims to avoid use of these results to inform vaccination policy discussion while capturing the important effect vaccination would have on an FMD outbreak from the NBAF. Furthermore, the modeling of vaccination is designed to reflect the fact that the laboratory will operate (and therefore the response to accidents at the laboratory) only after 2020. Additionally, the exact speed and throughput of the vaccination-based response is considered sensitive information and such details will change considerably over the next nine years. To this end, the team interviewed SMEs at USDA to understand how a vaccination campaign may unfold in an outbreak around 2020 (see Appendix A6, USDA Vaccination Interviews for full interviews) and used this input, together with vaccination parameters from USDA 2011 (which is itself a vaccination study) to create a plausible set of vaccination parameters for the Updated SSRA.

Essentially, the scenario proposed by USDA SMEs involves a delay before vaccination can commence to confirm serotype and acquire formulated vaccine; once vaccine is available it is available in unlimited quantities. The vaccination campaign is triggered as soon as the first herd is detected. NAADSM is commonly used to model administration of vaccine in a ring around detected, infected units. While a ring vaccination strategy would plausibly be employed during an outbreak, it is one of many possible vaccination strategies. Most NAADSM users model vaccine administration by a series of vaccination teams, similar to destruction capacity. However, almost all producers regularly vaccinate their own herds against other diseases and this expertise will certainly be leveraged by USDA during a large-scale outbreak. Given the approach to vaccination commonly implemented in NAADSM, the Updated SSRA team tried to capture the substantial vaccination capacity provided by producers in the vaccination capacity. However, the team was not able to truly implement the approach suggested by USDA because modifications to NAADSM that could model vaccination performed by producers have not been developed.

Triggering Vaccination

USDA indicated that for this scenario, the Updated SSRA team should assume that vaccination would likely be triggered by a single infected commercial herd near the NBAF.

Vaccination Capacity

For large outbreaks, vaccine (when available) will be distributed to each facility to be vaccinated. Vaccination will be undertaken by the workers at each facility simultaneously, enabling the most rapid response. Producers often administer their own vaccines, so this approach requires no special producer training. This approach is very different from the response commonly modeled in NAADSM in which a set of vaccination teams performs all vaccinations serially (similar to destruction, a set number of vaccination teams travels farm to farm). For this reason, a method was developed to approximate this type of response in NAADSM.

In order to simulate simultaneous vaccination in many locations a method was designed to model the complete vaccination of the initial outbreak area in the appropriate amount of time. The initial vaccination capacity was approximated by dividing the number of premises that need vaccination when vaccine becomes available by the number of days needed to vaccinate all premises given the range of herd sizes that exist in the area. Because vaccination rate (herds/day) changes as a function of time, and not as a function of outbreak size, if the outbreak becomes uncontrolled, the time required to vaccinate all premises will increase and this will effectively simulate logistical issues with the delivery of vaccine to multiple infection foci.

Because herd size is an important driver of the time needed to vaccinate a herd, the Updated SSRA team determined what fraction of premises could be vaccinated in a given time as a function of their size. Interviews with SMEs determined the range of possible vaccination rates at the premises of interest based on the resources available in each premises to handle animals (Table 6.1.4-23).

Type	Rate per 12 hr day	Head per day
Feedlot	Minimum	780
	Median	1440
	Maximum	1800
Cow-Calf	Minimum	300
	Median	750
	Maximum	1200
Swine	Minimum	960
	Median	1830
	Maximum	2700

Exploring a range of vaccination rates and premises sizes in Kansas led to a range of times required to vaccinate all premises (Table 6.1.4-24). The slowest reasonable rates require ten days to vaccinate all premises (which is the average of the three bad cases below), while the fastest reasonable rates require three days to vaccinate nearly all premises. This analysis assumes that not all premises can reach the highest rates of vaccination, but the largest premises have more resources to vaccinate more quickly than the smaller premises.

Table 6.1.4-24: Time to Vaccinate All Herds Given a Few Vaccination Rates and the Percent of Premises Sizes Left Out of the Analysis

Case Type	Vaccination Rate Basis	Percentile Left Out	Days to vaccinate
Bad Case	Feedlot median rate	Largest 1%	11
Bad Case	Swine median rate	Largest 1%	11
Bad Case	Cow-calf median rate	Largest 1%	9
Good Case	Feedlot low rate	Largest 5%	3
Good Case	Swine low rate	Largest 5%	3

These data suggest that even if vaccines were immediately given to each producer, between three and eleven days would be required to vaccinate all herds. To translate this value into a daily vaccination rate usable by NAADSM, several test runs were conducted in which the number of herds that were queued for vaccination was counted when vaccine would be available. A three-day and seven-day delay in the availability of vaccine was considered and several runs across several starting location types were examined. The number of herds queued for vaccination was averaged across the runs that vary by starting location type (the values were calculated separately for the two delays). This number of premises queued were then divided by the range of time needed to vaccinate all herds based on size (3-11 days) to determine a range of plausible vaccination rates. From this analysis, a range of vaccination strategies was used for outbreaks in Kansas (the rate was re-computed for outbreaks in other states):

- 7-day delay to vaccination, 90 herds per day (Strategy A)
- 7-day delay to vaccination, 1,800 herds per day (Strategy B)
- 3-day delay to vaccination, 200 herds per day (Strategy C)

Recall that the concept of operations in this FMD response scenario is for USDA to simply centrally distribute and dispense vaccine to producers so that they can vaccinate their own herds. Therefore, even the seemingly high rates of vaccination are not driven by federal resources but by the resources available at each farm. That being said, no current version of NAADSM can account for dynamic vaccination rates based on the number of premises in need of vaccination. For this reason, any of these rates may be inappropriately small for outbreaks that evolve quickly and inappropriately large for small outbreaks. Also, NAADSM is commonly used to model vaccination as a serial process undertaken by a set number of teams. For these reasons, the vaccination rates above are not at all intended to reflect the reality of what will happen after an outbreak, but a mathematical construct to better simulate the effect of this disease control measure.

For all cost-benefit analyses, all three plausible vaccination strategies were used. For baseline epidemiological analysis, the use of all three vaccination strategies would triple the amount of modeling needed to perform the analysis. To determine which vaccination strategy would be used for the baseline, runs with several different starting locations were compared. Vaccination Strategy A leads to median outbreaks that are from two- to seven-fold more extensive (in terms of head culled or head

vaccinated) than the other two strategies on average. At the extreme outputs, Strategy A leads to p90 outbreaks that are less than twice as extensive as the other two strategies on average and p5 outbreaks that are two- to eight-fold more extensive than the other two strategies on average. Across all outputs (p50, p10 and p90) outbreak duration was similar. For this reason, Strategy A is the conservative worst case of the plausible scenarios, but uniformly produces estimates of impact within the same order of magnitude as the other strategies. Moreover, the fold-difference between the extreme (p10 and p90) epidemiological outputs compared to the median (a measure of variance) is similar across the strategies (within about 10%).

For these reasons, Strategy A was chosen to represent vaccination in NAADSM in Kansas for most studies. So, the vaccination parameters for the baseline included:

- Vaccination is triggered once one infected herd is detected; and
- Vaccination capacity for the first six days is 0, on day 7 (and all days after) 90 herds per day can be vaccinated each day.

Given the uncertainty in the actual implementation of a vaccination strategy in an emergency, all cost-benefit analysis considers all three plausible strategies.

Vaccine Immune Period

Vaccine immune period was based on USDA 2011 parameters:

*“Experimental studies on the duration of immunity using single dose high potency emergency vaccines have generally shown that titers remain high 6 months after vaccination [Cox & Barnett, 2009]; [USDA, 2011]. One study showed titers in cattle peaked at 2 months and remained high, declining slightly up to 6 months [Cox et al., 2010]. Another study showed waning titers in vaccinated cattle 43 days after vaccination [Barnett et al., 1996]. There are few challenge studies available beyond 28 days post-vaccination. One challenge study in cattle showed protection from clinical disease and high titers at 6 months [Cox et al., 2010]. Another challenge study in pigs showed protection at 7 months [Cox et al., 2003]. To reflect the uncertainty due to the lack of experimental data available, and the fact that immunity generally lasts at least 6 months, **the duration of immunity for all species is assumed to follow a BetaPERT distribution with a minimum of 28 days, a maximum of 220 days, and a mode of 180 days.**” [USDA 2011]*

Delay in Immunity Following Vaccination

The delay in immunity following vaccination was based on USDA 2011 parameters. However, an additional delay was added to large feedlots to help account for the additional time it would take to vaccinate an entire large feedlot, based on the feedlot vaccination rates discussed in the vaccination capacity section. For premises types that exclusively concern themselves with large herds (like the large feedlot and large swine operations), the time to vaccinate the median herd was determined. If this delay

was longer than the delay used to calculate the vaccination rate, additional time was added to the delay in protective immunity.

*“Vaccine parameters were developed under the assumption that high potency emergency vaccines ($PD_{50} \geq 6$) would be used. NAADSM assumes that vaccination is 100% effective. Therefore the delay in immunity parameter should be selected to reflect the time required for a herd to become completely protected from clinical disease/virus shedding. Experimental studies have shown that vaccinated cattle and sheep are partially protected as early as 4 days post vaccination but may take up to 14 days for complete protection [Cox & Barnett, 2009]; [Barnett & Carabin, 2002]; [Barnett et al., 2004]; [Orsel et al., 2005]; [Orsel et al., 2007]; [Madhanmohan et al., 2010]; [USDA 2011]. Results varied by study design, species, challenge strain, and vaccine. Onset of immunity in pigs generally takes longer to achieve than for other species, generally requiring at least 21-28 days for complete protection [Doel et al., 1994; Parida et al., 2007]. In consultation with subject matter experts, a value of **24 days was chosen for swine and 10 days for non-swine species.**” [USDA 2011]*

***For the Updated SSRA, large feedlots had an additional delay of 6 days.**

Time Between Vaccinations

Time between vaccinations was based on USDA 2011 parameters:

*“Revaccination in NAADSM can occur in situations where a new vaccination ring is created around herds that had also been located within an older vaccination ring and were previously vaccinated. The OIE Manual of Diagnostic Tests and Vaccines for Terrestrial Animals [2010] recommends that revaccination occur at 4-12 months and we have assumed that the duration of immunity for most herds will last approximately 6 months. We have assumed that, under conditions of limited vaccination resources, decision makers would not elect to revaccinate a herd unless at least **6 months** had elapsed since the prior vaccination.” [USDA 2011]*

Triggering Vaccination Ring

Vaccination ring zone size was also based on USDA 2011 parameters:

*“The size of a vaccination ring zone should be the smallest area necessary to control the outbreak, taking into consideration geographical barriers, climatic conditions, the number and distribution of detected FMD infected herds, the density of farms, and species present. Therefore the optimal ring size will vary by location. However, a modeling study of vaccination strategies using data from the 2001 U.K. outbreak found that the optimal ring size had a radius from 8-10km and was robust to variation in epidemiological parameters such as susceptibility of 49 species and transmissibility of virus [Tildesley et al., 2006]. Therefore a **vaccine ring with a radius of 10km was chosen for all production types.**” [USDA 2011]*

Vaccination Priority

The evidence basis for production type prioritization is from USDA 2009; the following evidence basis was provided:

“Feedlots are prioritized for vaccination given the large number of cattle on a premises making it difficult to depopulate all of the cattle in a timely fashion and because they are terminal animals that fit a vaccinate to slaughter strategy thus conserving destruction capacity and production value. Swine are next because of the potential for high levels of shedding and risk of transmission. Cow-calf and Dairy operations are lower priority because they are smaller sized operations that are more easily destroyed and are long lived animals that will require destruction. Sheep and goats are last given that they are a minor species.” [USDA 2009]

Backyard production types were prioritized lowest on the list, based on SME input. The vaccination prioritization entered into NAADSM is outlined below:

Priority for vaccination:

1. Ring
2. Days holding
3. Production type
4. Feedlot(L)
5. Feedlot(S)
6. Swine(L)
7. Swine(S)
8. Cow-calf
9. Dairy
10. Sheep
11. Goats
12. Beef(BY-SS)
13. Swine(BY-SS)
14. Small Ruminants(BY-SS)

6.1.5 Estimating Probability of Spread to States Other than Kansas

The 2010 SSRA leveraged a sales barn production type, developed by the 2010 SSRA team, to capture the risk that interstate animal movement could spread FMD between states. The 2010 SSRA was rightly criticized for this approach because only a portion of interstate animal movement occurs through sales barns. The Updated SSRA team knows of no group that has included premises contact rates in NAADSM that uses a solid evidence basis to simulate interstate movement. Therefore, premises from a variety of states could not be included on the same model map.

Instead of modeling sales barns specifically, interstate disease spread was estimated in the Updated SSRA by modeling the states in the region independently. The probability that an animal with a latent or subclinical infection gets shipped to another state is calculated for each outbreak modeled in Kansas. If an infected animal is determined to have moved to another state, that event triggers a model run for the other state and the consequences across all affected states are considered together. This method is elaborated upon briefly below.

To determine the probability that an infected shipment of animals is moved from Kansas to another state, the Certificates of Veterinary Inspection (CVIs), which are required for most types of interstate animal movement, were acquired for the state of Kansas for shipments to the other states in the modeled region (see Appendix A6, 2010 CVIs for Modeled Region). This analysis included the records of more than 10,000 animal shipments (more than 500,000 animals) originating in Kansas and traveling to other states in the modeled region during 2010. From these data, the number and type of animals moving from Kansas to each other state per day were calculated. Given the total number of animals of each type in Kansas, the chance that any given animal would be shipped out of state on any given day was calculated. Running modeling scenarios in NAADSM with Kansas alone, the number of animals with latent and subclinical infections was recorded on a daily basis (clinically infected animals are unlikely to be granted a CVI). These animals are counted until the outbreak is announced. To simulate the possibility that CVIs may be granted for animals outside the known infected area in a state after an outbreak is detected, latent and subclinical animals data are collected from NAADSM modeling runs over the first month, even after the outbreak is announced, but this total is reduced by 99% to account for the additional scrutiny and reduced demand for animals from that state. By the end of the month, uncontrolled outbreaks are normally identified all over the infected state, so no animals are considered to be transported out of state after this time. Given the number of animals that could spread the disease and the number of animals moving on any day, the probability that the disease could spread to another state from an outbreak in Kansas can be calculated.

This analysis also considered the total number of shipments and number of premises in Kansas to calculate the risk that an infected shipment occurred to determine if shipment-based risk was worse than animal-based risk. For all cases, calculations based on infected animals caused a greater risk than infected shipments and therefore this shipment-based method was not carried through the analysis to partially compensate for the fact that this modeling approach artificially reduces the chance of disease spread across borders by modeling the states independently and preventing shipments between states other than Kansas.

The method above was used to predict the probability that an infected animal would be shipped from Kansas to another state. To determine where in that state the animal went, a more detailed set of CVI data was used. This CVI dataset included the animal type, purpose of the shipment (e.g., feeding or breeding) and the destination city. All CVI data were compiled from paper records into spreadsheet format. This resource intensive project limited the amount of data that could be collected. Therefore, the team collected and analyzed information from only the counties near the NBAF. Using these data, the types and locations of premises receiving an infected animal can be determined; specifically, the state, city and facility type (e.g., feedlots received cattle shipped for feeding, for example). Locations receiving animals destined for slaughter (rare in the CVI set) were removed from the model and not considered as possible starting locations. A facility that matched the facility type and location were selected for each destination location mentioned in the CVIs and the relative probability of an outbreak starting at each of these locations was calculated based on the number of animals received by that facility compared to the total received by that state. That is, if a feedlot in Sioux City, Iowa, receives

1,000 cattle each year from Kansas and Iowa receives 100,000 cattle overall, 1% of all outbreaks modeled in Iowa will be modeled to start in the Sioux City feedlot chosen.

This method has several strengths and weaknesses that should be highlighted. First, the use of CVI data captures the movement of animals from any facility in Kansas to any other state in the model, not just those animals sold through sales barns. This method also accounts for the probable destination of interstate shipments, which should focus secondary outbreaks in the areas with the most livestock industry. The modeling of each state separately facilitates the incorporation of state-specific mitigation efforts (as described below, each state has a unique estimate for culling resources, for example). Most importantly, this method has a solid evidence basis for the long-distance movement that does occur.

Regarding weaknesses of this approach, one major weakness is that this method overly isolates state borders; disease cannot spread due to indirect contact or wind-borne spread between states. Moreover, the model does not consider second-order spread among states that received an infected animal from Kansas (the spread of disease from Oklahoma to Texas, for example). Also, CVI data does not capture “illicit” movement of animals and the movement of animals to sales barns in another state.

A method should be developed to include all states in a single modeling region to enable direct and indirect disease spread among states in NAADSM. This inclusion relies on the generation of evidence-based production types specific for each state with contact rates adjusted to consider trans-border contacts. The contact rates and distance functions must be adjusted to reflect the risk of animal movement via short and long-distance movement.

6.1.6 Estimating Extent of Outbreaks in Other States

In order to model each state independently, a separate NAADSM baseline file was created for Nebraska, Colorado, Iowa, Missouri, Texas, and Oklahoma. Scenarios were run using each state’s baseline scenario file to estimate the outcome of an FMD outbreak in the region. While most parameters remained the same for each state, parameters developed using the within herd model were determined for each state. State-specific contact rates were determined for Missouri and Iowa, because SME input indicated that the livestock practices in those states were the most different from Kansas. Destruction rate parameters were developed when state interview data were available. The Updated SSRA team took advantage of parameters developed for Texas in USDA 2011 whenever possible.

6.1.6.1 General NAADSM Setup

The general NAADSM setup was the same for all states.

6.1.6.2 Production Types

Updated SSRA Production Types

The same production types were used for all states.

Wildlife

For the Updated SSRA, the team collected limited data on wildlife populations in the additional states modeled. While most states maintain harvest data on wildlife species in their state, estimates of total population or population density were not always available. All states modeled had significant deer populations. Elk and Pronghorn were only present in some states; these populations tend to be small compared to deer populations. Nebraska also has two bighorn sheep populations with between 100-200 animals total [Taylor, 2011].

Feral swine could play a significant role in an FMD outbreak in several states modeled. Texas, Oklahoma, and Missouri all have significant, uncontrolled feral swine populations (Figure 6.1.6-1). Colorado, Iowa, and Nebraska have small feral swine populations. Feral swine would likely play a minor role in an FMD outbreak in these states. All three states have task forces to eradicate introduced swine [Garner, 2011; Pelzer, 2011]. Iowa has trapped and killed a total of 181 feral swine since 2006 [Garner, 2011].

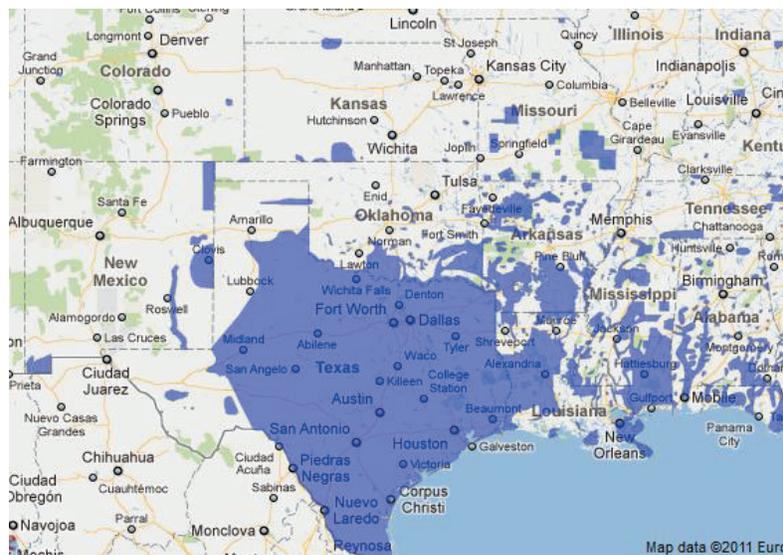


Figure 6.1.6-1: Map of Swine Populations in the Modeled Region [The University of Georgia College of Veterinary Medicine, 2007]

Susceptible Animal Populations -Farm/Facility Sizes and Locations

For the Updated SSRA, the team used CAFO data, D&B data, and a dataset developed by LLNL using NASS Agricultural Census data to build a population file for each state (Table 6.1.6-1). Population files were created for each state as described for Kansas in Section 6.1.4.3.

Table 6.1.6-1: Sources Used to Create Each Animal Population File

State	CAFO	D&B	LLNL 2007
Colorado (CO)	X	X	X
Iowa (IA)	X		X
Missouri (MO)	X	X	X
Nebraska (NE)	X	X	X
Oklahoma (OK)	X	X	X
Texas (TX)	X	X	X

Results

The number of livestock facilities and animals identified across the modeled region through evaluation and reconciliation of all the datasets are provided in Table 6.1.6-2 and Table 6.1.6-3.

Table 6.1.6-2: Number of Facilities Identified, Divided by Production Type and State

	CO	IA	MO	NE	OK	TX
Cattle Facilities						
Cow-Calf	6,433	16,047	45,030	15,849	32,506	104,819
Dairy	392	2,391	13	483	970	255
Feedlot (s)	2,405	6,561	896	1,718	8,039	410
Feedlot (l)	168	7	4	287	912	198
Beef (by-ss)	4,151	3,870	8,433	1,999	9,765	40,603
Swine Facilities						
Swine(s)	219	1,390	954	587	353	440
Swine(l)	19	8,658	749	1,379	234	57
Swine(by-ss)	898	526	1,420	310	2,219	3,974
Small Ruminant Facilities						
Goats	1,532	1,451	3,202	781	4,152	19,832
Sheep	834	2,794	1,506	974	1,080	5,564
SmRu(by-ss)	1,892	1,526	2,261	636	2,405	9,585
Total	30,294	45,221	64,468	25,003	62,635	185,737

Table 6.1.6-3: Number of Animals Identified, Broken Down by Production Type and State

	CO	IA	MO	NE	OK	TX
Cattle Population						
Cow-Calf	786,095	1,646,253	3,747,572	3,448,357	2,612,850	9,429,452
Dairy	192,636	360,452	24,517	48,016	117,545	1,288,896
Feedlot(s)	544,576	1,788,490	61,917	284,722	1,158,614	65,935
Feedlot(l)	1,763,397	25,608	21,501	1,659,594	1,306,828	4,984,694
Beef(by-ss)	32,228	26,780	63,691	15,808	68,043	309,223
Swine Population						
Swine(s)	11,571	1,646,253	98,442	68,500	18,318	30,218
Swine(l)	48,234	360,452	3,073,406	2,211,421	2,307,588	2,291,419
Swine(by-ss)	4,681	1,788,490	7,968	1,880 ^a	11,321	16,078
Small Ruminant Population						
Goats	41,271	50,461	90,986	32,665	115,689	1,098,525
Sheep	500,046	203,745	74,573	74,445	71,007	1,037,594
SmRu(by-ss)	11,029	9,250	13,519	3,954	14,100	55,921
Total	3,935,764	28,675,676	7,278,092	8,299,361	7,801,903	20,607,955

^aIn the model file a feedlot was mislabeled as a by-ss facility, this facility was removed from the total for this table.

Disease Progression

Herd Level Disease Periods

Herd-level disease phases were estimated as described for Kansas. State-specific parameter development and results are listed in Appendix A6, Within-Herd Model Data and Herd-Level Parameter Development.

Within-Unit Prevalence

The proportion of animals infected in a herd is expressed by the within-unit prevalence function. Within-unit prevalence functions were calculated for each production type for each state using output from the within-herd model. Calculation details and complete functions are found in Appendix A6, Within-Herd Model Data and Herd-Level Parameter Development.

Disease Spread

Direct Contact Rates and Distance Distributions

USDA SMEs expressed concern that production practices in Missouri and Iowa are significantly different from Kansas and recommended that the Updated SSRA team develop a new contact rate for these states. Due to time constraints the team was unable to create a full set of direct contact parameters; however, several SMEs from each state were interviewed to determine how the contact parameters for their state would vary from the contact rates developed for Kansas (Appendix A6, Direct Contact Rate

and Distance Distribution Parameters). Contact rates were multiplied by 365, so that they were expressed in shipments per year for SME interviews. The evidence basis for these contact rates is weak; however, SME advice indicated that this approach was more accurate than applying Kansas parameters to these states. Direct contact rates and distances for Texas were developed for the USDA 2011 study. The evidence basis for these parameters can be found in Appendix A6, Texas Direct Contact Parameters Evidence Basis. The same parameters were used to describe backyard-small-scale (Beef BY-SS, Swine BY-SS, Small Ruminant BY-SS) contact for all states, so these parameters are not listed again in this section. State specific direct contact rate parameters and direct contact distance distributions are provided for each state in Appendix A6, Direct Contact Rate and Distance Distribution Parameters.

Indirect Contact Rate

Indirect contact rate and distance distributions were the same for all states except Texas. The same parameters were used to describe backyard-small-scale (Beef BY-SS, Swine BY-SS, Small Ruminant BY-SS) contact for all states, so these parameters are not listed again in this section. State specific parameters are listed in Appendix A6, Indirect Contact Rate and Distance Distribution Parameters, along with the evidence basis for the Texas parameters. Probability of infection given exposure was the same for all production types.

Effect of Movement Control on Both Direct and Indirect Contact

The same movement control parameters were used for all states.

Airborne and Local Spread

The same airborne and local area spread parameters were used for all states.

Detection

As described above, the approach was to use the “probability of observing” function to describe both observation and reporting in the model prior to the declaration of an outbreak (called “obs and rep fx”) from this point forward. The obs and rep fx was developed for each state because it takes into account state-specific data on the estimated prevalence of symptomatic disease over time in an average herd, determined with the within herd model – a function of the herd size population distribution – and production type specific disease characteristics. All other data used to develop these parameters were constant for all states. The corresponding multiplier function (“reporting” function) was calculated for each state. Functions are provided in Appendix A6, Within-Herd Model Data and Herd-Level Parameter Development.

Tracing

The tracing parameters developed for Kansas were used for all states modeled.

Zones

Zone parameters were not used for any state modeled, as explained above.

Destruction

Destruction capacity was the only destruction parameter developed for each state; all other parameters were the same. Information was collected on each state's destruction capacity through a series of interviews with state veterinarians, emergency coordinators, and health commissioners on resources available at the state level. Kansas, Missouri, Nebraska, and Iowa each provided an estimate of the number of teams they would be able to recruit and these estimates were used to calculate state-specific destruction capacities. For those states that did not provide an estimate, the mean destruction rate was used. Destruction parameters were developed as described in Section 6.1.4. Individual state destruction capacities are not provided because this information is considered sensitive because it reveals strong and weak points in the nation's preparedness for an agricultural emergency.

Vaccination

The vaccination parameters developed for Kansas were used for all states modeled.

6.1.7 Determine Overall Risk Should an Accident Occur

As described above, the overall risk of an outbreak in the Updated SSRA considers the range of impact of each outbreak in Kansas and other states individually, and the probability that an infected animal would move between Kansas and one or more of the other states. For events which only a few possible starting locations in Kansas are identified, the risk of interstate disease spread is calculated for the event starting at each location. This approach pertains to the solid and liquid waste events, each of which can infect only a handful of possible premises. For events that can begin an infection at multiple starting locations (for example, the transference pathway) the outcomes from a modeling run for each Kansas starting location are ranked by impact (total head culled, for example). The risk of movement is calculated for the starting location that causes the median impact and the starting locations that cause the p5, p25, p75 and p95 impacts.

The probability of an outbreak starting in any given location is then combined with the probability that the outbreak spreads to another state. For example, assume that Premises A is the starting location in 50% of simulations for Event 1. If outbreaks in Premises A have a 10% risk of spreading to Texas (and no risk of spreading to other states), then 45% of outbreaks for Event 1 start in Premises A but spread to no other state whereas 5% of outbreaks for Event 1 start in Premises A and spread to Texas. The probabilities of spread to all six other states in the model are considered together, as are all the possible combinations of the disease spreading to multiple states.

For the events that spread from Kansas to multiple states, the consequences are considered together for those simulations. Head culled, premises culled, head vaccinated and premises vaccinated are summed across all states where the outbreak is considered to have spread. For disease duration, the longest duration of an outbreak in any of the states affected was reported. Continuing the example from above, following from Event 1, if an outbreak in Kansas starting from Premises A lasted for 100 days and involved the culling of 100,000 animals and an outbreak in Texas lasts for 120 days and involves the culling of 50,000 animals, then 45% of outbreaks due to Event 1 last for 100 days and involve the culling

of 100,000 head and 5% last for 120 days and involve the culling of 150,000 animals. In the economic analysis, the animals and premises affected by the outbreak were reported on a state-by-state basis.

6.1.8 Considering Uncertainty

The modeling in the Updated SSRA must contend with at least three types of uncertainty. The first type of uncertainty is pure epistemic uncertainty. Epistemic uncertainty – uncertainty that stems from incomplete knowledge of a subject – arises due to unknowns regarding agricultural practices (for example, how many premises share the same veterinarian) and the epidemiology of FMD (e.g., the dose of FMDv that would infect 1% of cattle). True epistemic uncertainty complicates the interpretation of the results of this project in absolute terms. For this reason, the Updated SSRA presents an analysis of the sensitivity of key results to the most uncertain parameters. Those parameters include infectious dose thresholds, direct and indirect contact rates, effectiveness of control measures on reducing direct and indirect contacts, culling rates and vaccination rates.

Uncertainty related to the initial focus of an infection due to a release event is largely driven by aleatory uncertainty (although some aspects are driven by epistemic uncertainty, like the probability that a herd would be infected by a low-concentration aerosol, but these aspects are explored separately). Unknowns related to the weather conditions that prevail during a release event, the distribution of animals in a pasture or the identity of a researcher that incompletely decontaminates (which determines the researcher’s likely location to encounter a susceptible animal) all contribute to the variety of possible premises that could be initially infected. For some release events (like the waste scenarios) the aleatory uncertainty is small and the outbreak can plausibly start at only one or two premises. For other events, like many of the large aerosol releases, the aleatory uncertainty is large (and driven by the variety of meteorological conditions that could transport the material from the NBAF to susceptible animals) and there are many possible starting locations (many of which involve the simultaneous initial infection of multiple premises).

Uncertainty due to starting location is explored and discussed fully in the Updated SSRA. For each release event, all possible starting locations are modeled and the consequences of outbreaks that start at each location are shown. The consequences of the outbreak for each starting location are ranked to identify significant “cuts” through the data. For example, of all possible starting locations, it is possible to identify and discuss the median starting location (in terms of its outbreak consequences) and the p5, p25, p75, and p95 starting locations.

Even for release events with few possible starting locations, the possibility that outbreaks could spread to other states (which was determined to occur in most outbreaks) exacerbates the uncertainty of starting locations. The probability of disease spread to other states due to an outbreak in a given location is used to modify the baseline probability of the outbreak starting in that location in Kansas. Taking the same example from above, Premises A is the starting location in 50% of simulations for Event 1. If outbreaks in Premises A have a 10% risk of spreading to Texas (and no risk of spreading to other states), then 45% of outbreaks for Event 1 start in Premises A but spread to no other state whereas 5%

of outbreaks for Event 1 start in Premises A and spread to Texas. The other 50% of simulations start in another location in Kansas, some of which spread to other states (some portion, and probably not 10%, of these outbreaks spread to other states).

To determine which of the starting locations in each state should be linked to the outbreak starting in any given location in Kansas, the rank order of the premises are matched. That is, a median starting location in Kansas is linked to the median starting location in every other state (and the probability that this location actually initiates an outbreak in other states is calculated as above). In this way, the maximum uncertainty is presented because the starting locations that lead to the largest outbreaks in Kansas are linked to the starting locations that lead to the largest outbreaks in other states, and so on. Linking starting locations randomly or linking locations on the opposite ends of the variance (such as linking the p5 starting location in Kansas to the p95 starting location in Kansas) would reduce the total uncertainty presented by driving all outputs toward the median result. Once the total consequences of an outbreak across all states are known, and the probability of this interstate spread is considered, the starting locations are re-ranked and new “cuts” through the uncertainty taken for the final output (new median starting conditions are assigned, which consider a particular starting location and the starting locations of all states to which the disease has spread).

Another type of uncertainty explored by the Updated SSRA arises from the fact that NAADSM is a stochastic model that produces a different result in each model iteration. This uncertainty is largely aleatory because the model calculates if an infection spreads from an infected premises to others in the surrounding area by determining if a contact was made, and if so, where the contact was by using draws against a probability distribution. Also, the efficacy of control measures is driven, to some degree, by the uncertainty of an infected premises being discovered and its placement in a queue for destruction. For example, each day, the model determines if an infected animal (or contaminated worker) moves from one farm to another, thereby possibly spreading the disease, given the probability that movement would occur on any given day. These small differences add up across the myriad possible contacts and produce a different output (in terms of duration and consequences) for each iteration. Across all iterations, a median result and other “cuts” can be identified. In the 2010 SSRA, typically, only the median result was discussed and used in the final results. In the Updated SSRA, the team presents not only the median results, but also less likely, but possible, outcomes. Considering these other cuts together allows the reader to understand what portion of the risk space a given result occupies given the uncertainty inherent in the NAADSM model. For example, 90% of all results from the model will lie between the p5 and p95 (the iterations for which 5% or 95% of the consequences were smaller) cuts.

The 2010 SSRA explicitly explored the epistemic uncertainty related to modeling parameters (in a separate section) for the baseline result (an outbreak starting in a cow-calf farm), but did not explore sensitivity of important results (like the benefit of additional culling capacity) to these changes. Also, sensitivity of results to changes in the aerosol infection threshold was not explored in the 2010 SSRA. In the results, uncertainty of starting location was shown as the only “cuts” through the uncertainty space and the median results for that starting location were the only ones shown. All graphs depicted the

median results for a variety of starting locations that were possible for each pathway. Uncertainty arising from the variability in epidemiological modeling was discussed, but not presented as part of the final results. The Updated SSRA captures all these types of aleatory uncertainty by presenting baseline results with uncertain starting locations and epidemiological output and explores epistemic uncertainty in the sensitivity analysis.

6.1.9 Example: Putting It All Together

To better illustrate how the epidemiological modeling approach considers uncertainty in starting location and NAADSM outbreaks, consider the following simple example. A modest spill outside of containment creates an aerosol that is transported by the wind and can infect one of two premises (Premises A 73% of the time and Premises B 27% of the time that at least one premises becomes infected). NAADSM is used to predict the extent and duration of an outbreak starting at each of these locations and the two possible starting locations can be ranked by their median impact (such as duration, herds culled, or, in this example, head culled). In Figure 6.1.9-1, below, the Y-axis represents the probability that an outbreak would start in any given location and the X-axis represents the impact (in head culled) of outbreaks at this location. Because outbreaks starting in Premises A are less consequential than outbreaks starting in Premises B, Premises A occupies the bottom 73% of the risk space and Premises B occupies the remaining 23% (because no other locations can be initially infected by this event).

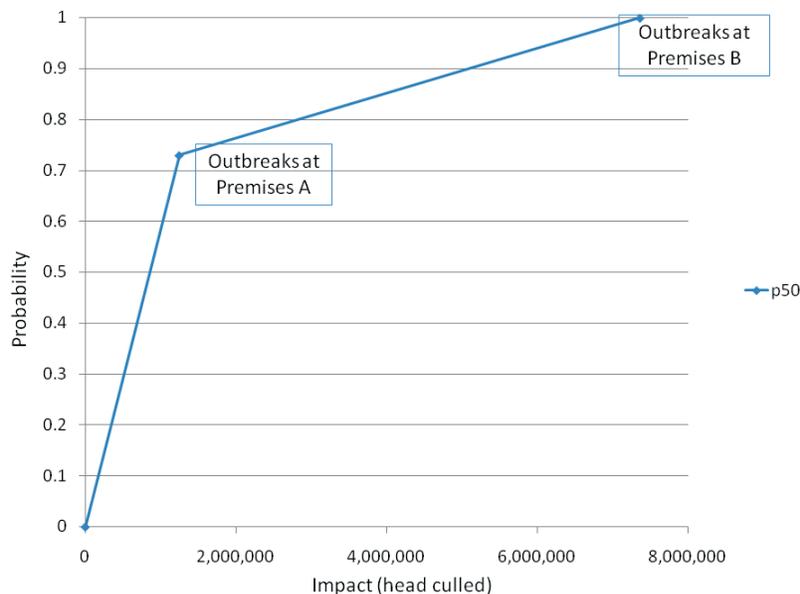


Figure 6.1.9-1: Cumulative Risk Distribution Function Showing Median Impact vs. Possible Starting Locations for the Example

This graph resembles graphs used to describe risk in the 2010 SSRA and explicitly considers the uncertainty in the starting location. However, only the median epidemiological output is shown. In the Updated SSRA, uncertainty is shown not only for starting location but for the uncertainty in the output of NAADSM. The p5, p25, p75, and p95 outputs were added to the median results in Figure 6.1.9-2. This analysis is informative because it shows the vast difference in consequences between the two locations disappears at the highest consequence outputs of NAADSM (the p75 and p95). Also, this analysis suggests, for both locations, the majority of outbreaks result in a million or more head culled but no outbreaks result in more than eight million head culled.

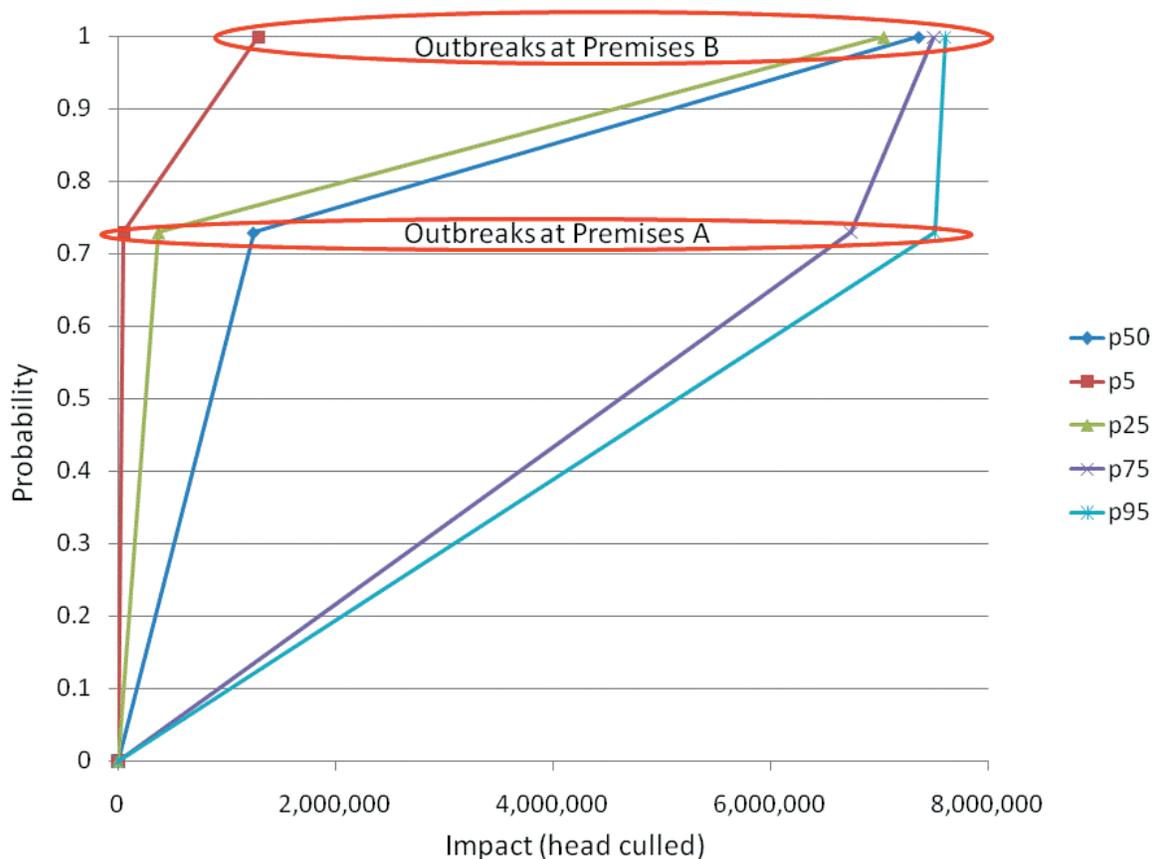


Figure 6.1.9-2: Cumulative Risk Distribution Function Showing Impact vs. Possible Starting Locations for the Example, Given Uncertainty in the NAADSM Outputs

To illustrate how the risk of movement to other states is considered, it is easiest to focus solely on the median NAADSM output for now. For an outbreak at each location, the chance that the disease would spread to another state is computed, where the probability that the disease would spread is considered alongside the probability of the outbreak starting in that location in Kansas, originally. The consequences across all states are summed to compute the total consequences for the outbreak that spreads to multiple states. These possibilities can be ranked and plotted as above. In Figures 6.1.9-3 and 6.1.9-4,

the total impact of outbreaks across all states is summed and ranked and plotted as a function of probability that the disease spreads to other states (or stays in Kansas). Figure 6.1.9-3 highlights how outbreaks that stay in Kansas are a fraction of all the outbreaks that start in any location in Kansas (in this case, only 20% of the outbreak starts stay in Kansas). Also note that the total consequences of outbreaks that stay in Kansas are the same if the impact is summed across all states (because the impact in other states is zero).

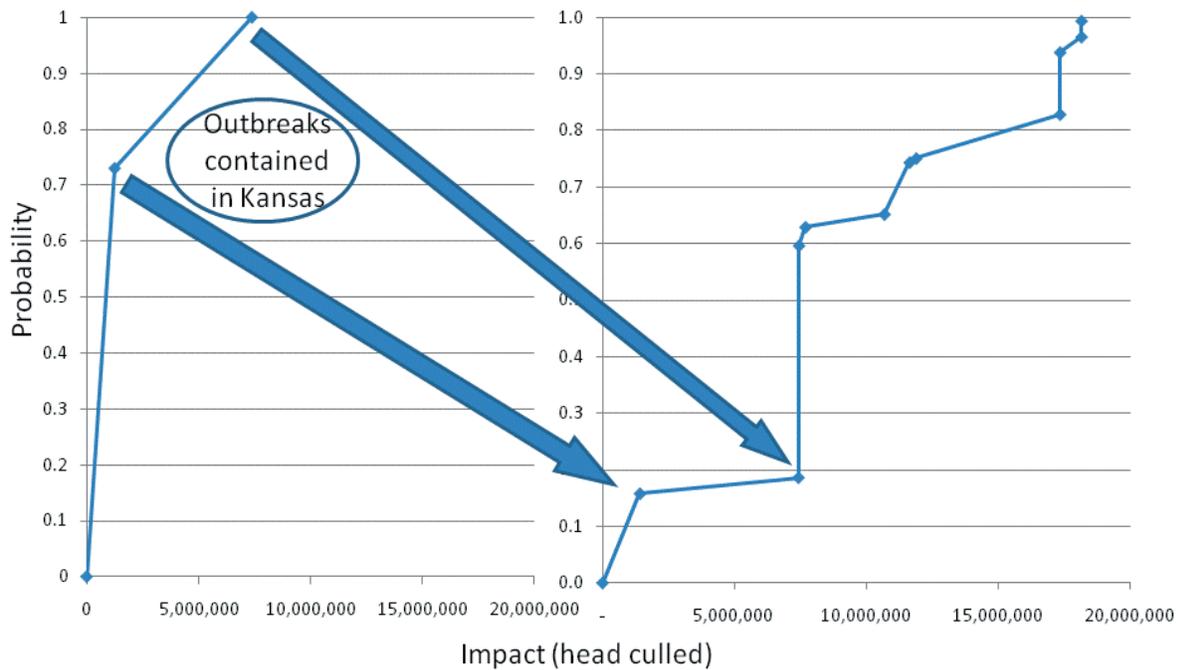


Figure 6.1.9-3: Impact of Outbreaks in Kansas (left) and Impact of Outbreaks Summed Across all States (right) as a Function of Probability the Spread Would Occur

Arrows illustrate the outbreaks that are contained in Kansas.

Figure 6.1.9-4 highlights how consequences of the outbreak that spread to other states add to the total risk of the outbreak. The arrows point out outbreaks considered to spread from the two initial starting locations to various other states. Each other data point on the curve is a different combination of states into which FMD was considered to spread. The total impact is summed across all states to obtain the X-axis value. For example, the one data point at 0.6 on the Y-axis and 7.4M on the X-axis represents outbreaks that start in Premises A and spread to Colorado, Iowa, Nebraska, and also Texas. This specific outcome is calculated to occur 40% of the time that an outbreak begins for this event (or 55% of the time an outbreak occurs at Premises A). Note also that the outbreaks that spread from Premises A are less consequential in total than outbreaks that spread from Premises B. This phenomenon results from the fact that the high-consequence premises in Kansas are linked to high-consequence premises in other states (and low-consequence premises in Kansas are linked to low-consequence premises in other states) to unmask all the uncertainty inherent in the choice of starting locations in each state.

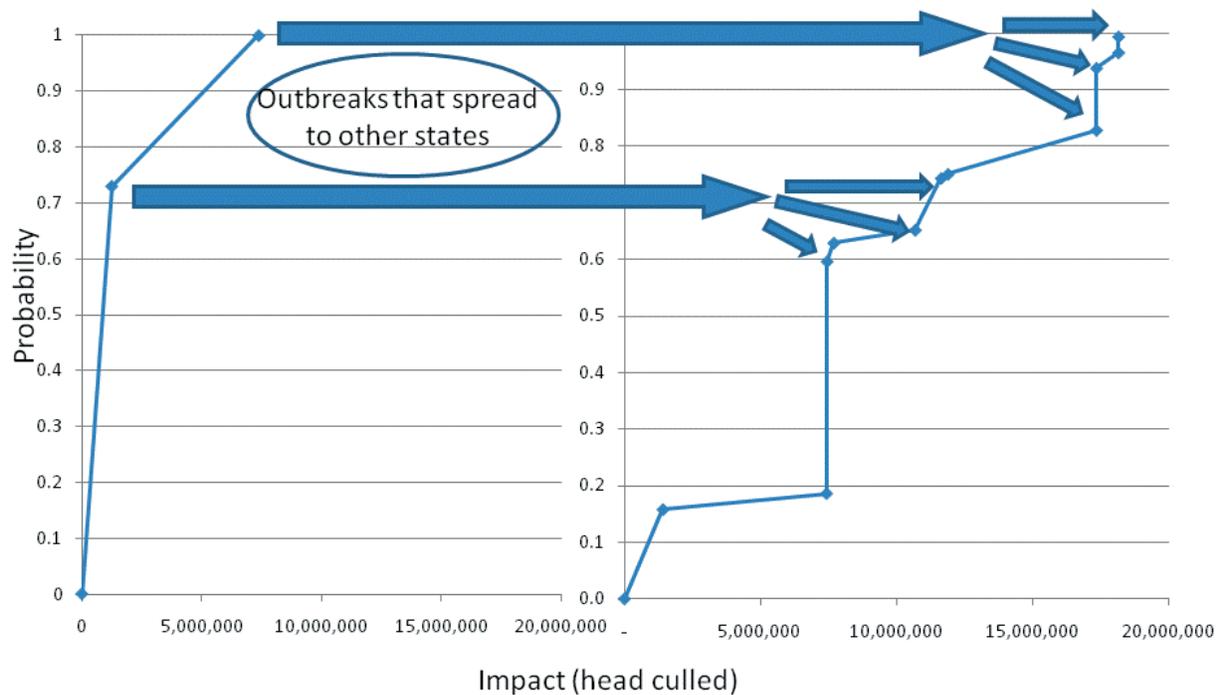


Figure 6.1.9-4: Impact of Outbreaks in Kansas (left) and Impact of Outbreaks Summed Across all States (right) as a Function of Probability the Spread Would Occur

Arrows illustrate the outbreaks that spread to other states from Kansas.

The data shown in Figure 6.1.9-4 (and most data shown in the 2010 SSRA) is derived from the median NAADSM outputs. Although it may be the “most likely” simulation of the outbreak, the median output of NAADSM alone does not capture the possible paths an outbreak could plausibly take. For this reason, in the Updated SSRA, uncertainty related to starting location *and* the modeling in NAADSM is presented. In Figure 6.1.9-5, the summed impact of outbreaks across all states is given for the median, p5 and p95 NAADSM outbreaks. Together, these data present uncertainty in the starting location of the outbreak within Kansas, the uncertain probability of spread to other states (and which combination of states should it spread) and the uncertainty of the extent and duration of outbreaks that occur in Kansas and the other states. If only the median NAADSM outbreak were considered, uncertainty in starting location and spread to other states (the Y-axis) would suggest the outbreak could involve the culling between 400,000 and 17 million animals for 80% of possible outcomes. Once the p5 and p95 NAADSM outbreaks are considered, between 4,000 and 32 million animals could be culled to capture 80% of the possible outcomes (the points that cover this space are shown by an arrow in Figure 6.1.9-5).

There are several ways to use the data provided. If the NAADSM parameters used are thought overly conservative (such that the outbreak would spread more aggressively than modeled), then one could consider only the p95 line for NAADSM outputs to reflect reality. Conversely, one could consider only

the p5 line if it is thought the parameters would overestimate the spread of the disease. Alternatively, the p5 outbreaks could reflect the possibility that outbreaks were noticed early and contained well, whereas the p95 outbreaks could reflect many things going wrong in controlling the disease. Using this logic, more than 50% of the outbreaks involved the culling of less than 50,000 animals if the outbreak were well contained. Conversely, none of the poorly controlled outbreaks involved the culling of less than 30 million animals.

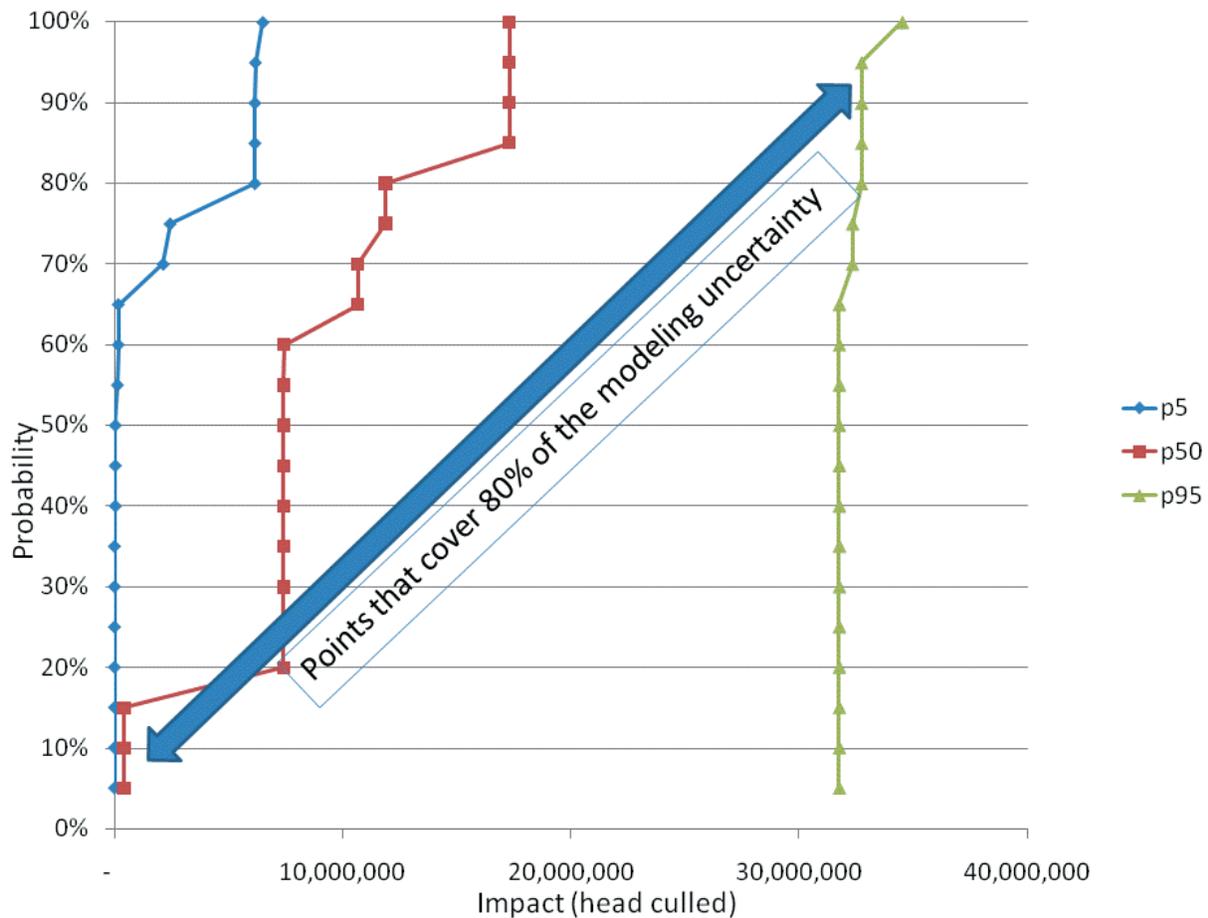


Figure 6.1.9-5: Impact of Outbreaks Summed Across all States as a Function of Probability the Spread Would Occur

NAADSM p5, p50, and p95 outputs are shown.

The arrow links the p5 starting location-p5 NAADSM output with the p95 starting locations-p95 NAADSM output. Between the tips of the arrow is 80% of the uncertainty due to outbreak starting location, interstate spread and NAADSM-driven

6.2 Results

To model the impact of an outbreak of FMD caused by a release from the NBAF, more than 750,000 NAADSM iterations were run in more than 4,000 model runs. The more complex release events (those that could infect many possible premises) were simulated by more than 100 model runs and more than 200,000 model iterations. Approximately 1.5 terabytes of data were generated by NAADSM across all model runs in this effort (equivalent to the quantity of text in about 1,500 encyclopedias). NAADSM was adapted to the study by the development of a database of more than 700,000 premises (80 million animals) based on real location and holding data for large premises and computed livestock locations for small premises in a region comprising Kansas and six nearby states. The development of contact parameters specific to practices in each state enabled the model to be used for this region. Outbreaks in other states were modeled independently of outbreaks in Kansas; however, they were linked by calculations based on the chance that infected animals would be shipped between the states.

6.2.1 Summary of Impact

The modeling performed by the Updated SSRA team has reinforced the commonplace notions regarding an outbreak of FMD: if the disease is detected early and only a few premises are infected, the outbreak can be contained; if the disease is not detected early, it may spread to many premises within the state of Kansas and other states. The various NBAF release events examined could start infections at the many types of facilities that surround the NBAF. If the initial premises infected is a backyard operation or a premises that raises goats, the disease is less likely to spread explosively to many other facilities and to other states before it is contained, versus outbreaks that begin in feedlots, commercial cow-calf operations or larger swine operations in the Manhattan, Kansas, area. However, if the disease spreads to many premises before it is detected, the consequences are similar regardless of where the outbreak began.

The qualitative description explains why the modeling results are dominated by the aleatory uncertainty inherent in the NAADSM model (for example, the timing of an animal shipment relative to the arrival of an infection to that premises). For any given outbreak starting location (or locations for aerosol events that simultaneously infect more than one premises initially), the epidemiological results vary significantly between the median NAADSM output and the p95 output (for which only 5% of the iterations produce more consequential outbreaks) and the p5 (for which only 5% of the iterations produce less consequential outbreaks). In general, the p95 outputs from NAADSM can be thought of as reflecting the most poorly controlled outbreaks (outbreaks are detected relatively late, or shipments of animals within the state or to other states occurred soon after the disease reaches a premises), whereas the p5 outputs from NAADSM generally reflect outbreaks in which all events favored containment (the disease was detected early and shipments of animals did not follow the arrival of the disease to a new premises, etc).

In the most poorly controlled outbreaks involving the surreptitious release of FMDv, the model predicts the impact is significant, regardless of where the outbreak starts. Assuming that all animals that are ever

infected are culled, between 20 and 30 million animals would be culled, 50 to 70 million animals vaccinated and the outbreak and associated control measures would last several years (mostly to depopulate farms that were infected sometime in the outbreak). The disease itself would be circulating amongst livestock for, at most, a year and a half (about 500 days) before control measures could contain it. Given that the virus is no longer circulating, mass culling may not be the strategy adopted to return U.S. agriculture to normal operations, as explained further below in Section 6.2.1.2.

In contrast, the consequences of the median (p50) and best case (p5) outbreaks depend significantly on where the outbreak begins. This dependence on starting location reflects the degree to which the initially infected facility is integrated with the larger agricultural economy. If a relatively large commercial producer is the first location infected, the chances are significant that an outbreak spreads to other facilities and other states before the implementation of effective control measures, and therefore, the median (and sometimes even best case) NAADSM output suggests that more than a million animals would be culled and the disease would spread to several other states (given that mass culling is used to control the outbreak even after the virus is no longer circulating). If a small goat herd is the first premises infected, then even the median NAADSM output suggests that the disease is likely well contained and does not spread much beyond the initial few premises infected. Across all possible premises initially infected (with a few exceptions for the isolated small ruminant producers), the median results predict that between one and 16 million animals would be culled, and between seven and 40 million animals would be vaccinated, in a disease outbreak that lasts more than a year (assuming mass culling is the strategy used to deal with previously infected animals). If a relatively small or isolated premises is initially infected, the best case NAADSM outputs (p5) suggests that the outbreak could be contained in about a month and involve the culling and vaccination of less than 50,000 animals. See summary Tables 6.2.1-1, 6.2.1-2, and 6.2.1-3 for a review of the data.

Some FMDv releases are initiated by a catastrophic natural disaster (tornado and earthquake events) damaging the NBAF. Even though these events foster the release of a significant amount of FMDv and lead to the initial infection of many farms simultaneously (the large tornado release typically infects more than 50 farms due to the amount of infectious material released from the NBAF), the fact that these events are obvious to the response community enables the implementation of control measures before the first animal starts to show signs of infection. For this reason, the chance that the disease spreads to other states is lower than in smaller surreptitious releases and the consequences and extent of the overall outbreak is smaller. In the best cases, the outbreak can be contained to the premises initially infected and very few animals are culled and vaccinated in an outbreak that lasts no more than a month. Across all outputs, the impact and duration of an FMD outbreak caused by a natural disaster can be extremely severe (with millions of animals culled and vaccinated), but not as severe as in surreptitious releases that initially infect fewer farms. For example, compare the median large tornado output (two million animals culled) and the median liquid waste event (between four and twelve million animals culled), despite the fact that the liquid waste events do not result in the simultaneous infection of more than two farms from the initial release, the resultant impact is significantly higher. The results from these release events should be considered cautiously because the model assumes that the

agricultural industry around the NBAF operates normally after the catastrophic event (except for the implementation of control measures). That is, the havoc unleashed by the large tornado or earthquake does not alter the number of animals sold or visited by service providers and does not alter the locations of the animals (animals are not killed and fences are not destroyed by the disaster). Moreover, the release of FMDv from the NBAF may be attended by the release of several other pathogens, some of which are zoonotic, so business as usual will certainly not occur because of the hazards to agricultural workers nearby.

6.2.1.1 Effect of Conservative Parameters

As described in the methods, uncertainty underlies many parameters used in the model. When insufficient evidence was available to choose among a variety of possible values for a parameter, in general, the most conservative value was chosen (that is, the parameter that leads to the largest disease outbreak). Under no circumstances was a “conservative” value chosen in the face of evidence that a less conservative value better reflected reality. For example, there is little evidence underpinning the degree to which indirect contact between farms can be controlled after an outbreak. In this case, a relatively modest reduction to indirect contact was chosen out of many possible values, which allows the outbreak to continue even after detection. Because conservative values are often used, the consequences of a real outbreak of FMD may be smaller than is predicted here. However, as shown in the sensitivity analysis section below, the change of any particular parameter to a value less conservative than the baseline usually reduces the consequences of only a few types of outbreaks (those starting in particular locations or only if the median NAADSM output is considered). Even when the results are sensitive to the change of a parameter, the degree to which the results change is almost always less than an order of magnitude for all outbreak starting locations, vaccination strategies applied or NAADSM outputs. For this reason, even though conservative parameter values were sometimes chosen, the results described here are likely to approximate the results of an outbreak controlled under more optimistic circumstances unless all values chosen were overly conservative. Moreover, insofar as this approach does over-estimate the consequences of an outbreak, it may partially compensate for the inability to account for the contribution of wildlife in the model (as described in section 6.2.1.3, below), which may exacerbate an outbreak but is not accounted for in our modeling.

6.2.1.2 Modeling the Consequence of Large Outbreaks

As discussed above, the Updated SSRA model predicts that millions of animals would be culled in many of the outbreaks resulting from the NBAF FMDv events evaluated. Most animals are culled because they were infected or were part of an infected herd. Because culling capacity is relatively low, compared to the number of herds that need to be culled, the model predicts that herds are often culled even though the virus is no longer circulating in the herd (all animals were infected, recovered and were naturally immune by the time the herd was destroyed). Additionally, a minority of animals would be culled because of contact between a non-infected herd and an infected herd. No one has developed a module for NAADSM that enables the model to choose options other than culling for the final disposition of herds that are naturally immune after infection. The model also predicts that many millions of animals may be vaccinated during the outbreak.

For small outbreaks, the culling of thousands of animals may be the most effective means to rid FMD and enable the fastest recovery of the livestock industry in the U.S. However, there are only a few circumstances in which the culling of millions of animals would be the best means to control a large outbreak while supporting the recovery of the livestock industry. In the face of a large outbreak, USDA policy can accommodate a variety of strategies to minimize the economic consequences of an outbreak while simultaneously reducing its extent and duration. These strategies may include mass culling of some types of herds, and the slaughter and sale of other herds, depending on market forces and how the approach would enable the U.S. to most quickly recapture its key export markets. Similarly, the final disposition of millions of vaccinated animals will depend on the role of those animals within the livestock industry and market forces. One option may be chosen for dairy herds, another for sheep, and yet another for swine. These options may be different, depending on the size and location of the herds in the U.S.

To our knowledge, no one has developed a version of NAADSM that can reflect this complex and dynamic decision making process, and therefore the results presented in this study simply report animals involved in the outbreak and its control as culled or vaccinated. In a real response, many of the animals predicted to be culled by the Updated SSRA model may enter the market.

6.2.1.3 How Wildlife May Affect the Results

As described in the methods section (6.1), and further in the appendix, Kansas and the surrounding states support a relatively large population of and variety of wildlife species susceptible to FMD, including deer, feral swine, elk and pronghorn. To the Updated SSRA team's knowledge, no one has developed a version of NAADSM that quantitatively includes the contribution of wildlife to an outbreak of FMD. Given the data collected on these wildlife populations, an outbreak of FMD may not be as easy to control as predicted by the model presented here. At the very least, the presence of wildlife provides more opportunity for the pathogen to spread through naïve hosts and be perpetuated in the environment. That being said, the contribution of wildlife to the duration and extent of outbreaks in Europe is uncertain. For example, none of the samples taken from wildlife during and after the FMD outbreak in the United Kingdom in 2001 showed evidence of infection [Kitching, 2002].

Wildlife could contribute to the risk of an FMD outbreak in several unique and consequential ways. Wildlife populations, especially deer, can be found in parts of the area around the NBAF that are not home to domestic species. Therefore, the chance that a release of FMDv would initiate an outbreak is increased because areas that are currently modeled to not host susceptible species could be visited by susceptible wildlife during a release event. Additionally, if an outbreak of FMD begins in wildlife, the fact that these animals are observed more rarely and less closely than domestic species implies that the outbreak may be detected relatively late.

Moreover, in some areas, wildlife enters (or contacts the fence-line of) premises where susceptible species are kept. The extensive range of many wildlife species implies that a single infected wildlife herd could come into close proximity with many susceptible domestic herds. Wildlife therefore affords

another mechanism for direct contact between infected species that is not accounted for in the model (although the degree to which this actually occurs and the risk from such contacts is uncertain). This direct contact will not be controllable by efforts to limit the shipment of animals after an infection.

Lastly, because these animals are wild, they are more difficult to find and cull than domestic animals. If this measure is chosen for disease control, additional manpower will be required to control FMD infection circulating in wildlife, the personnel involved may be separate and non-overlapping with those required to control infection amongst domestic animals. For example, sharpshooters, hunters and game wardens may have the primary responsibility to control infection in wildlife and these roles are not considered critical to the control of the outbreak in domestic animals.

6.2.1.4 Summary of Results by Event

The results across all release events are shown in the summary tables below (Tables 6.2.1-1, 6.2.1-2, and 6.2.1-3) for disease duration (which measures how long new infections continue to occur in livestock), head culled and head vaccinated across all seven modeled states. Results are shown given uncertainty in starting location (which includes the degree to which the disease spreads to other states) and NAADSM output. When considering disease duration, note that all release events modeled cause outbreaks that last the same amount of time when the worst reasonable starting location (p95 location) and worst reasonable NAADSM output (p95) is considered. These worst case outbreaks all spread to several other states and the same location (the p95 location in the other states) is the focus of the infection in the other states regardless of how the outbreak evolves in Kansas when the p95 outputs are considered. The outbreak in the other states last longer than any outbreak in Kansas and therefore the duration of the outbreak is defined by the duration of the outbreak in these other states and not the duration in Kansas. This phenomenon is most obvious when considering the p95 starting locations and p95 NAADSM output because less consequential outbreaks do not necessarily spread to other states, or, when they do spread, start in less consequential locations in other states.

Table 6.2.1-1: Summary of Disease Duration Estimates across Events

Name	Events	Shortest duration (p5 locations-p5 NAADSM output)	Median duration (p50 locations-p50 NAADSM output)	Longest duration (p95 locations-p95 NAADSM output)
Aerosol BSL-3Ag AHR	AA10 High	14 days	270 days	533 days
Aerosol Non Containment	OA2, OA3	28 days	424 days	533 days
Aerosol Necropsy Room	NA10 (High)	79 days	424 days	533 days
Aerosol BSL-3E/BSL-3E SP	EA10 (High)	79 days	424 days	533 days
Solid Waste Transfer Station	AS5-AS6, NSW4-NSW6, NST2-NST4,	13 days	24 days	533 days

Table 6.2.1-1: Summary of Disease Duration Estimates across Events

Name	Events	Shortest duration (p5 locations-p5 NAADSM output)	Median duration (p50 locations-p50 NAADSM output)	Longest duration (p95 locations-p95 NAADSM output)
	ES4-ES6			
Solid Waste Landfill	AS5-AS6, NSW4 -NSW6, NST2-NST4, ES4-ES6	13 days	147 days	533 days
Liquid Waste A	AL3-AL4, AL7- AL8, NL3- NL4,NL7-NL8, EL5	20 days	424 days	533 days
Liquid Waste B	AL3-AL4, AL7- AL8, NL3-NL4, NL6- NL8, EL5	13 days	424 days	533 days
Liquid Waste C	AL3-AL4, AL7- AL8, NL3-NL4, NL7-NL8, EL5	188 days	424 days	533 days
Liquid Waste D	AL4, AL8, NL7- NL8, EL5	25 days	424 days	533 days
Transference	ATR1-ATR4, ATF2-ATF3, NTH1- NTH12, NTB1-NTB6, ETP1-ETP12-, ETB1-ETB6, OTP2-OTP5, OTF2- OTF3, OTB3- OTB5	35 days	424 days	533 days
Tornado Medium	T-Medium	6 days	62 days	533 days
Tornado High	T-High	240 days	424 days	533 days
Earthquake High	E-High	8 days	59 days	533 days

Table 6.2.1-2: Summary of Head Culled Estimates Across Events

Name	Events	Least head culled (p5 locations-p5 NAADSM output)	Median head culled (p50 locations-p50 NAADSM output)	Most head culled (p95 locations-p95 NAADSM output)
Aerosol BSL-3Ag AHR	AA10(High)	13,000	7,100,000	25,000,000
Aerosol Non Containment	OA2, OA3	4,000	7,400,000	32,700,000
Aerosol Necropsy Room	NA10 (High)	2,000,000	11,700,000	32,000,000
Aerosol BSL-3E/BSL-3E SP	EA10 (High)	2,000,000	11,700,000	32,000,000
Solid Waste Transfer Station	AS5-AS6, NSW4- NSW6, NST2- NST4, ES4-ES6	0	90	21,700,000
Solid Waste Landfill	AS5- AS6, NSW4 - NSW6, NST2- NST4, ES4-ES6	80	1,000,000	27,100,000
Liquid Waste A	AL3-AL4, AL7-AL8, NL3-NL4,NL7- NL8, EL5	500	3,800,000	30,000,000
Liquid Waste B	AL3-AL4, AL7-AL8, NL3-NL4, NL6- NL8, EL5	500	5,000,000	34,000,000
Liquid Waste C	AL3-AL4, AL7-AL8, NL3-NL4, NL7- NL8, EL5	1,700,000	11,700,000	38,000,000
Liquid Waste D	AL4, AL8, NL7- NL8, EL5	60,000	6,000,000	32,000,000
Transference	ATR1-ATR4, ATF2- ATF3, NTH1- NTH12, NTB1- NTB6, ETP1- ETP12-, ETB1- ETB6, OTP2- OTP5, OTF2- OTF3, OTB3- OTB5	48,000	16,000,000	35,000,000
Tornado Medium	T-Medium	100	700,000	17,000,000
Tornado High	T-High	270,000	2,200,000	19,000,000
Earthquake High	E-High	5,700	300,000	19,000,000

Table 6.2.1-3: Summary of Head Vaccinated Estimate Across Events

Name	Events	Least head vaccinated (p5 locations-p5 NAADSM output)	Median head vaccinated (p50 locations-p50 NAADSM output)	Most head vaccinated (p95 locations-p95 NAADSM output)
Aerosol BSL-3Ag AHR	AA10(High)	22,000	10,200,000	60,000,000
Aerosol Non Containment	OA2, OA3	10,000	7,500,000	67,000,000
Aerosol Necropsy Room	NA10(High)	2,300,000	38,000,000	66,000,000
Aerosol BSL-3E/BSL-3E SP	EA10 (High)	2,300,000	38,000,000	66,000,000
Solid Waste Transfer Station	AS5-AS6, NSW4- NSW6, NST2- NST4, ES4- ES6	0	18,000	50,000,000
Solid Waste Landfill	AS5- AS6, NSW4 - NSW6, NST2- NST4, ES4- ES6	7,000	160,000	56,000,000
Liquid Waste A	AL3-AL4, AL7-AL8, NL3- NL4,NL7- NL8, EL5	10,000	26,000,000	63,000,000
Liquid Waste B	AL3-AL4, AL7-AL8, NL3-NL4, NL6- NL8, EL5	10,000	28,000,000	71,000,000
Liquid Waste C	AL3-AL4, AL7-AL8, NL3-NL4, NL7-NL8, EL5	2,300,000	38,000,000	66,000,000
Liquid Waste D	AL4, AL8, NL7-NL8, EL5	74,000	29,000,000	65,000,000

Table 6.2.1-3: Summary of Head Vaccinated Estimate Across Events

Name	Events	Least head vaccinated (p5 locations-p5 NAADSM output)	Median head vaccinated (p50 locations-p50 NAADSM output)	Most head vaccinated (p95 locations-p95 NAADSM output)
Transference	ATR1-ATR4, ATF2-ATF3, NTH1-NTH12, NTB1-NTB6, ETP1-ETP12-, ETB1-ETB6, OTP2-OTP5, OTF2- OTF3, OTB3- OTB5	30,000	39,000,000	71,000,000
Tornado Medium	T-Medium	11,000	1,000,000	45,000,000
Tornado High	T-High	380,000	25,000,000	47,000,000
Earthquake High	E-High	8,800	470,000	46,000,000

6.2.2 Comparing SSRA Results to those of Other Modeling Teams

Modeling was used in this study primarily to identify the release pathways of greatest risk and to ascertain the relative importance of control and mitigation measures to reduce the risk of performing cutting-edge science with high-consequence livestock pathogens at the NBAF. For this reason, the *absolute* impact of any outbreak predicted by the models used is less important than the *relative* impact between events and the reduction in impact that various control and mitigation measures afford, as explained in the Cost-Benefit section (6.3). Given the primary purpose of the study, comparing the results with models analyzing the impact of outbreaks in different geographic areas would not augment the analysis.

Given the complexity and scale of U.S. agriculture and irreducible uncertainty in parameterizing some aspects of an FMD outbreak (e.g. What is the chance than an infected deer would infect a nearby cattle herd?), no model can predict the extent or duration of an outbreak in the U.S. with certainty and the models used in the Updated SSRA are no exception. To determine why two model results differ is extremely difficult and beyond the scope of this analysis. Even if two models were given the exact same question (the consequences of an outbreak starting in a feedlot in Manhattan, for example), understanding why they produce different results requires extensive testing of BOTH models (the manipulation of input variables to determine the consequences on the results) and, likely, access to the code underlying the models. Without these resources, any hypothesis regarding the reasons behind the differences in output between two models would simply be conjecture.

Achieving the best prediction possible of the scale and duration of a possible FMD outbreak in the U.S. will however support decision-making related to livestock disease control in general. From scrutinizing the similarities and differences of several modeling approaches (and the consequent results) a better estimate of a true value could be obtained. Over the next few years, parallel estimation (by different teams) of the scale and duration of an outbreak starting at the NBAF (or from any accidental introduction area within the U.S.) would advance this effort.

6.2.3 FMD Epidemiological Impact by Event

6.2.3.1 Overview of Aerosol Events (AA10, NA10, EA10, OA2, OA3)

In this section, the results of epidemiological modeling of all aerosol release events, except those caused by natural disasters such as tornado or earthquake, are presented. Aerosol releases caused by natural disasters, such as these, are self-announcing (it is obvious to everyone that the incident occurred) and would likely trigger disease control measures even prior to the first infection. For these reasons, releases triggered by natural disasters are considered separately.

Many non-catastrophic aerosol release events resulted in the release of material insufficient to cause an infection downwind for any meteorological condition modeled and for any infection threshold considered (each threshold is a function of herd size, as discussed above). Those release events are described in the Section 5, but the associated epidemiological impact is not modeled (because no infections were caused). For those (non-natural disaster related) aerosol events that did result in a release of sufficient material for potential downwind infection (within containment), a complete HEPA filtration failure had to occur (Events AA10, NA10, and EA10). The resulting frequency of an initial infection given total HEPA filtration failure is estimated at less than once every trillion years ($\sim 1 \times 10^{-30}$); given this extreme improbability of occurrence, these events were not considered credible and were not carried through economic analysis. However, to be certain that this was an appropriate approach, epidemiological modeling was performed on these events. The results presented below indicate that even though these events lead to a significant outbreak, they are within an order of magnitude of the impact observed with all other events evaluated; with the corresponding frequency of infection being so low, these events would not be expected to result in significant risk.

6.2.3.2 Aerosol Releases from BSL-3Ag Animal Holding Rooms (Event AA10—High Q).

Of the releases modeled, only the release that involves the total failure of the HEPA filtration system causes enough infectious material to be released so that an infection is calculated to occur outside the NBAF, and even in that case, only the high-value source term releases a sufficient amount to cause a downwind infection. However, if this event occurs, it can be very serious because many premises may be simultaneously infected by the aerosol release. Table 6.2.3-1 shows the probability that meteorological conditions transport enough material from this event to infect at least a single premises (and at least a given number of premises simultaneously). The probability of at least one downwind infection occurring is nearly 95%. Also, many meteorological conditions lead to several premises infected downwind simultaneously by this release (and in fact, most conditions lead to five or more

premises infected initially). Because this release is surreptitious, this unlikely event can have significant consequences due to the explosive starting conditions.

Table 6.2.3-1: Probability that Meteorological Conditions will Prevail to Cause at least a Threshold Number of Initial Premises Infected upon an Aerosol Release from an AHR

Number of premises	1+	2+	5+	10+	20+	50+
Probability	93.9%	85.9%	65.2%	39.7%	19.5%	3.8%

This release occurs without the knowledge of the surrounding community, and therefore the infections that occur could be missed by the affected producers. For this reason, infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to these other states. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-2.

Table 6.2.3-2: Probability of Interstate Spread of FMD from an Infection Initiated by an Aerosol Release from an AHR

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	23%	59%	82%

The possible duration of the disease outbreak is shown in Table 6.2.3-3. The total disease duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the disease outbreak in that state.

Table 6.2.3-3: Duration of Disease Outbreaks from an Infection Initiated by an Aerosol Release from an AHR

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	14 days	88 days	351 days
p50	41 days	270 days	492 days
p95	420 days	473 days	533 days

Figure 6.2.3-1 shows head culled and vaccinated for the outbreaks initiated by a release from non containment across all possible starting locations and for three NAADSM output percentiles.

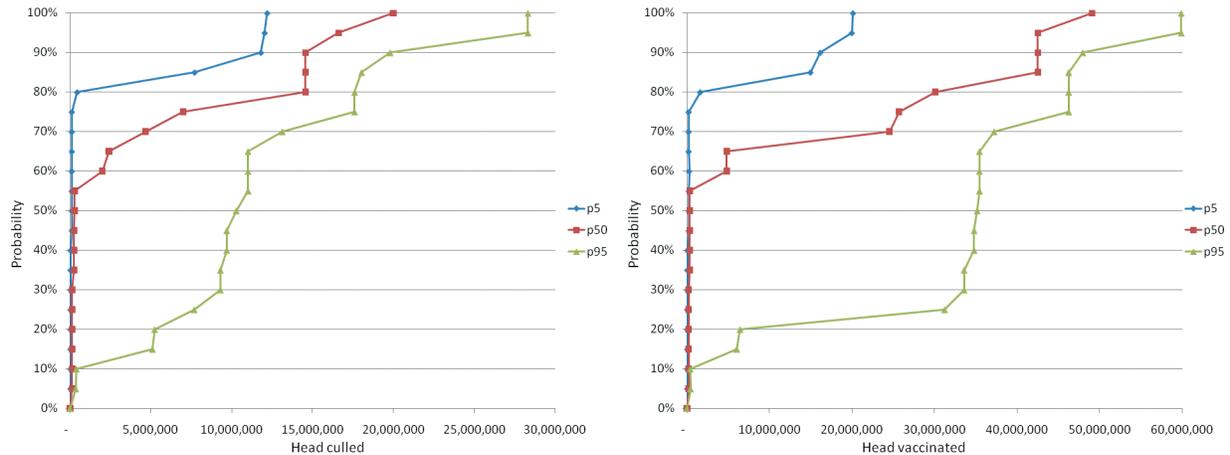


Figure 6.2.3-1: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by an Aerosol Release from an AHR

6.2.3.3 Releases from the BSL-3Ag Necropsy Suite (Event NA10—High Q)

Similar to what was observed for the BSL-3Ag AHRs (AA10), of the aerosol events modeled, only the event that involves the total failure of the HEPA filtration system causes enough infectious material to be released so that an infection is calculated to occur outside the NBAF, and even in that case, only the high-value source term releases a sufficient amount of material to cause a downwind infection. An infection is calculated to occur in only one possible location from this release, and the necessary associated meteorological conditions prevail only 0.1% of the time that the releases occur. That is, for 99.9% of releases, the wind does not transport enough material to a livestock premises to result in an infection.

This release occurs without the knowledge of the surrounding community, and therefore the infections that occur could be missed by the affected producers. For this reason, infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to these other states. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-4.

Table 6.2.3-4: Probability of Interstate Spread of FMD from an Infection Initiated by an Aerosol Release from the BSL-3Ag Necropsy Suite

The probability of spread to other states is given using the p5, p50, and p95 NAADSM outputs. Although the probability of spread to other states is never truly 100%, the probability is so great that it is considered 100% for this analysis.

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	78%	81%	100%

The possible duration of the disease outbreak is shown in Table 6.2.3-5. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state,

the duration of the outbreak in that state. Using the p5 NAADSM output, even if the disease spreads to other states, the outbreak lasts longer in Kansas than the other states, so there is no change in outbreak duration. Whereas, using the median NAADSM output, outbreaks in other states last longer than the outbreak in Kansas and so outbreak duration is determined by the length of the outbreak in the secondary states and the probability that it spreads there (which occurs in the median starting location case).

Table 6.2.3-5: Duration of Outbreaks from an Infection Initiated by an Aerosol Release from the BSL-3Ag Necropsy Suite
 Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	79 days	274 days	492 days
p50	79 days	424 days	492 days
p95	79 days	473 days	533 days

Figure 6.2.3-2 shows head culled and vaccinated for the outbreaks initiated by a release from the BSL-3Ag Necropsy Suite across all three NAADSM output percentiles. Using a particular NAADSM output, not much variability is observed in the impact. Essentially, the slight differences in impact, from the lowest impact starting locations to the highest, result from the spread to other states. Using the p95 NAADSM output, no variance is observed because almost all outbreaks spread to all other states modeled. Using the other two NAADSM outputs presented, the additional impact observed occurs when the disease spreads to other states. Although six different secondary state combinations are represented in the lines on the graph, the differences in the impact in those states is relatively small.

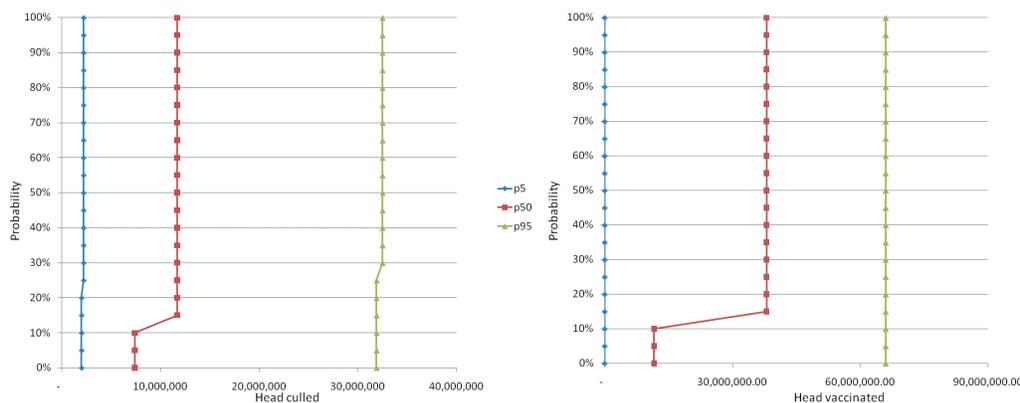


Figure 6.2.3-2: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by an Aerosol Release from the BSL-3Ag Necropsy Suite

The variability observed within a NAADSM output line is largely due to the risk of spread from Kansas to other states.

6.2.3.4 Releases from the BSL-3E/BSL-3E SP Rooms (Event EA10)

As in the aerosol releases modeled from AHR and Non-Containment, of the BSL-3 aerosol releases modeled, only the release that occurs due to a total failure of the HEPA filtration system causes enough infectious material to be released so that an infection is calculated to occur outside the NBAF, and even in that case, only the high-value source term releases a sufficient amount to cause a downwind infection. An infection is calculated to occur in only one possible location from this release, and the necessary associated meteorological conditions prevail only 0.1% of the time that the releases occur. That is, for 99.9% of releases, the wind does not transport enough material to a livestock premises to result in an infection. This is the same premises that is infected by the releases from the BSL-3Ag Necropsy Room under the same weather conditions, so the results for this event are identical to those above.

6.2.3.5 Non-Containment Releases (Events OA2, OA3)

Of the aerosol releases modeled, only those that involve the failure of primary *and* secondary containment cause enough infectious material to be released so that an infection is calculated to occur outside the NBAF, and even in those cases (AA10, NA10, ANC10), only the high-value Q source term releases a sufficient amount to cause a downwind infection. An infection is calculated to occur in only one of two possible locations from this release, and the necessary associated meteorological conditions prevail only 0.4% of the time that the releases occur. That is, for 99.6% of releases, the wind does not transport enough material to a livestock premises to result in an infection. In this section, the epidemiological impact of releases that result in at least one infection are described.

The two locations that could be infected by the aerosol (based on meteorological conditions) are very different from each other in terms of herd size and type of operation. If the smaller of the two premises is initially infected, the median outbreak leads to the destruction of less than one million animals in Kansas. If the larger of the two premises is initially infected, the median outbreak leads to the destruction of many millions of animals in Kansas alone. Given this difference, the aleatory uncertainty depicted by the starting location is significant.

This release occurs without the knowledge of the surrounding community; and therefore, the infections that occur could be missed by the affected producers. For this reason, infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to those states. Once again, the differences between the two possible starting premises significantly change the consequences of the outbreak, as outbreaks beginning in the smaller location are five-fold more likely to be contained in Kansas. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-6.

Table 6.2.3-6: Probability of Interstate Spread of FMD from an Infection Initiated by an Aerosol Release from Non-Containment

The probability of spread to other states is given for using the p5, p50, and p95 NAADSM outputs. Although the probability of spread to other states is never truly 100%, the probability is so great that it is considered 100% for this analysis.

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	78%	90%	100%

The possible duration of the disease outbreak is shown in Table 6.2.3-7. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state.

Table 6.2.3-7: Duration of Outbreaks from an Infection Initiated by an Aerosol Release from Non-Containment

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	28 days	83 days	492 days
p50	48 days	424 days	492 days
p95	420 days	473 days	533 days

Figure 6.2.3-3 shows head culled and vaccinated for the outbreaks initiated by a release from non containment across all possible starting locations and for three NAADSM output percentiles.

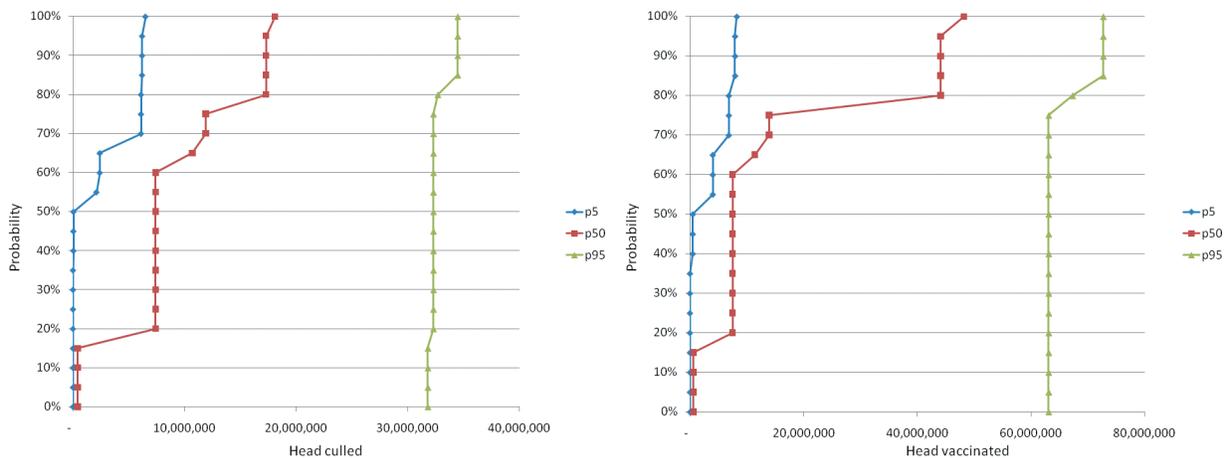


Figure 6.2.3-3: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by an Aerosol Release from Non-Containment

Solid Waste Release Events (Events AS5-AS6, NSW4-NSW6, NST2-NST4, ES4-ES6)

In the solid waste release events, the release can occur at the waste transfer station in Manhattan, Kansas, or at the landfill where the waste is buried. Because the factors leading to the release are distinct for each release location, the events are modeled separately. The epidemiological consequences of these two release events differ because they are considered to begin in different types of facilities in different locations. These two sets of results are discussed below.

6.2.3.6 Solid Waste Releases from the Transfer Station (AS5-AS6, NSW4-NSW6, NST2-NST4, ES4-ES6)

The facility that may be infected by the release is a relatively small goat facility, so the consequences of the outbreak are comparatively small (but still significant). The p5 NAADSM output predicts that this outbreak will occur but that it will not spread to other facilities and the goats will become naturally immune before FMD spreads to any other location. In more consequential outbreaks, infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to these other states. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-8. Note that only the highest-consequence output from NAADSM predicts a significant probability of spread from outbreaks starting at this facility and spreading to other states.

Table 6.2.3-8: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Solid Waste at the Transfer Station

The probability of spread to other states is given for using the p5, p50, and p95 NAADSM outputs. Although the probability of spread to other states is never truly 0%, the probability is so small that it is considered 0% for this analysis.

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	0%	0%	61%

The possible duration of the disease outbreak is shown in Table 6.2.3-9. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. Because there is one possible starting location in this event and the median and lower outputs predict no spread to other states, the duration is completely defined by the duration of the outbreak in Kansas for those NAADSM outputs.

Table 6.2.3-9: Duration of Outbreaks from an Infection Initiated by Release of Infectious Solid Waste from the Transfer Station

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	13 days	24 days	272 days
p50	13 days	24 days	492 days
p95	13 days	24 days	533 days

Figure 6.2.3-4 shows head culled and vaccinated for the outbreaks initiated by a release of infectious waste from the transfer station across three NAADSM output percentiles. Using a particular NAADSM output, not much variability is observed in the impact. If the outbreak can be identified and contained in Kansas, the consequences are relatively minor. Should the outbreak spread to other states (60% of cases for the p95 NAADSM output), the consequences can be almost as large as any other release event.

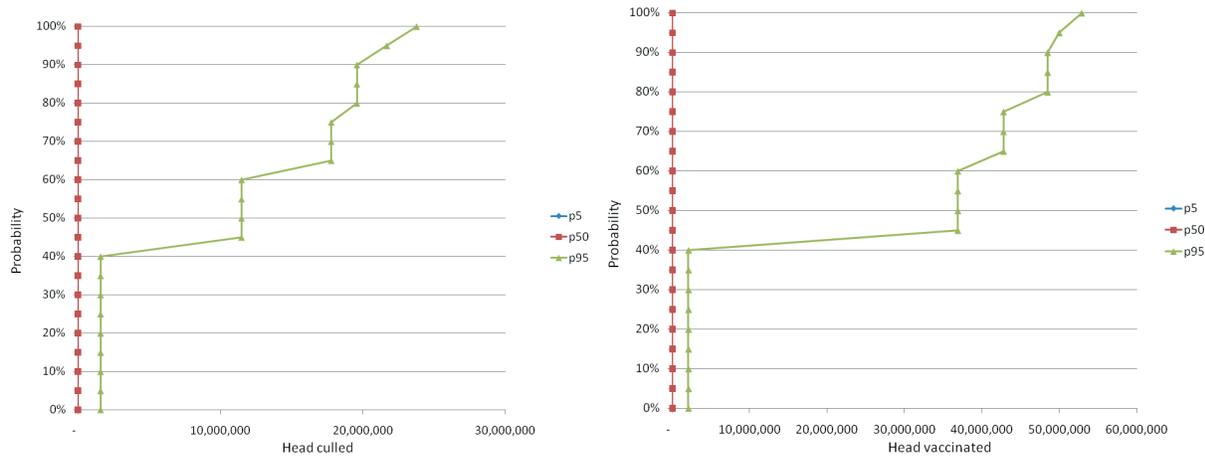


Figure 6.2.3-4: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Solid Waste from the Transfer Station

The variability observed within a NAADSM output line is largely due to the risk of spread from Kansas to other states.

6.2.3.7 Solid Waste Releases from the Landfill (AS5- AS6, NSW4 -NSW6, NST2-NST4, ES4-ES6)

The facility that may be infected by the solid waste landfill release is a relatively small swine facility. In the more consequential outbreaks, infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to these other states. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-10. Note that the lowest-consequence output from NAADSM predicts nearly no probability of spread from outbreaks starting at this facility to other states, whereas the highest consequence outbreaks nearly always spread to other states even though the outbreak is starting at the same location.

Table 6.2.3-10: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Solid Waste from the Landfill

The probability of spread to other states is given for using the p5, p50, and p95 NAADSM outputs.

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	1%	51%	96%

The possible duration of the disease outbreak is shown in Table 6.2.3-11. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. Because outbreaks in other states are predicted to last longer than an outbreak in Kansas starting in this facility, the outbreak duration is defined by the possibility of spread to other states (for example, the p50 starting locations and p50 output predicts the spread of the disease from Kansas to Iowa alone, where the outbreak lasts 147 days).

Table 6.2.3-11: Duration of Outbreaks from an Infection Initiated by a Release of Infectious Solid Waste from the Landfill			
Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.			
Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	13 days	48 days	275 days
p50	13 days	147 days	492 days
p95	13 days	473 days	533 days

Figure 6.2.3-5 shows head culled and vaccinated for the outbreaks initiated by a release of infectious waste from the landfill across three NAADSM output percentiles. Because there is just one starting location in Kansas for this outbreak, the consequences are defined by the risk (probability and consequences) of the disease spreading to the other states.

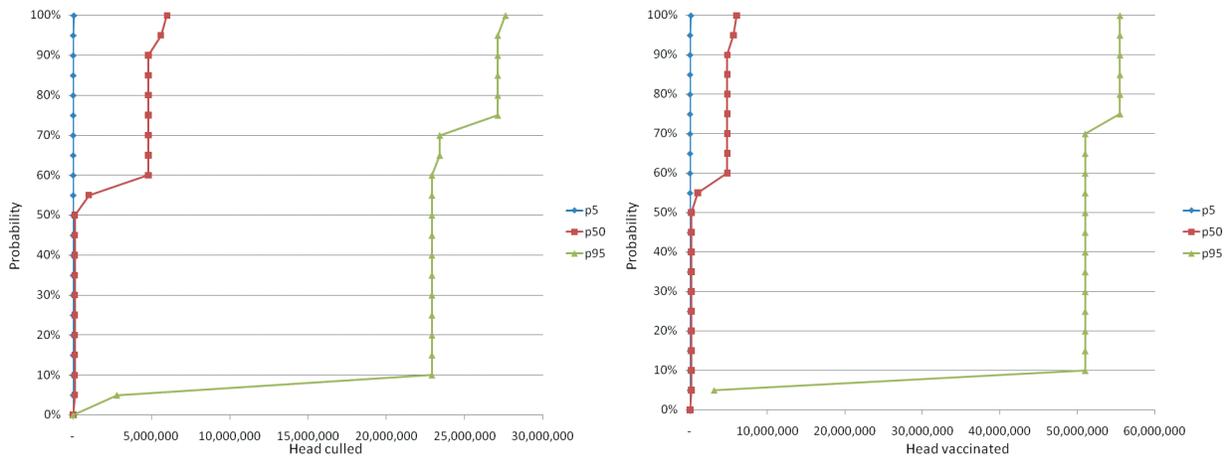


Figure 6.2.3-5: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Solid Waste from the Landfill

The variability observed within a NAADSM output line is largely due to the risk of spread from Kansas to other states.

Liquid Waste Release Events (Events AL3-AL4, AL7-AL8, NL3-NL4, NL6- NL8, EL5)

In the liquid waste release events, the release can occur anywhere along the line that runs from the NBAF to the treatment plant or along the creek that flows nearby (see Section 5 – Fate and Transport). Because the factors leading to the release are distinct for each release location, the events are modeled separately. In this section, the consequences for a release at each location are discussed in turn; by proximity to the NBAF (Liquid Waste A is the release closest to the NBAF and Liquid Waste D is the release furthest from). Although all the liquid waste releases infect at most a single premises, in two locations, these premises hold more than one species, so are modeled as two locations (a cattle location combined with either a swine location or a sheep and a goat location) at the same spot. These events have a 50% probability of starting in each species.

6.2.3.8 Liquid Waste Location A (Events AL3-AL4, AL7-AL8, NL3-NL4, NL7-NL8, EL5)

The facility that may be infected by this release is a relatively small facility that houses sheep and goats. In the more consequential outbreaks, infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to these other states. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-12. Note that the lowest-consequence output from NAADSM predicts nearly no probability of spread from outbreaks starting at this facility to other states.

Table 6.2.3-12: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Liquid Waste from Location A

The probability of spread to other states is given for using the p5, p50, and p95 NAADSM outputs. Although the probability of spread to other states is never truly 0%, the probability is so small that it is considered 0% for this analysis.

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	0%	70%	86%

The possible duration of the disease outbreak is shown in Table 6.2.3-13. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. Because outbreaks in other states are predicted to last longer than an outbreak in Kansas starting in this facility, the disease duration is defined by the possibility of spread to other states.

Table 6.2.3-13: Duration of Outbreaks from an Infection Initiated by Release of Infectious Liquid Waste from Location A

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	20 days	67 days	328 days
p50	20 days	424 days	492 days
p95	21 days	473 days	533 days

Figure 6.2.3-6 shows head culled and vaccinated for the outbreaks initiated by a release of infectious waste from location A across three NAADSM output percentiles. Because outbreaks in other states are large in comparison to outbreaks in Kansas which began at the small sheep and goat facility, the consequences of the outbreak are largely defined by the risk of spread to other states.

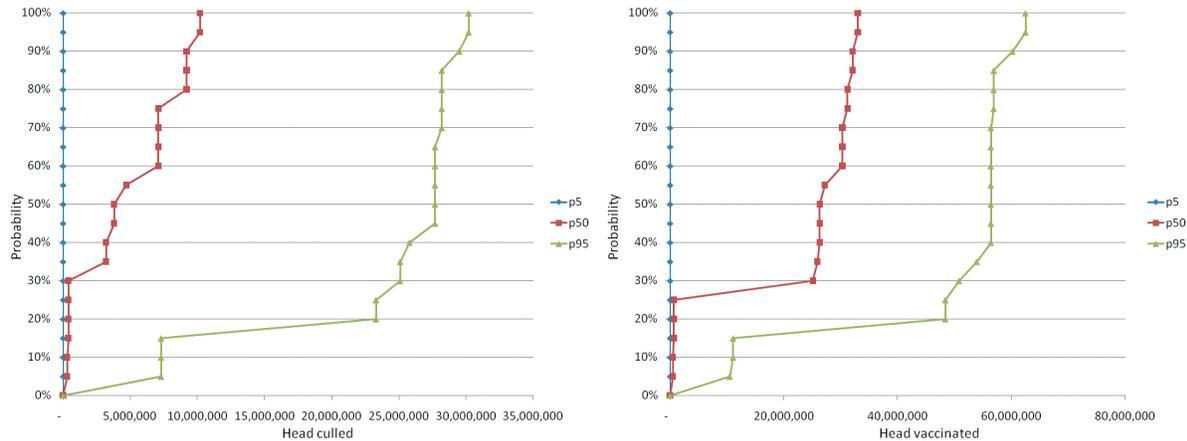


Figure 6.2.3-6: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Liquid Waste from Location A

The variability observed within a NAADSM output line is largely due to the risk of spread from Kansas to other states.

6.2.3.9 Liquid Waste Location B (Events AL3-AL4, AL7-AL8, NL3-NL4, NL6-NL8, EL5)

The facility that may be infected by this release is a backyard facility that houses swine and cattle. In the more consequential outbreaks, infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to these other states. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-14. Note that the lowest-consequence output from NAADSM predicts nearly no probability of spread from outbreaks starting at this facility to other states.

Table 6.2.3-14 Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Liquid Waste from Location B

The probability of spread to other states is given for using the p5, p50, and p95 NAADSM outputs. Although the probability of spread to other states is never truly 0%, the probability is so small that it is considered 0% for this analysis.

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	0%	86%	92%

The possible duration of the disease is shown in Table 6.2.3-15. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. Because outbreaks in other states are predicted to last longer than an outbreak in Kansas starting in this facility, the outbreak duration is defined by the possibility of spread to other states.

Table 6.2.3-15: Duration of Outbreaks from an Infection Initiated by Release of Infectious Liquid Waste from Location B

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	13 days	78 days	335 days
p50	13 days	424 days	492 days
p95	15 days	473 days	533 days

Figure 6.2.3-7 shows head culled and vaccinated for the outbreaks initiated by a release of infectious waste from location B across all possible starting locations and for three NAADSM output percentiles. Because outbreaks in other states are large compared to outbreaks in Kansas begun at the backyard facility, the consequences of the outbreak are largely defined by the risk of spread to other states.

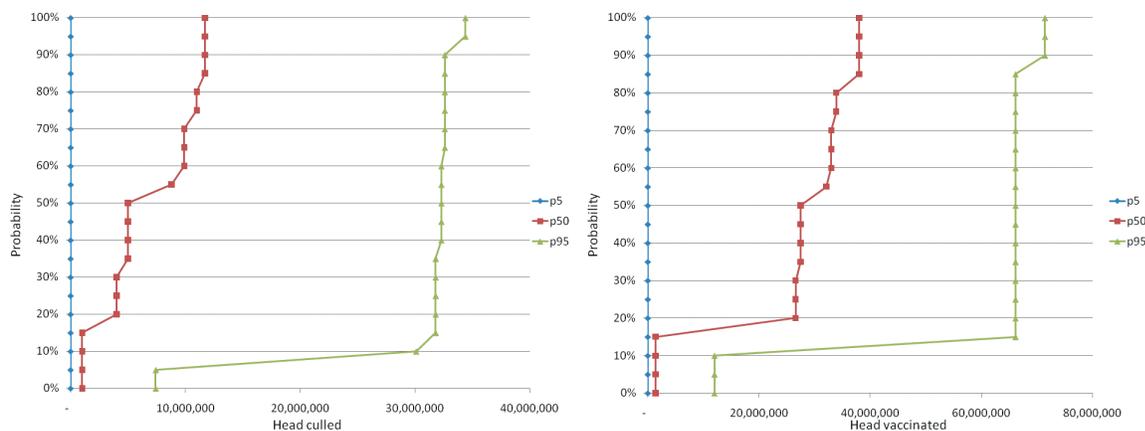


Figure 6.2.3-7: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Liquid Waste from Location B

The variability observed within a NAADSM output line is largely due to the risk of spread from Kansas to other states.

6.2.3.10 Liquid Waste Location C (Events AL3-AL4, AL7-AL8, NL3-NL4, NL7-NL8, EL5)

The facility that may be infected by this release is a large swine facility, so the outbreaks that start here are comparatively consequential. Infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to these other states. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-16. Note that even the lowest-consequence output from NAADSM predicts a significant risk of spread to other states.

Table 6.2.3-16: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Liquid Waste from Location C

The probability of spread to other states is given for using the p5, p50, and p95 NAADSM outputs. Although the probability of spread to other states is never truly 100%, the probability is so great that it is considered 100% for this analysis.

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	96%	98%	100%

The possible duration of the disease is shown in Table 6.2.3-17. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. For the p5 NAADSM output, outbreaks in Kansas last longer than outbreaks outside of Kansas; for other outputs, the duration is defined by the risk of spread to other states, even though the median starting locations for the p5 output includes the spread to five other states.

Table 6.2.3-17: Duration of Outbreaks from an Infection Initiated by Release of Infectious Liquid Waste from Location C

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	188 days	280 days	492 days
p50	188 days	424 days	492 days
p95	188 days	473 days	533 days

Figure 6.2.3-8 shows head culled and vaccinated for the outbreaks initiated by a release of infectious waste from location C across three NAADSM output percentiles. With this starting location, generally when the outbreak spreads to other states, it spreads to multiple other states, so there is not much variability amongst possible starting locations.

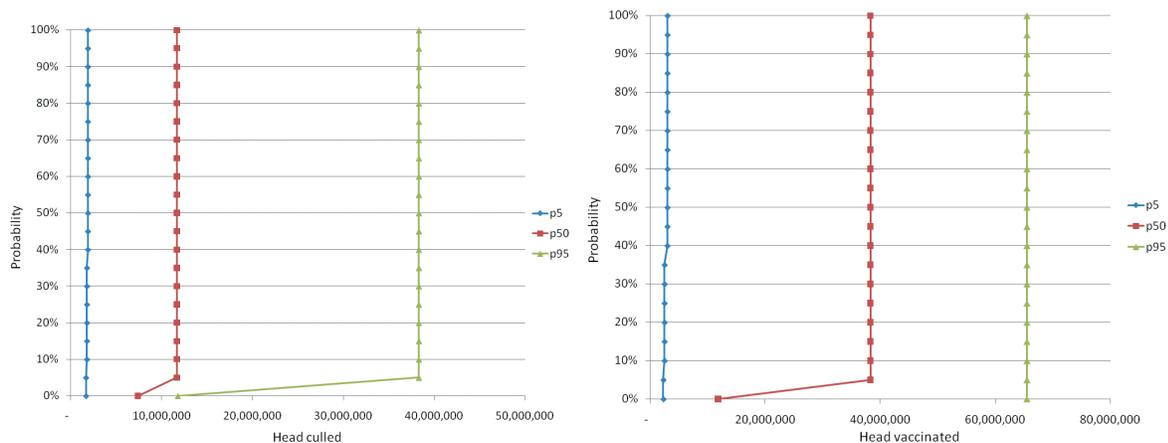


Figure 6.2.3-8: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Liquid Waste from Location C

6.2.3.11 Liquid Waste Location D (Events AL4, AL8, NL7-NL8, EL5)

The facility that may be infected by this release is a cow-calf facility. Infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to these other states. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-18.

Table 6.2.3-18: Probability of Interstate Spread of FMD from an Infection Initiated by Release of Infectious Liquid Waste from Location D.

The probability of spread to other states is given for using the p5, p50, and p95 NAADSM outputs. Although the probability of spread to other states is never truly 100%, the probability is so great that it is considered 100% for this analysis.

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	2%	95%	100%

The possible duration of the disease is shown in Table 6.2.3-19. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. For the p5 NAADSM output, outbreaks in Kansas last longer than outbreaks outside of Kansas, for other outputs, the duration is defined by the risk of spread to other states.

Table 6.2.3-19: Duration of Outbreaks from an Infection Initiated by Release of Infectious Liquid Waste from Location D

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	25 days	261 days	492 days
p50	25 days	424 days	492 days
p95	25 days	433 days	533 days

Figure 6.2.3-9 shows head culled and vaccinated for the outbreaks initiated by a release of infectious waste from location D. With this starting location, generally when the outbreak spreads to other states, it spreads to multiple other states, so there is not much variability amongst possible starting locations.

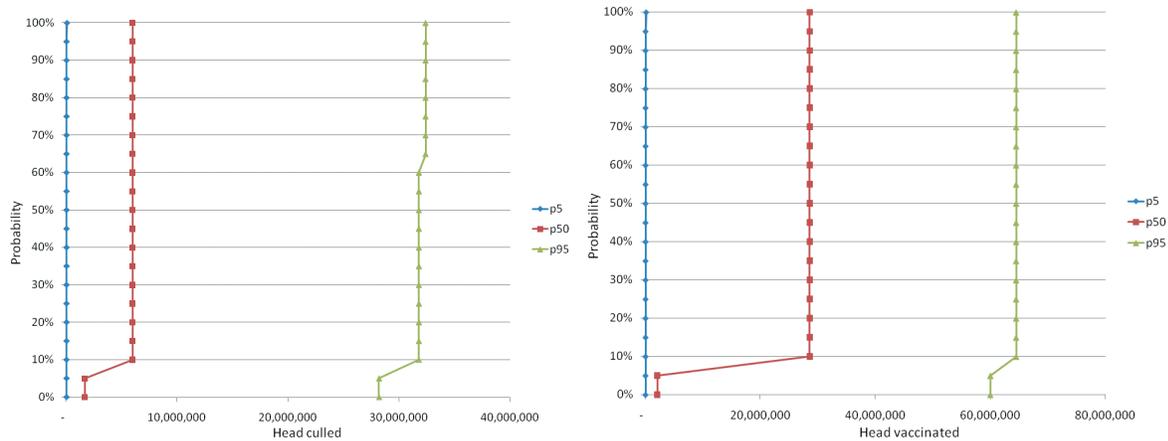


Figure 6.2.3-9: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by Release of Infectious Waste from Location D

Transference Events (Events ATR1-ATR4, ATF2-ATF3, NTH1 -NTH12, NTB1-NTB6, ETP1-ETP12-, ETB1-ETB6, OTP2-OTP5, OTF2-OTF3, OTB3-OTB5)

When infectious FMDv material leaves the NBAF on a person, that person could come in contact with a susceptible species and transfer the material to that animal, starting an outbreak. This release event could occur with infectious material carried by a person on a fomite, by a person with contamination on the hand, foot, other body part or in the respiratory system (human vector). As described in the methods in Section 6.1, the possible starting locations of the initial transference driven infection were determined by interviewing personnel on the K-State campus (those who work on livestock disease and personnel in general) to identify all the locations where they may encounter livestock. It was found that, although many people contact livestock near Manhattan, others contact animals in nearly every part of Kansas. Much of the variance in the data shown in the section below is dependent on the type of premises initially infected and its location. The location of the first infected premises does not depend on how people carry the infectious material or how they were contaminated (because they don't know they are contaminated behavior doesn't change). Because the location of the initial infected premises does not vary depending on how the contamination event occurred, the epidemiological consequences provided below are applicable to all transference events.

Infected animals may be shipped to other states before the outbreak is noticed, spreading the illness to these other states. The probability of interstate spread of FMD in this event is shown in Table 6.2.3-20.

Table 6.2.3-20: Probability of Interstate Spread of FMD from an Infection Initiated from Transference Events

The probability of spread to other states is given for using the p5, p50, and p95 NAADSM outputs. Although the probability of spread to other states is never truly 100%, the probability is so great that it is considered 100% for this analysis.

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	26%	93%	100%

The possible duration of the disease outbreak is shown in Table 6.2.3-21. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. For the p5 NAADSM output, outbreaks in Kansas last longer than outbreaks outside of Kansas, for other outputs, the duration is defined by the risk of spread to other states.

Table 6.2.3-21: Duration of Outbreaks from an Infection Initiated from Transference Events
 Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	35 days	266 days	492 days
p50	48 days	425 days	492 days
p95	420 days	473 days	533 days

Figure 6.2.3-10 shows head culled and vaccinated for the outbreaks initiated from transference events across all possible starting locations and for three NAADSM output percentiles. The consequences in each NAADSM output line vary because the outbreak can begin in one of several locations and because the risk of disease spread to other states.

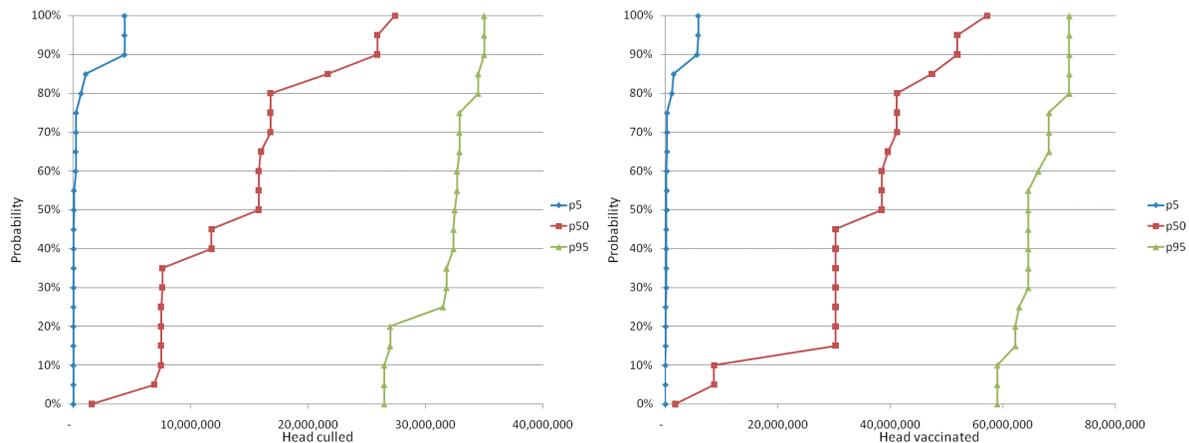


Figure 6.2.3-10: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated from Transference Events

Aerosol Releases Due to Natural Disasters (Events T- Medium, T-High, E-High)

A few release events involve a natural disaster striking the NBAF and causing a disruption of containment (which results in the aerosol release of FMDv). These releases are modeled separately from other aerosol releases because they are self-announcing. That is, it is obvious to the emergency response community that a tornado has struck the NBAF and that it would be prudent to take preemptive disease control measures. To reflect this heightened awareness of a potential outbreak, two modeling methods were used as detailed previously in the methods (Section 6.1). First, movement control restrictions could be preemptively emplaced on all premises that may be affected by the release

event. Secondly, observation and reporting probabilities could be preemptively increased to reflect the increased suspicion (which is enabled by the “unicorn” premises type, as described in the methods). Both options are explored below.

The effect of preemptive controls enabled by a self-announcing release is shown below as a function of the number of premises infected in Figure 6.2.3-11. In all cases, 10^8 PFU are released. In the baseline case (the nominal condition in which no preemptive control measures are enacted and all control parameters are in their normal value), the event is surreptitious (such as the release from the animal holding room--Event AA10). In a self-announcing case, the outbreak could be detected immediately (enabled by the “unicorn farm” premises type or simply using the minimum direct contact rates). Note that although the impact of the outbreak started in a large number of premises are similar in surreptitious and self-announcing events, the consequences of outbreaks that start in 30 or fewer premises is much less when the event is self-announcing than in events that are surreptitious. In fact, the impact of the p5 outbreaks in a surreptitious event is as consequential as the median outbreaks from self-announcing events. Outbreaks that begin in more than 30 premises are difficult to control and the preemptive movement controls have little effect. Further, note how, for both methods of modeling preemptive movement, restrictions produce similar outcomes.

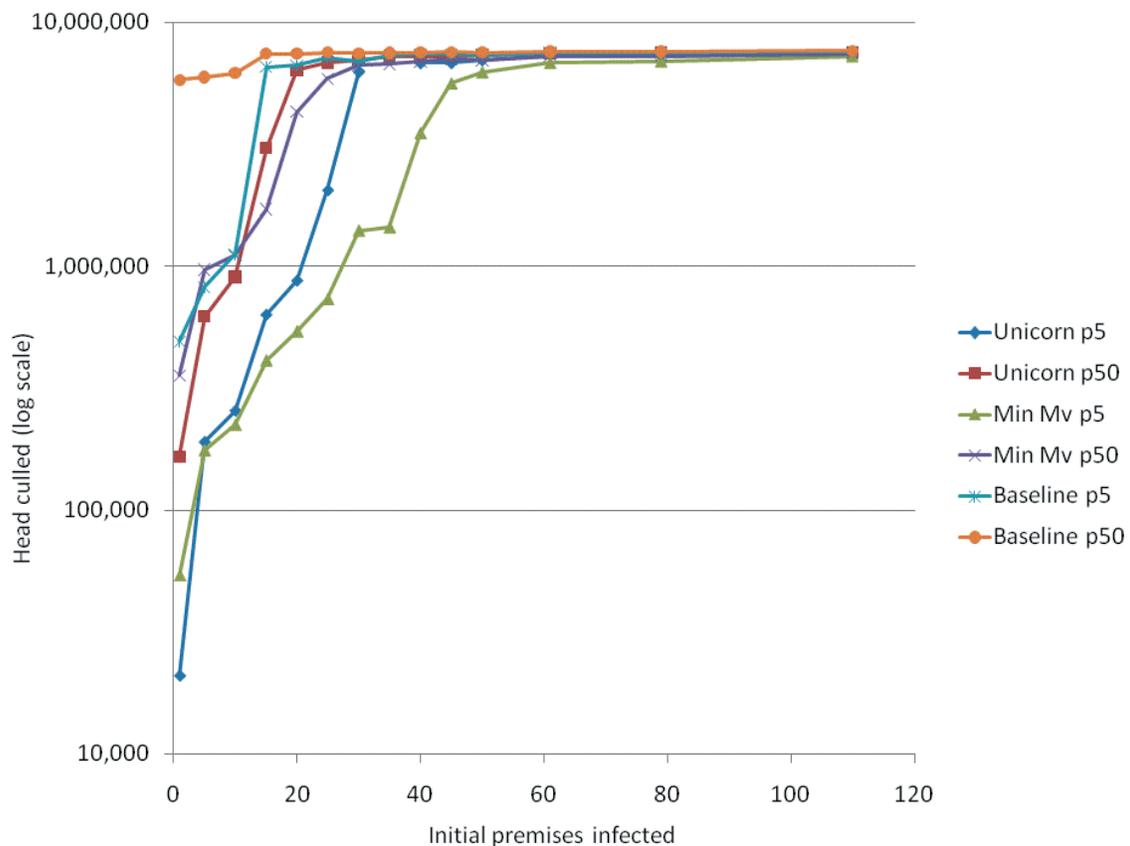


Figure 6.2.3-11: Impact in Kansas of Surreptitious (baseline) and Self-Announcing (unicorn and min mv). Releases of 10^8 PFU of FMDv from the NBAF as a Function of Initial Premises Infected

For releases in which the primary aerosol infects fewer than 30 farms, the consequences of the outbreak are much reduced in a self-announcing event compared to a surreptitious event.

It should be noted that modeling the release of FMDv from the NBAF due to a natural disaster is of limited value because of the significant disruption that the natural disaster itself will cause. For example, a large tornadic event will undoubtedly break fences, incapacitate producers, scatter livestock, and otherwise disrupt the normal function of the agricultural system. Moreover, an event that causes the release of FMDv from the NBAF due to a disruption of the building envelope may also to release a variety of other non-zoonotic and zoonotic infectious disease agents (although work with infected large animals is likely to be limited to two different high consequence pathogens at a time due to space constraints, infected small animals and pathogen stock may be released). Therefore, a large FMD outbreak may need to be controlled in the context of other outbreaks, some of which pose a health risk to the responders. In general, agricultural business-as-usual is unlikely to continue after a significant natural disaster striking the NBAF, but this fact is not reflected in the modeling itself.

6.2.3.12 Tornado (Medium Q Release—Event T-Medium)

In this event, a significant tornado results in the release of $\sim 10^8$ PFU of FMDv (the medium Q source term). Due to the amount of material released, the number of farms initially infected downwind is large with most meteorological conditions leading to the initial infection of more than five farms (Table 6.2.3-22).

Table 6.2.3-22: Probability that Meteorological Conditions will Prevail to Cause at Least a Threshold Number of Initial Premises Infected upon a Medium Aerosol Release Caused by a Tornado						
Number of premises	1+	2+	5+	10+	20+	50+
Probability	95.9%	91.7%	56.6%	17.2%	2.1%	0.0%

Even though preemptive control measures are in place, because so many premises are infected initially, the disease can still spread to other states. This probability is given in Table 6.2.3-23, below.

Table 6.2.3-23: Probability that FMD will Spread to Other States upon a Medium Aerosol Release Caused by a Tornado			
	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	30%	41%	44%

The possible duration of the disease outbreak is shown in Table 6.2.3-24. The total disease outbreak duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. Because the disease may spread to other states that were not initially affected by the release, these states are modeled to not take preemptive control measures and therefore the disease spreads as if it were introduced by a surreptitious release.

Table 6.2.3-24: Duration of Outbreaks from an Infection Initiated by a Medium Aerosol Release Caused by a Tornado

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	6 days	28 days	84 days
p50	33 days	62 days	492 days
p95	243 days	473 days	533 days

Figure 6.2.3-12 shows head culled and vaccinated for the outbreaks initiated from medium Q value releases due to tornados across all possible starting locations and for three NAADSM output percentiles.

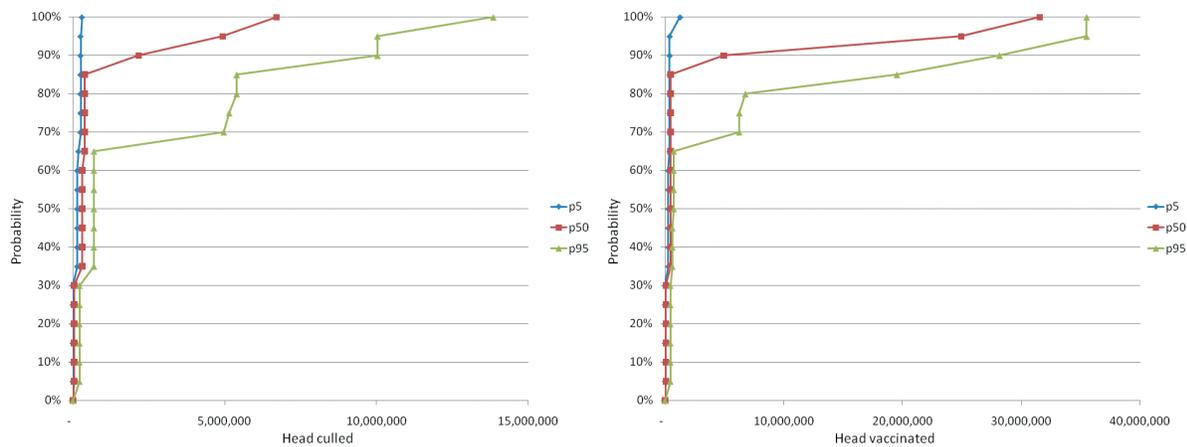


Figure 6.2.3-12: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by a Medium Aerosol Release from a Tornado

6.2.3.13 Tornado (High Q Release—Event T-High)

In this event, a significant tornado results in the release of $\sim 10^{10}$ PFU of FMDv. Due to the amount of material released, the number of farms initially infected downwind is very large with most releases leading to the simultaneous initial infection of 50 or more farms (Table 6.2.3-25).

Table 6.2.3-25: Probability that Meteorological Conditions will Prevail to Cause at Least a Threshold Number of Initial Premises Infected after a High Aerosol Release Caused by a Tornado

Number of premises	1+	2+	5+	10+	20+	50+
Probability	100.0%	100.0%	100.0%	100.0%	100.0%	88.1%

Even though preemptive control measures are in place, because so many premises are infected initially, the probability that the disease will spread to other states is still significant. This probability is given in Table 6.2.3-26, below.

Table 6.2.3-26: Probability that FMD will Spread to Other States from a High Aerosol Release Caused by a Tornado

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	70%	92%	96%

The possible duration of the disease outbreak is shown in Table 6.2.3-27. The total disease duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. Because the disease may spread to other states that were not initially affected by the release, these states are modeled to not take preemptive control measures and therefore the disease spreads as if it were introduced by a surreptitious release.

Table 6.2.3-27: Duration of Outbreaks from an Infection Initiated by a High Aerosol Release Caused by a Tornado

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	240 days	272 days	333 days
p50	252 days	424 days	492 days
p95	252 days	473 days	533 days

Even though the tornado is a self-announcing event, the fact that more than 50 premises are initially infected by the material dispersed by the tornado makes this outbreak very difficult to control.

Figure 6.2.3-13 shows head culled and vaccinated for the outbreaks initiated from a high aerosol release due to tornados across all possible starting locations and for three NAADSM output percentiles.

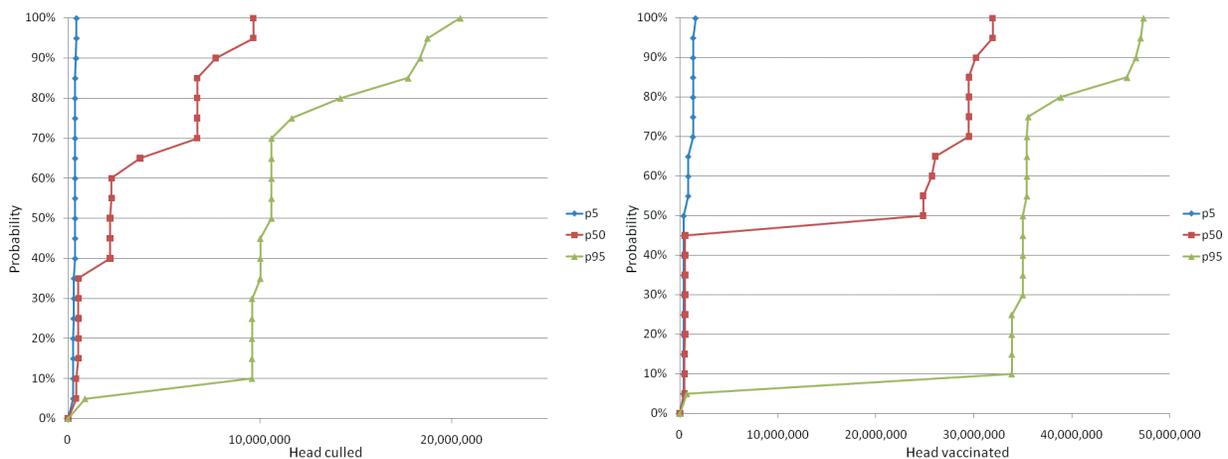


Figure 6.2.3-13: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by a High Aerosol Release from a Tornado

6.2.3.14 Earthquake (High Q Release—Event E-High)

In this event, an earthquake affecting the NBAF results in the release of FMDv at the High Q source term (see Section 4.5.4 for source term determinations). Due to the amount of material released, several farms can be initially infected downwind (Table 6.2.3-28).

Table 6.2.3-28: Probability that Meteorological Conditions will Cause at Least a Threshold Number of Initial Premises Infected upon a High Aerosol Release Caused by an Earthquake

Number of premises	1+	2+	5+	10+	20+	50+
Probability	93.9%	85.9%	65.2%	39.7%	19.5%	3.8%

Despite this explosive beginning, this event is easier to control than the aerosol release from the animal holding room in the absence of functioning HEPA filtration (event AA10) even though the same amount of material is released. This is because preemptive control measures can be enacted in this self-announcing case. The spread from many premises to areas distal from the NBAF does present some (albeit reduced) probability that the disease will spread to other states. This probability is given in Table 6.2.3-29, below.

Table 6.2.3-29: Probability that FMD will Spread to Other States Upon a High Aerosol Release Caused by an Earthquake

	NAADSM output p5	NAADSM output p50	NAADSM output p95
Probability of spread to other states	13%	22%	42%

The possible duration of the disease outbreak is shown in Table 6.2.3-30. The total disease duration is a function of the duration of the outbreak within Kansas, and, if it spreads to another state, the duration of the outbreak in that state. Because the disease may spread to other states that were not initially affected by the release, these states are modeled to not take preemptive control measures and therefore the disease spreads as if it were introduced by a surreptitious release.

Table 6.2.3-30: Duration of Outbreaks from an Infection Initiated by a High Aerosol Release Caused by an Earthquake

Duration is given for several starting location combinations (due to the possibility of spread to other states) using the p5, p50, and p95 NAADSM outputs.

Starting Locations (including risk of movement to other states)	NAADSM output p5	NAADSM output p50	NAADSM output p95
p5	8 days	18 days	72 days
p50	34 days	59 days	112 days
p95	48 days	473 days	533 days

Because an earthquake is a self-announcing event, most outbreaks due to the resulting release are relatively small (median impact of less than one million head culled) despite the fact that many premises can be infected simultaneously by the release itself.

Figure 6.2.3-14 shows head culled and vaccinated for the outbreaks initiated from large releases due to earthquakes across all possible starting locations and for three NAADSM output percentiles.

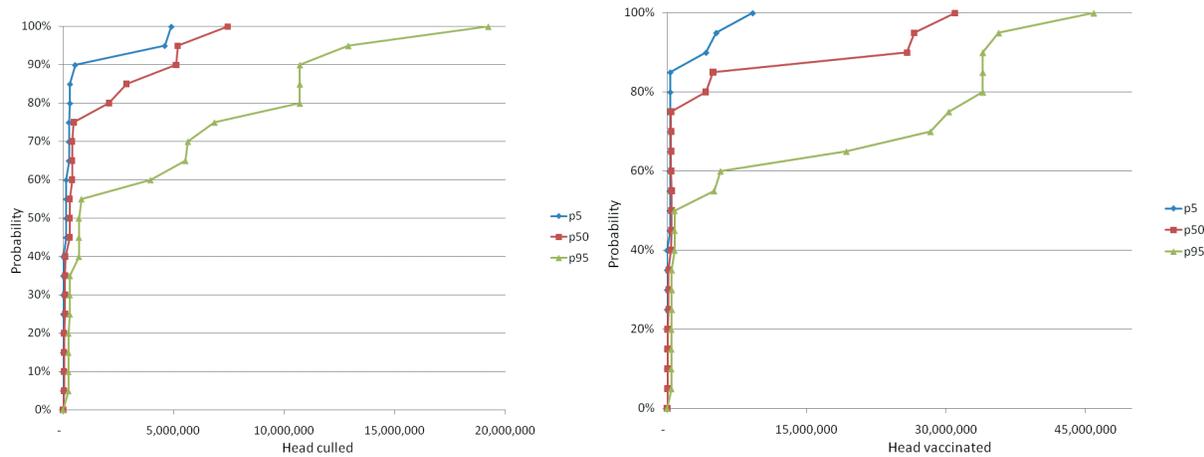


Figure 6.2.3-14: Head Culled (Left) and Vaccinated (Right) for Outbreaks Initiated by a High Aerosol Release Caused by an Earthquake

6.3 Cost-Benefit and Sensitivity Analyses

In this section, the effect of changing the modeling parameters used in the baseline analysis is explored. In some cases, the change of an input parameter can simultaneously explore potential benefits of implementing additional outbreak detection/control measures, as well as illuminate how uncertainty could affect the baseline modeling results. That is, exploring the effect of greater or lesser (than baseline) culling rates informs how uncertainty in the baseline value may reduce the confidence in any particular result, while simultaneously illuminating the affect of culling rate investment. Increasing the culling rate may reduce the impact of an outbreak; failure to invest in the maintenance of culling capacity may exacerbate an outbreak. Recall that the Updated SSRA team did not explore how changes in a vaccination strategy affect the outbreak because that topic is so complex that it cannot be treated fairly in the context of a larger risk assessment. However, each of the analyses described below was performed in the context of the three plausible vaccination strategies used in this report to ensure that the conclusions hold, regardless of how vaccination proceeds.

When the costs of improving disease control or detection systems are discussed, only the pre-outbreak costs are considered because cost is a secondary factor in decision-making in the face of an ongoing emergency. Pre-event costs are especially important when they support the response to low-probability, high-consequence events such as the outbreaks described in this report (because the expenditure will not have a real value if the event never occurs). For outbreak detection systems, almost all costs are realized before the event occurs. For outbreak response systems, pre-event costs typically include the training of responders, and the purchase and maintenance/storage of equipment and supplies. Costs to field culling teams and replace consumables used in the management of the outbreak would be realized only if the outbreak occurs and are not considered here.

6.3.1 Considering Large Outbreaks

Once an outbreak reaches a certain size, it is limited in extent by the availability of susceptible animals. In our model, once an outbreak involves the culling of about seven million animals in Kansas, it has reached nearly its maximum size and can worsen only marginally thereafter. For some starting locations, like large feedlots, NAADSM predicts that an outbreak would probably reach that maximum size; that is, the median NAADSM output predicts over seven million animals culled. In these cases, even if an enhanced mitigation measure drops the average consequences of an outbreak, the median consequences may not change significantly (see Figure 6.3.1-1). In the case illustrated in the figure below, the improvement does drop the average outbreak consequences, but still more than 50% of the outbreaks result in approximately seven million animals culled. In short, the entire consequence curve shifts to the right (the outbreaks with the greatest consequences occur at higher percentile outputs). However, if just the p50 output is considered, no benefit would be observed. For this reason, we test the value of mitigation measures against a variety of NAADSM outputs in this section. Clearly, the most valuable mitigation measures would reduce the consequences of even the worst outbreaks. However, measures that mitigate the consequences of only the less severe outbreaks still have value in many cases and, in fact, make the probability that an outbreak would reach its maximum size less likely.

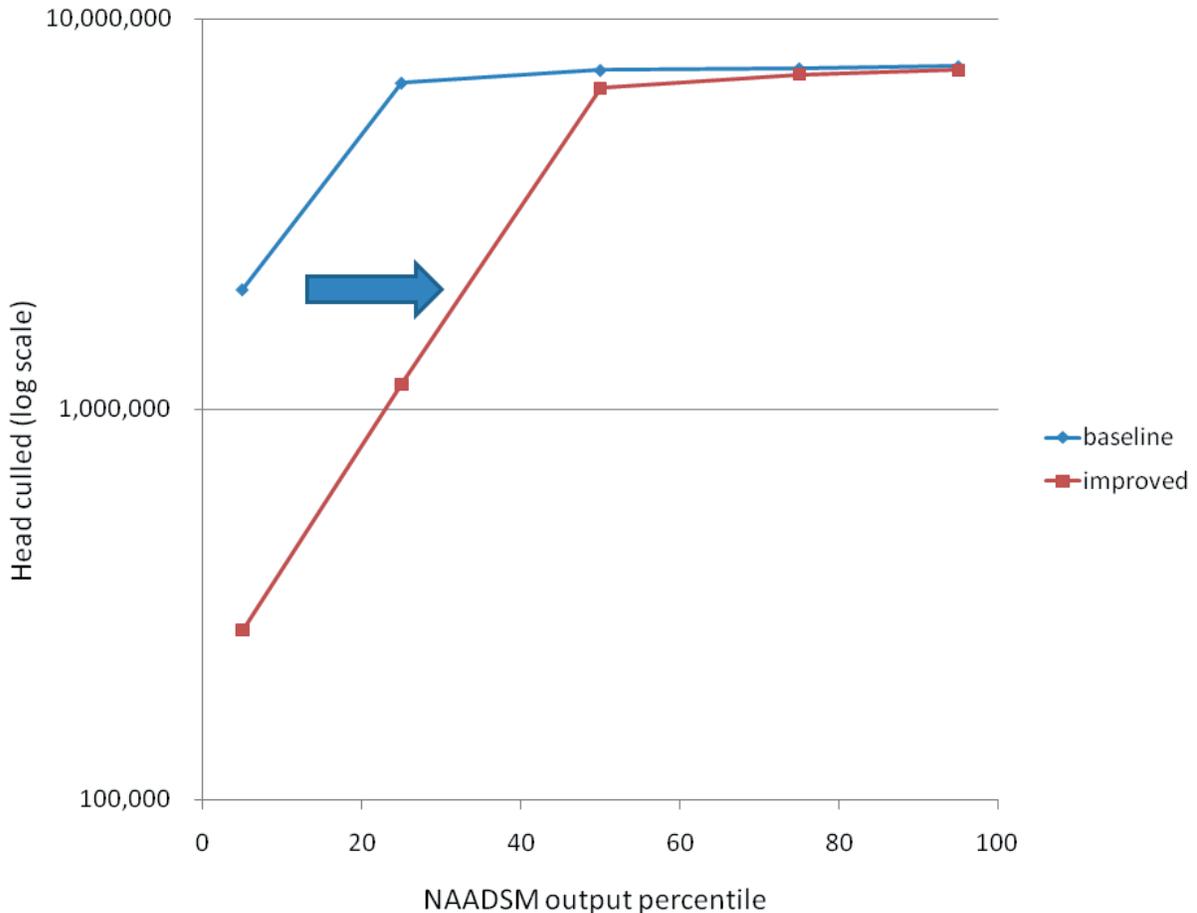


Figure 6.3.1-1: Consequences as a Function of the Percentile of the NAADSM Output for a Notional Large Outbreak with Baseline Parameters and in the Context of a Notional Improved Mitigation System

Note that although the improvement reduces the average outbreak consequences, the median consequences are still roughly the same. Simply put, the entire curve is shifted to the right (higher consequences occur only at greater output percentiles) as indicated by the arrow.

6.3.2 Effect of Culling Rate

Although the Updated SSRA team collected a significant amount of data to predict the number of premises that could be depopulated each day in an FMD outbreak, the fact that the model used does not distinguish large and small premises depopulation, and the fact that the U.S. has never had an outbreak that required the depopulation of more than 100,000 animals, brings into question the accuracy of the parameters used when applied to the control of a real outbreak. Moreover, because the fielding of culling teams requires the interplay of state and federal resources in an outbreak that may involve many states, predicting the true culling rate before an event occurs is complex. For this reason, the Updated SSRA team explored the effect of changes in the baseline culling rate in outbreaks in Kansas, from half the baseline rate to up to 10-fold more herds culled per day. Recall that the average

culling rate in the states we examined is approximately three to four herds per day, per state involved in the outbreak. This analysis, therefore, explores culling rates of two to 40 herds per day, on average.

6.3.2.1 Effect of Changing the Culling Rate

The culling rate was reduced by as much as half and increased by as much as 10-fold in this analysis. In Figure 6.3.2-1, the effect of culling rate on outbreak duration is displayed relative to the duration when baseline parameters are used (a value of two indicates that the outbreak now lasts twice as long). Each line represents a different outbreak starting facility type, notional vaccination strategy, and percentile of NAADSM outputs. The effect of changing the culling rate is significant across all facility types, vaccination strategies, and most NAADSM outputs considered (for very small outbreaks, like the cow-calf p5 output, there is no effect of increasing or decreasing the culling rate). Specifically, up to three-fold increases in culling rate decrease the outbreak duration by more than a factor of 10. Similarly, if the predicted (baseline) culling rate cannot be achieved, the outbreak will last longer, by as much as 30-fold.

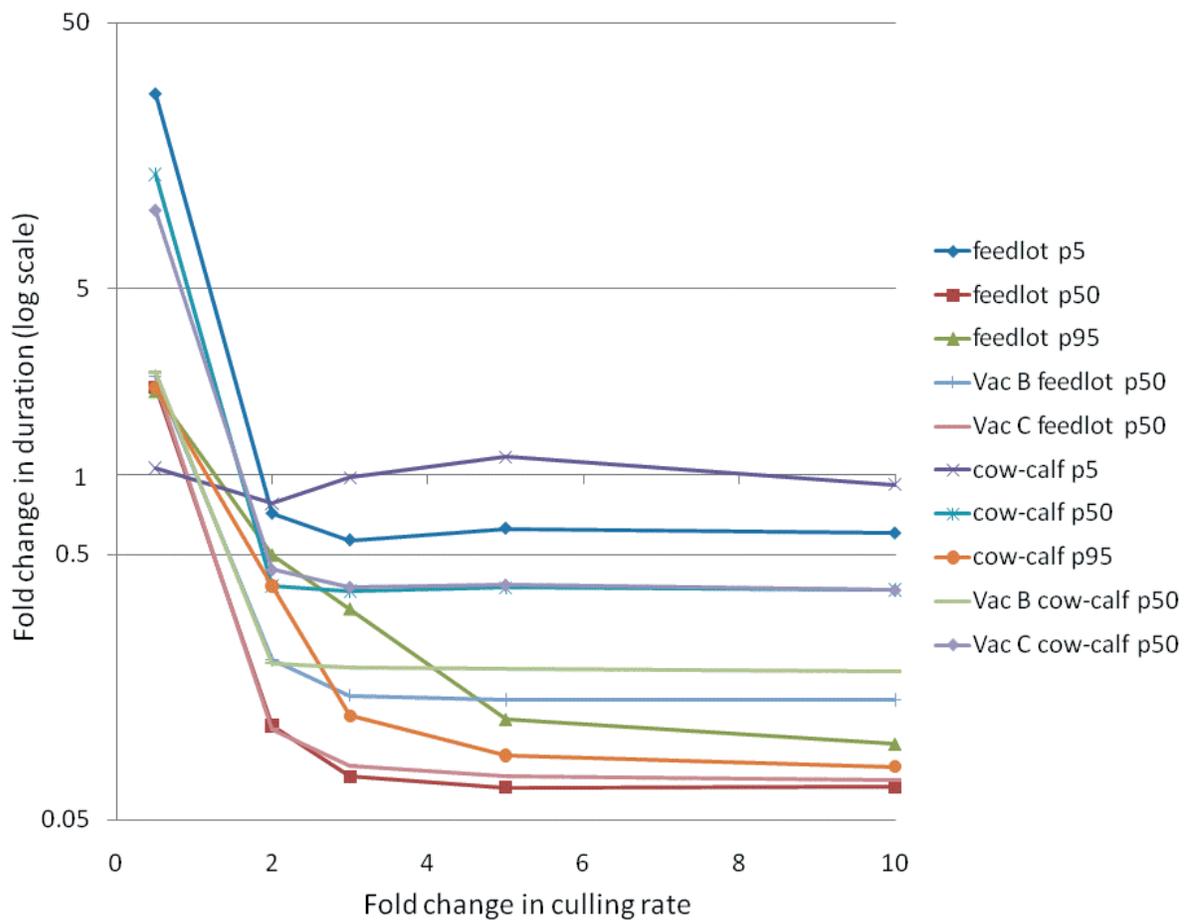


Figure 6.3.2-1: Effect of Changes to the Culling Rate on Outbreak Duration in Kansas

All axes are relative to the baseline culling rate (results that lie along $y=1$ have no effect on duration compared to baseline, like the cow-calf p5 line). Each line represents either a unique combination of outbreak starting facility type, NAADSM output, or vaccination strategy (vaccination strategy A was used unless otherwise noted).

Because outbreak duration is defined not only by the time that the outbreak continues to spread to new farms, but also the time required to depopulate all farms that have been infected, it is assumed that culling rate would affect outbreak duration even if culling rate did not affect the number of farms that become infected. This is one of the reasons why disease duration (which reflects how long a virus circulates in the population) was used as the main output in the results section.

In fact, culling rate has a significant effect on the total number of animals culled, as well as outbreak duration, suggesting that culling rate is important for the control of the outbreak itself, not just the depopulation of herds that were infected (as shown in Figure 6.3.2-2). The effect of changing the culling rate is significant across all facility types, vaccination strategies, and most NAADSM outputs considered (for very small outbreaks, like the cow-calf p5 output (not shown), there is no effect of increasing or decreasing the culling rate). Specifically, increases in culling rate up to three-fold decrease the number of animals culled by more than a factor of five. Only doubling the culling rate has a modest effect on the largest outbreaks (the p95 outbreaks for both locations shown), but a significant effect on other outbreaks. Similarly, if the baseline culling rate cannot be achieved, the outbreak will involve more animals, by as much as three-fold.

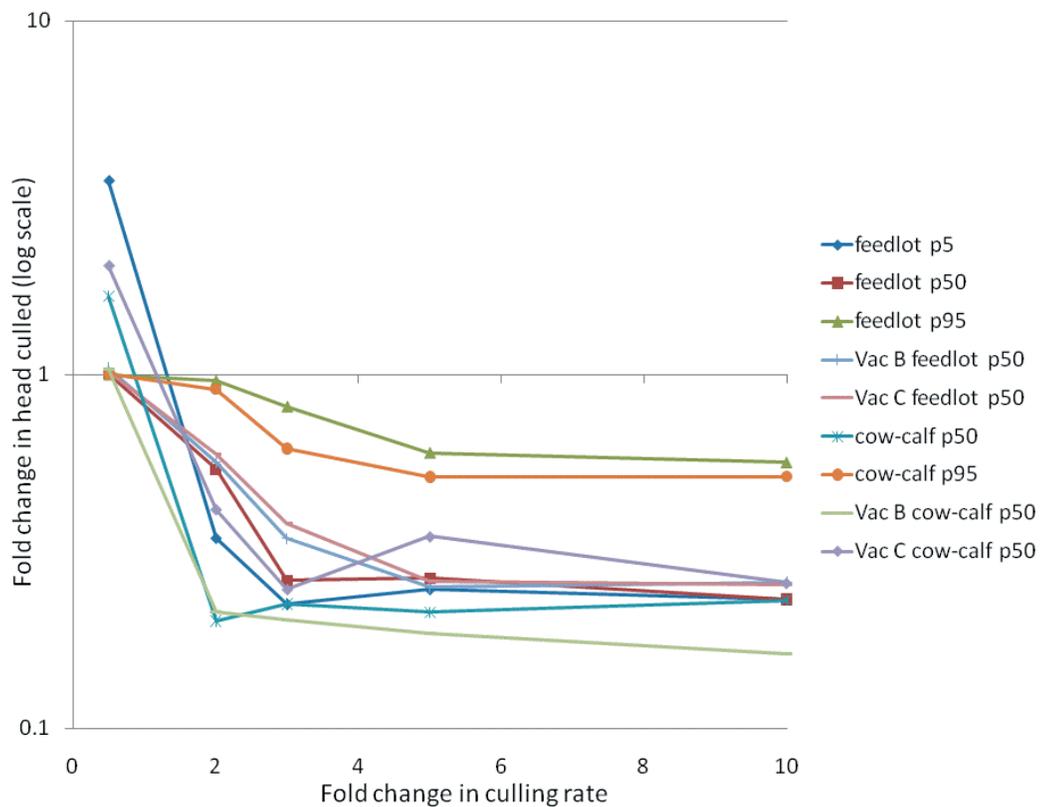


Figure 6.3.2-2: Effect of Changes to the Culling Rate on Number of Animals Culled in Kansas

All axes are relative to the baseline culling rate (results that lie along y=1 have no effect on head culled compared to baseline). Each line represents either a unique combination of outbreak starting

facility type, NAADSM output, or vaccination strategy (Vaccination strategy A was used unless otherwise noted).

To ensure that increased culling rates reduced the impact of an FMD outbreak, regardless of the type of facility at which the outbreak begins, the culling rate was varied in outbreaks starting in all premises types (Figure 6.3.2-3). As demonstrated, increasing the culling rate over the baseline decreases the impact of the outbreak across all premises types used in the model, and across all plausible vaccination strategies. However, if the outbreak is very small (such as the median outbreak starting in a backyard facility), no benefit of increasing the culling rate is observed (not shown).

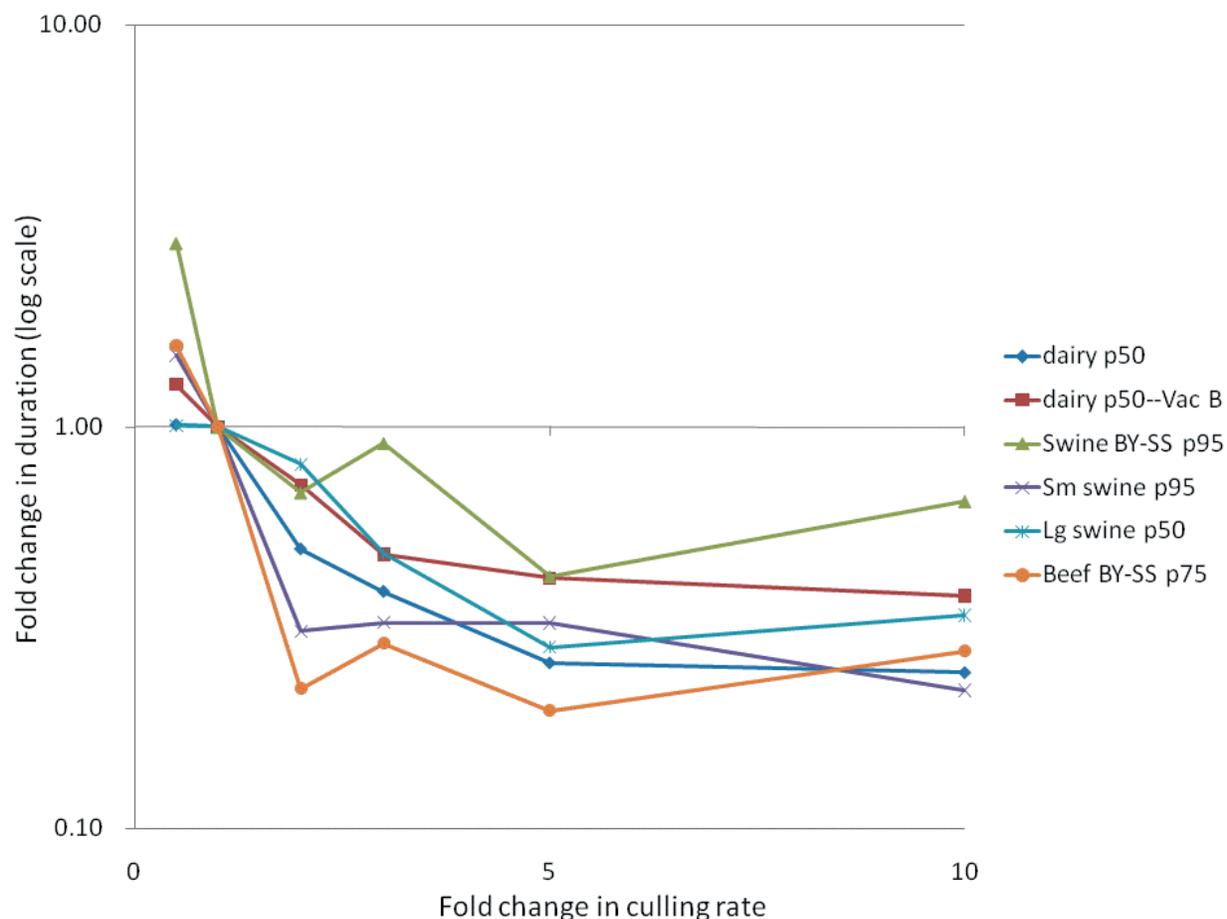


Figure 6.3.2-3: Effect of Changes to Culling Rate on Head Culled in the Outbreak in Kansas

Each line represents a different starting premises type, vaccination strategy (Vaccination Strategy A is used unless otherwise noted), or NAADSM output. BY-SS designates a small, backyard facility.

The importance of culling rate holds even if the baseline contact rates are changed for every premises type in the model (Figure 6.3.2-4). This figure shows the median output for outbreaks that start in a feedlot across several culling rates, in the context of direct and indirect contact rates two-fold greater or lesser than the baseline. Note that the importance of culling rate still holds under the different contact rates. The somewhat reduced impact of increasing culling rate, in the context of indirect contact rates twice the baseline, is due to the fact that the outbreak approaches maximum size for these outbreaks.

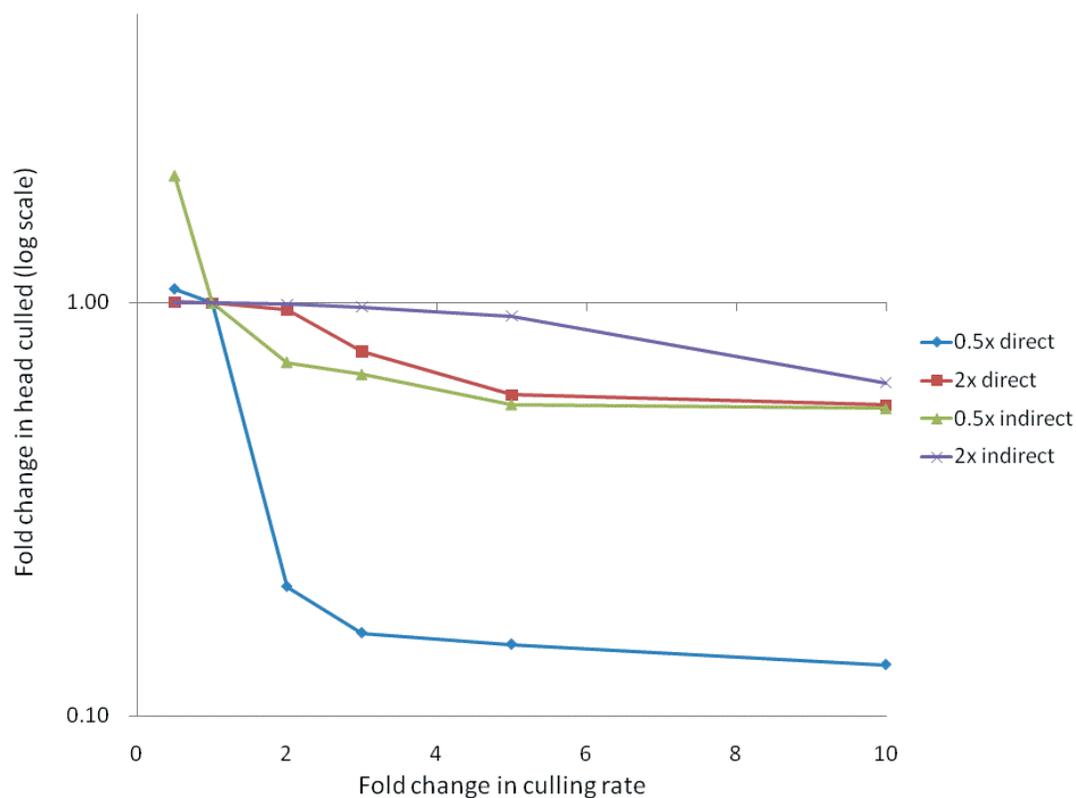


Figure 6.3.2-4: Effect of Changes to the Culling Rate on Number of Animals in the Context of Changed Direct and Indirect Contact Rates

All axes are relative to the baseline culling rate (results that lie along $y=1$ have no effect on duration compared to baseline). Each line represents a set of contact rates that is half or twice the baseline for all premises types.

This analysis suggests that any reduction in the culling rate from the baseline will significantly exacerbate an outbreak of FMD. For this reason, ensuring that states can field and sustain as many culling teams as currently estimated is critical. In the Updated SSRA, the estimates of the number of culling teams were taken from state stakeholders at face value. Further studies could investigate the resources that states have marshaled to train, exercise, and retain culling teams to evaluate their estimates for the number of teams that could be fielded (and for how long) and how federal resources would be used in a multi-state response.

Equally critically, this analysis shows that modest increases in culling capacity (by three-fold) significantly ameliorate the outbreak. In the section below, the cost and feasibility of increasing culling capacity is explored.

6.3.2.2 Cost of Increasing Culling Rate

This section explores the costs that would be required to increase destruction capacity in a single state. Both the training and physical resources needed to increase capacity must be considered. Based on multiple state interviews, states on average believe that they will be able to recruit 13 culling teams to support a sustained culling operation. The baseline culling rate is $\frac{1}{3}$ herd per day per captive bolt team (see Section 6.1.4.3). Therefore, the current culling capacity of a single average state is roughly four herds per day.

Current destruction capacity in each state is supported by existing federal resources, including Destruction, Decontamination, Disposal (3D) teams and federal equipment resources. In order to increase destruction capacity, both the number of culling teams in each state and supporting resources supplied by the federal government must be increased. SMEs consulted to estimate these resources are provided in Appendix A6.

Personnel

Culling teams and 3D teams differ both in number of team members and their specialized training requirements. Culling teams are typically composed of 12 members. A single task force leader oversees a Destruction Crew, an Animal Handling Crew, and an Animal Removal Crew. The Destruction Crew includes a crew leader, two captive bolt shooters, one designated captive bolt loader, and a captive bolt service technician. Depending on the operation, the animal handling crew and the animal removal crew will each employ between one and six personnel [Hill, 2011]. The animal removal team is responsible for removing the animal from the area where animals are being destroyed, whereas a 3D team will handle disposal. The size of these crews is determined by the availability of existing facility personnel onsite to aid in animal movement and carcass removal; larger facilities and feedlots may have enough personnel on hand to eliminate the need for animal handling crews and animal removal crews entirely. Since most of the facilities in Kansas tend to be smaller, cow-calf operations, the assumption was made that a full team was needed.

The cost to double the number of culling teams available to support destruction lies entirely in training, because all other costs (cost for deployment, for example) are realized only after the outbreak occurs. The costs to double capacity through online classes and in-person training are outlined in Table 6.3.2-1. Every member of a culling team must receive basic Incident Command System (ICS) structure training to become familiarized and effective within an ICS response. ICS training modules have already been developed by the government; these modules are offered free of charge and therefore would add no additional costs. All members must also receive training on biosecurity, which includes understanding the core concepts of biosanitation and practical training on appropriate personal protective equipment (PPE). Depending on the organization administering this biosecurity training, the cost per participant is expected to be several hundred dollars.

Shooters, loaders, and service technicians additionally participate in one-day training on the captive bolt kit system. This practical training encompasses captive bolt operation, cleaning, and replacement of

parts that wear. Shooters also undergo hands-on training to become effective at animal destruction using the captive bolt kit. This intensive, hands-on training is animal-specific and lasts one day per animal species. Although there are two shooters per team, it is recommended that a third person – typically a loader – also become proficient in destruction in order to serve as a backup and to prevent shooter fatigue. The cost figures below assume that shooters and loaders receive the full three-day course, which covers all three types of vulnerable animal species (cattle, swine, and small ruminants). This assumption was made in order to assure full deployment of teams regardless of scenario, and to provide for the most conservative cost estimates.

In general, it is recommended (and potentially required due to member turnover) that training courses are re-administered for all teams each year. Therefore the analysis considered training courses as a necessary annual cost to maintain proficiency. The intensive three-day, animal-specific captive bolt training is an exception; re-certification only every three years is considered prudent. To standardize the animal-specific captive bolt training as an annual cost in the calculations, the cost for this training was treated as an average yearly cost (the cost was divided across three years).

Table 6.3.2-1: Cost of Training 13 Culling Teams

Training Component	Required Members	Cost per Member	Cost per Team	Total Annual Costs
ICS 100 Level Course	12	\$0	\$0	\$0
Biosecurity Training	12	\$250	\$3,000	\$39,000
Captive Bolt Core Training	4	\$300	\$1,200	\$16,000
Animal-Specific Captive Bolt Training	3	\$2,000	\$6,000	\$78,000
TOTAL	-	-	\$10,200	\$133,000

Note: Other training may be prudent or required by regulations in some areas, but is not considered in this analysis. This additional training could include first aid training for all members; higher level ICS courses for task force leaders or destruction team leaders; and, specialized captive bolt service training for service technicians that would allow on-site repair of broken captive bolt kits that cannot be fixed through simple replacement of parts that wear.

3D contractors (All-Hazards response companies with specialized training) support the depopulation efforts of culling teams in biosanitation and carcass disposal roles. Five All-Hazards companies are under contract with the federal government to act as 3D service providers during an outbreak and are maintained to support any state-level culling team. Additional All-Hazard response companies can become 3D-proficient through training events run by the equipment manufacturers. These training events are typically hosted at and paid for by the National Veterinary Stockpile (NVS), the agency that issues 3D contracts. A 3D training event builds upon standard competencies possessed by All-Hazards response companies; the 3D training event focuses on concepts specific to animal disease outbreaks, including various levels of PPE use. The All-Hazards companies bring their own PPE to this training event.

The cost for this one-day training event is \$600 for two representatives from an All-Hazards response company; these representatives then train others on their team (“train the trainer”). As with other training events discussed in this document, travel and per diem expenses are not included and may add costs.

In addition to the 3D training course, NVS recommends an annual large scale exercise/demonstration for 3D contractors. This exercise provides hands-on depopulation experience with actual equipment and live animals. A single exercise is large enough for all existing 3D teams. As is the case with culling training, annual exercises and re-training are recommended and are therefore considered reoccurring costs (Table 6.3.2-2). Large scale exercises have historically been paid for by the NVS.

Training component	Annual Cost
3D “Train the Trainer” Course	\$3,000
3D Large Scale Exercise	\$20,000
TOTAL	\$23,000

Equipment

Culling equipment is available as a federal resource through the NVS. In this study, the assumption is made that the current level of federal equipment resources supports the current culling capacity across the country. Since these resources are shared among all states, it is assumed that increased culling capacity in a single state will require a proportional increase in supporting federal resources.

NVS culling equipment components can be categorized as either animal handling equipment or animal destruction equipment. Animal handling equipment includes livestock panels, squeeze-shoots, and other mobile equipment used to corral and direct animal movement to enable efficient culling. While some facilities such as feedlots will already have appropriate animal handling equipment onsite, other facilities such as small cow-calf facilities, which represent most of the premises in the modeled region, will have little or no animal handling equipment. Therefore, it is assumed that all teams require a set of animal handling equipment. There are both one-time costs and annual costs associated with animal handling equipment: one-time procurement cost is a combination of purchase and delivery costs (estimated at \$600,000), whereas annual costs cover storage and routine equipment maintenance (estimated at \$60,000 per year).

Animal destruction during an eradication campaign may be carried out by teams using captive bolt kits, teams operating mobile electrocution units, or both. Currently captive bolt kits are used whenever necessary and on all facility types. However, in the future, captive bolt use may be largely relegated to small operations and used as a secondary option for medium operations. Mobile electrocution units are considered most efficient for larger operations.

For our analysis, we calculated costs for two strategies: a captive bolt only strategy, and a mixed captive bolt/electrocution unit strategy. In the captive bolt strategy, all increased culling capacity is achieved through an increased number of captive bolt kits (Table 6.3.2-3). In the mixed strategy, half of all increased culling capacity is achieved through acquisition of mobile electrocution units, and the other half is achieved with captive bolt kits (Table 6.3.2-4).

Note: No cost data are currently available for mobile electrocution unit training courses. Therefore in the final cost calculation it was assumed that the cost to train a team in the use of the mobile electrocution unit is equal to the cost to train a team in the use of captive bolt kits. Also, no mobile electrocution units currently exist in the NVS stockpile.

Table 6.3.2-3: Cost of Culling Equipment Procurement for the Captive Bolt Strategy	
Animal Destruction Equipment	One-time Cost
Captive bolt kits	\$400,000
TOTAL	\$400,000

Table 6.3.2-4: Cost of Culling Equipment Procurement for the Mixed Bolt/Electrocution Strategy in which Half of New Culling Capacity is Provided by Mobile Electrocution Units	
Animal Destruction Equipment	One-time Cost
Captive Bolt Kits	\$200,000
Mobile Electrocution Units	\$2,000,000
TOTAL	\$2,200,000

Total Cost Calculations

Recall that, to increase the culling rate in Kansas, the state-specific resources (culling teams) must be increased and the federal resources to support culling in any state must be increased. Using this basis, a total five-year cost was calculated for each strategy by adding equipment procurement cost to the total annual costs across a five year period (Table 6.3.2-5).

Table 6.3.2-5: Total Cost to Double Culling Capacity in a Single State for Captive Bolt and Mixed Bolt/Electrocution Strategies

Culling Strategy	Annual Costs			One-time Cost	Total 5-Year Cost
	Training		Equipment storage	Equipment	
	3D Teams	Culling Teams			
All captive bolt	\$23,000	\$133,000	\$60,000	\$1,000,000	\$2,080,000
Captive bolt/electrocution	\$23,000	\$92,000	\$60,000	\$2,800,000	\$3,675,000

To increase culling capacity to levels beyond double current capacity, it was assumed that costs would scale linearly (Table 6.3.2-6).

Table 6.3.2-6: Total Costs to Increase Culling Capacity to Various Levels According to the Captive Bolt and Mixed Bolt/Electrocution Strategies

Culling Strategy	Total 5-Year Cost
All Captive Bolt	
2x capacity	\$2,080,000
3x capacity	\$4,160,000
5x capacity	\$8,320,000
10x capacity	\$18,720,000
Captive Bolt/Electrocution	
2x capacity	\$3,675,000
3x capacity	\$7,350,000
5x capacity	\$14,700,000
10x capacity	\$33,075,000

This analysis shows that achieving the desired, three-fold increase in culling capacity can be done for a relatively modest cost (\$4 to \$8 million) and may significantly reduce the extent of an outbreak. Note that although implementation of mobile electrocution units is far more expensive in this analysis, it is an artifact because the analysis does not consider the real-world difficulties of culling extremely large premises by captive bolt systems alone.

6.3.3 Effect of Contact Restrictions after Outbreak Detection

In this section, the effect of changes to the parameters that describe how livestock premises contact one another after an infection is discovered is discussed. After an infection is discovered, indirect and direct contact with infected premises decrease. Sensitivity to changes in these parameters is explored in two ways: by changing the amount by which contact is reduced and by changing the time needed to reach the minimum contract rate. Both types of changes illuminate how uncertainty in the parameterization of control measures effect the baseline results, and simultaneously describe how additional measures to support contact restrictions could mitigate the outbreak. This sensitivity analysis is critical because the

data underlying the degree to which contact will be curtailed during a real outbreak is sparse. Moreover, it is difficult to determine to what extent preparedness efforts can change behaviors and then reflect these in a model. For example, training producers on biosanitary guidelines may reduce the spread of a disease by limiting direct and indirect contact, but by how much this training reduces the spread of the disease is unknown. For this reason, this section should be understood primarily as a sensitivity analysis that also may begin to inform some investment decisions regarding means to reduce contact after an outbreak, but not as a strict cost-benefit analysis.

6.3.3.1 Changing Minimum Direct Contact Rate

The Updated SSRA team explored changes in the degree to which direct contacts can be reduced after an outbreak is announced by up to a factor of eight lower (from the baseline of 20% of pre-event contacts to 2.5%), and compared results in terms of duration, head culled, and head vaccinated to the baseline values. Although the degree to which direct contacts are reduced *can* have a significant effect on the results, the significance only holds for certain starting locations, vaccination strategies, and NAADSM outputs. Figure 6.3.3-1 shows the results for two representative starting locations and two NAADSM outputs (and the same vaccination strategy). Reducing the minimum direct contact rate significantly reduces the impact of the outbreak if the outbreak is relatively small (median or lesser) outbreaks in cow-calf operations and only the smallest outbreaks starting in feedlots (p5)). In contrast, if the outbreak is large, changing the minimum direct contact rate has little effect (median or larger) outbreaks in feedlots and only the largest outbreaks starting in cow-calf operations (p95)). This result reflects the phenomenon discussed in the introduction to the cost-benefit section. When an outbreak approaches the maximum size, a drop in the direct contact rate often does not reduce the size of an outbreak significantly (it is still reaching the maximum, even though it is less likely to reach the maximum for any iteration). However, when an outbreak is not reaching the maximum size, any drop in contact rates can further reduce the impact of the outbreak.

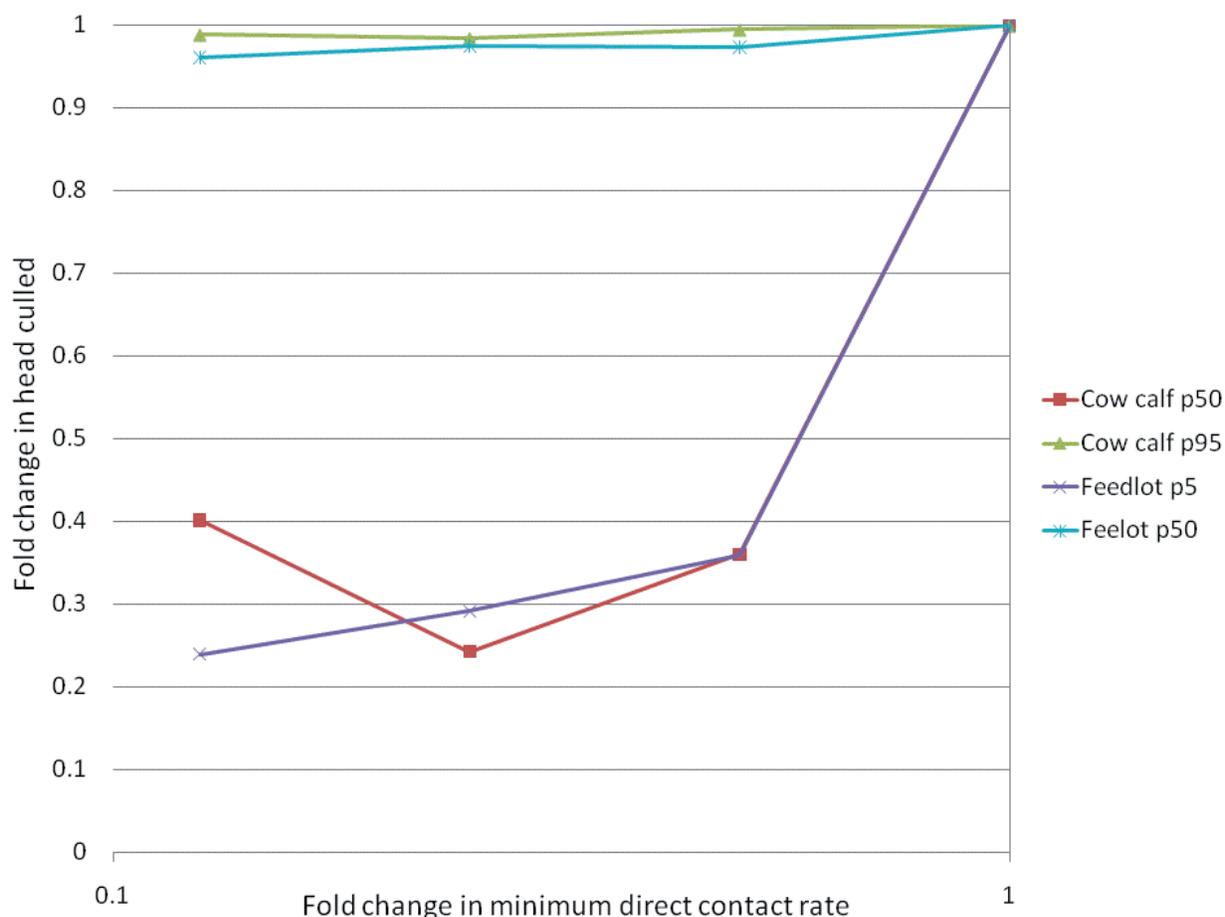


Figure 6.3.3-1: Effect of Reducing the Minimum Direct Contact Rate After an Outbreak on Head Culled for Two Example Model Runs (One Starting in a Cow-Calf Operation and One in a Feedlot) for Two NAADSM Outputs

Note the larger outbreaks are not sensitive to changes in the minimum direct contact rate.

6.3.3.2 Changing Minimum Indirect Contact Rate

The Updated SSRA team explored changes in the degree to which indirect contacts can be reduced after an outbreak is announced by up to a factor of eight lower (from the baseline of 40% of pre-event contacts to 5%), and compared results in terms of duration, head culled, and head vaccinated to the baseline values. Decreases in the minimum indirect contact rate significantly reduce the outbreak size and duration for all premises types, vaccination strategies, and NAADSM outputs examined (Figure 6.3.3-2). When considering head culled, large outbreaks (like the 95 percentile feedlot output) are also ameliorated by decreases of the minimum indirect contact rate, but larger decreases in the contact rate are needed to see the same impact. This result underscores the importance of the education of producers and the service providers that support them in biosanitary standards, both before and after an outbreak is declared. Clearly, stricter adherence to these standards would not only affect contact rate, but also provide other benefits in disease control, such as reducing the degree to which a disease can spread within a herd. Also, because outbreaks of the size modeled are beyond the ability of state

emergency managers to directly control with zones, this result underscores the importance of public communication strategies to rapidly inform the public, producers, and all other livestock handlers about the importance of eliminating contact with potentially infected animals.

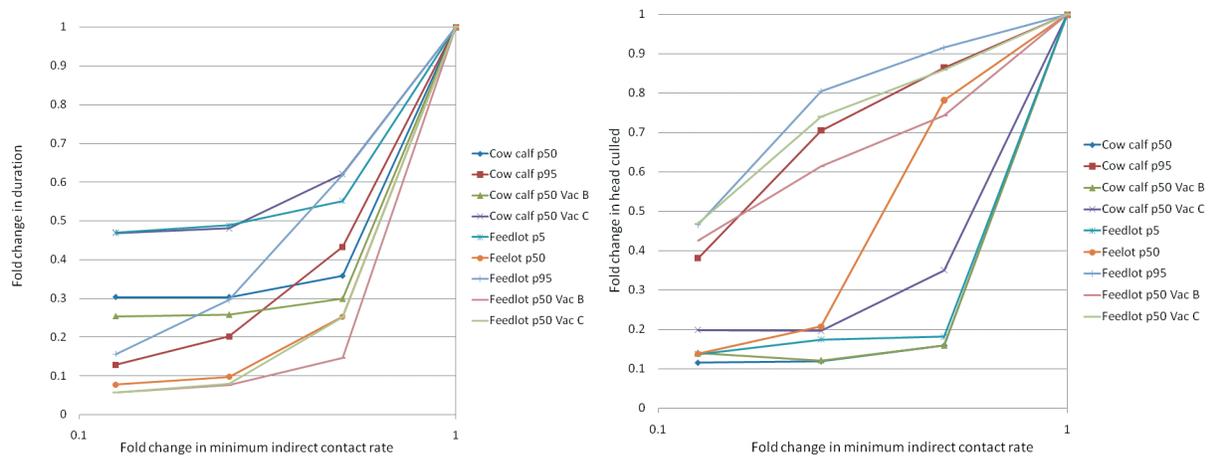


Figure 6.3.3-2: Effect of Reducing the Minimum Indirect Contact Rate After an Outbreak for Two Premises Types, NAADSM Outputs, and Vaccination Strategies

The left panel shows the change in duration; the right panel shows the change in head culled.

6.3.3.3 Changing the Time Needed to Reduce Direct Contacts

In addition to changing the degree to which direct contacts can be limited after an outbreak is discovered, the time needed to reduce contacts to a minimum can also be altered. The Updated SSRA team explored changes in the time to reduce direct contacts by up to a factor of eight (both greater and lesser) and compared the results in terms of duration, head culled, and head vaccinated to the baseline values. Although the time to reduce direct contacts *can* have a significant effect on the results, the significance only holds for certain starting locations, vaccination strategies, and NAADSM outputs. Figure 6.3.3-3 shows the results for two representative starting locations (and the same vaccination strategy and NAADSM output). As demonstrated, for outbreaks that start in a cow-calf operation under these conditions, reducing the time to a minimum direct contact rate decreased the head culled by up to a factor of two; however, decreasing that time for outbreaks that start in feedlots had no effect. This result reflects the phenomenon discussed in the introduction to this section. When an outbreak approaches the maximum size, a drop in contacts often does not reduce the size of the outbreak significantly (it is still reaching the maximum, even though it is less likely to reach the maximum for any iteration). However, when an outbreak is not reaching the maximum size, any drop in contact rates can further reduce the impact of the outbreak.

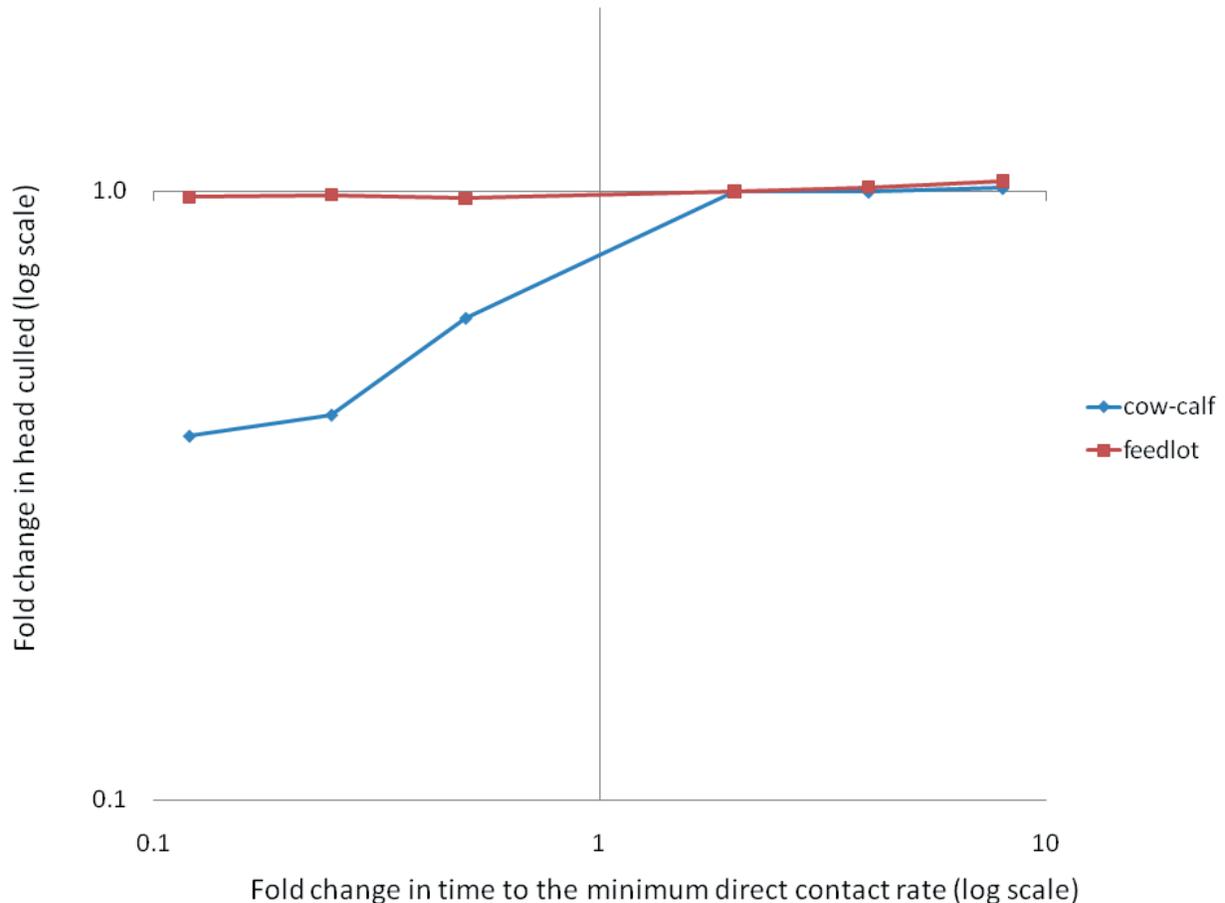


Figure 6.3.3-3: Effect of Changes of the Time to Reduce Direct Contact Rates on Head Culled for Two Example Model Runs (One Starting in a Cow-Calf Operation and One in a Feedlot)

The feedlot represents a model run insensitive to changes in the time to reduce direct contact rates, and the cow-calf operation represents a model run sensitive to changes in the time to reduce direct contact rates.

6.3.3.4 Changing the Time Needed to Reduce Indirect Contacts

Similarly, the time to minimum indirect contact rates can be altered. The Updated SSRA team explored changes in the time to minimum indirect contact rates by up to a factor of eight (greater and lesser) and compared the results in terms of duration, head culled, and head vaccinated to the baseline values. Increasing the time to minimum indirect contact rates can increase the impact of an outbreak by up to a factor of ten, and decreasing the time to minimum indirect contact rates can decrease the impact by up to a factor of five. However, this effect is seen only for certain starting locations, NAADSM outputs, and vaccination strategies (Figure 6.3.3-4.). In general, the effect of changing the time to minimum indirect contact rates has a significant effect on the outcome of the smaller outbreaks (the p5 NAADSM outputs for several starting conditions and the p50 NAADSM output for cow-calf facilities) and not on the impact of larger outbreaks (the p50 and p95 NAADSM output for feedlots and the p95 outputs for cow-calf operations).

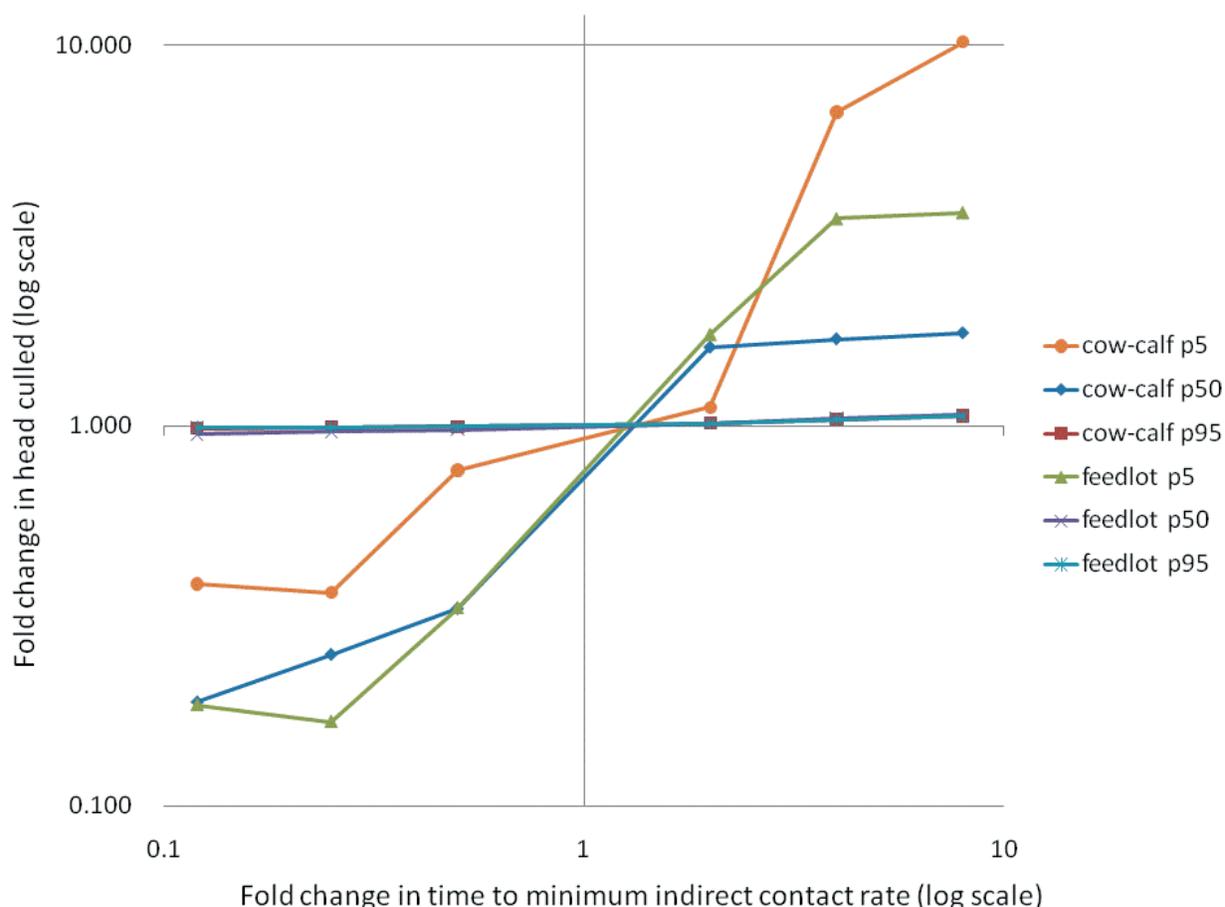


Figure 6.3.3-4: Effect of Changes to the Time to Reduce Indirect Contact Rates on Head Culled for Six Example Model Runs (Three Starting in a Cow-Calf Operation and Three in a Feedlot)

Note how the larger outbreaks (the median and 95 feedlot start and the p95 cow-calf start) are insensitive to changes in the time to reduce indirect contacts, whereas a significant benefit can be seen in smaller outbreaks. This effect is probably due to the large outbreaks reaching their maximum size.

6.3.3.5 Cost of Improving Movement Restrictions

As discussed, ascribing a particular modeling value for movement restrictions to real-world mitigation strategies is difficult. For example, what reduction in indirect contact rates would be afforded by a comprehensive biosanitary education campaign targeted at hoof trimmers? How much will a producer-targeted education campaign focused on the dangers of FMD reduce direct contacts after an outbreak is discovered? In this section, some good practices will be described that may reduce indirect and direct contacts after an outbreak. These strategies may be considered for adoption despite the fact that none of these strategies can be linked quantitatively to a demonstrated benefit in terms of a less severe outbreak.

There are two important factors in animal movement control at the local level: 1) notifying producers of an FMD outbreak and of associated animal movement requirements, which could continually evolve during an outbreak; and, 2) establishing traffic control measures that control shipments already en-route at the time of an outbreak declaration, and that later ensure ongoing adherence to changing animal movement requirements. Training of local responders in animal disease response is crucial and is addressed below, as well.

Producer Notification

Producer and citizen awareness programs have already been employed for a number of years in areas near other high consequence facilities. One such facility is Kansas's only nuclear power plant, the Wolf Creek Generating Station. The Wolf Creek Nuclear Operating Corporation conducts various activities in conjunction with Federal Emergency Management Agency's Radiological Emergency Preparedness (REP) Program. These activities include multi-agency exercises, producer awareness sessions, and literature distribution (including glove box manuals, calendars, and telephone book inserts containing emergency plan information and contact numbers). Multiple SME's echoed that it would be a logical extension to develop a program similar to the REP Program for facilities like the NBAF, to provide information useful in the control of an outbreak of disease.

In the context of an accident at the NBAF, a positive test result for FMD in a state is expected to immediately trigger a stop movement order lasting 24 to 72 hours for all animals within that state. Once an outbreak becomes public, word will spread through news media and social media outlets. However, local radio communication could be utilized to more rapidly reach producers. One strategy employed by the Wolf Creek Generating Station for local communication is the distribution of emergency radios (powered by AC and battery backup) to producers that would activate automatically during emergencies. The estimated costs to purchase emergency radios for producers in areas around the NBAF are shown in Table 6.3.3-1. Given that the news that an FMD outbreak is occurring will rapidly hit local and national media, the radios will possibly provide only a few hours of warning at best and may help marginally to reach producers who do not regularly follow news broadcasts. Given this limited audience, the benefit of distributing radios may be small.

Radius Around NBAF	Farms	Radio Costs
10 Kilometers	62	\$3,000
20 Kilometers	227	\$11,000
50 Kilometers	1629	\$80,000
100 Kilometers	7356	\$370,000

Other suggestions for improved producer notification are the development of local producer email lists for initial outbreak announcement and creation of a central information dissemination website for status updates.

Traffic Control

A variety of traffic control measures in different geographic locations will be employed to safely control and direct traffic immediately following an outbreak. The measures are needed to ensure that traffic unrelated to the shipment of animals can continue safely from areas in which the disease is identified, to facilitate the trade of livestock between unaffected areas, and also to ensure that illicit traffic in animals is not occurring from infected areas. Additionally, traffic control can limit the risk of the spread of disease on vehicles unrelated to the trade in animals. Some roads will become completely barricaded, while others will have checkpoints and cleaning and disinfection stations to safely allow vehicle passage. Although tabletop exercises have been carried out in order to explore movement control strategies, no quantitative data are currently available on the expected time needed by emergency planners to convene, identify optimal traffic control points, and execute an emergency traffic control plan. This timeframe could vary greatly based on the emergency response experience of local officials and unique challenges of the local infrastructure and terrain.

Exact implementation of an emergency traffic control plan will depend on the circumstances specific to the outbreak. Experts suggest that local and regional traffic control planning would significantly improve the effectiveness and execution speed of emergency traffic control during an emergency. Proactive development of several situation-specific logistical plans would simplify and streamline the decision making process. Pre-event identification of suitable traffic control points could be achieved during county emergency planning sessions. In addition to traffic control points, in some areas it may be particularly challenging to identify areas large enough to temporarily hold large vehicles for disinfection (such as county fairgrounds or highway construction staging areas); ideally these areas would have access to water as well. Once county-level plans have been developed for areas around the NBAF, regional planning could synthesize and further optimize traffic control plans for the region according to the most likely outbreak scenarios; route control prioritization will likely follow recent logistical research [Graham et al., 2008]. The costs to perform such regional planning studies were not determined in this study.

A potential extension of pre-event control point identification would be pre-event distribution of necessary traffic control equipment. Purchase and placement of dedicated barriers, signs, and other traffic control equipment in close proximity to control points would reduce the time and demand on heavy machinery and crews needed for traffic control point setup, enabling more effective movement control during an emergency (particularly if multiple infected premises are involved). A thorough examination of equipment needs would decrease local dependence on outside resources, which take longer to arrive than local resources, and could be limiting. For example, jersey barriers could be permanently positioned just off the roadside of locations expected to be used for road closure. Additionally, portable and permanent electronic signs could be positioned to either reduce traffic entering hot zones, or redistribute the traffic burden of heavily trafficked checkpoints. Concrete jersey barriers dedicated to appropriate control points could be purchased at an estimated cost of \$500 to \$1,000 each. Programmable electronic traffic signs cost roughly \$15,000 each.

Traffic control will also be important once initial movement restrictions are loosened; after initial stop movement, reestablishment of commerce will become a high priority. However, in many ways monitored, selective animal movement is more difficult to achieve than total stop movement. Checkpoint staffing, interstate permitting, and emergency activities coordination will be central once animal movement resumes in order to identify animal shipments that should be allowed to move.

One important finding from the 2009 Animal Stop Movement Order Functional and Full-Scale Exercise involving Kansas and Oklahoma was that typical Emergency Operation Centers (EOCs) are not outfitted with sufficient dedicated communication equipment to effectively achieve communication goals [SES, 2009]. An effective, interoperable communication infrastructure will be crucial for the exchange of information between EOCs, traffic control checkpoints, law enforcement, and health authorities. States could advance this capability through acquisition of satellite phones, creation of state-wide radio systems (preferably interoperable between adjacent states), and mobile cell phone towers that can be installed in control zones. Kansas is currently developing one such 800 MHz statewide radio system.

Local Responder Animal Disease Response Training

Animal emergency response training is important for personnel involved in all aspects of outbreak response; however, this training may be particularly pertinent to strengthening movement control capabilities. While the investigation of infected premises will be carried out largely by epidemiologists trained in contagious disease, and depopulated animals ultimately will be disposed of by teams that have received certification in biosecurity through the NVS, local responders typically lack animal-specific emergency training. SMEs have cautioned that conventional first responder training is contrary to animal disease response training in critical aspects and may lead to actions that actually worsen an outbreak.

The current availability of county-level animal disease response training programs is inadequate to prepare a sufficient number of first responders. Once an outbreak has been detected, it is expected that local responders will bear the burden of movement control and coordination activities, especially if the control area is large (multiple premises become infected) [Graham et al., 2008]. Personnel needs estimates for first responders during an FMD outbreak have ranged from hundreds to thousands, underlining the importance of the availability of animal disease response training.

One of the most highly praised disease response training programs arising from government grants in recent years was the Animal Disease Response Training program at Kirkwood Community College. Arguably the most influential course that evolved from this program was course AWR-206. This course was offered as both an eight-hour standalone course and a 16-hour course with a train-the-trainer component. AWR-206 covered biosecurity concepts, PPE instruction, and livestock disease response considerations, with a focus on integration of federal, state, and local responsibilities. Cost and reach information about AWR-206 is shown in Table 6.3.3-2. Although 1,400 students directly participated in the program, program analysts estimate that roughly tenfold more first responders were indirectly trained due to the success of the train-the-trainer aspect of the program. Development of the program

was associated with additional costs; however, re-implementation of this program would have few upfront costs as the program curriculum, course materials, and training staff are largely intact. The largest government contracts to develop and deliver animal disease response training programs have either recently expired or will expire soon.

Table 6.3.3-2: Cost and Reach of Animal Disease Response Training Course AWR-206 Developed by Kirkwood Community College, Fiscal Year 2010-2011

DHS Course Number	Number of Courses Taught	Number of Students	Number of Student Hours	Direct Costs	Indirect Costs	Total Cost	Cost per Student Hour	Cost per Student Trained
AWR 206	60	1,400	23,000	\$930,000	\$130,000	\$1,060,000	\$46	\$370

6.3.4 Observation and Reporting

The initial detection and reporting of an outbreak of FMD has several components. First, a producer must observe a clinically ill animal and report this finding to either the producer's veterinarian or a state or federal veterinarian. His/her veterinarian will contact a state or federal veterinarian who will dispatch a specially trained foreign animal disease diagnostician to collect samples. The samples will be sent to the Foreign Animal Disease Diagnostic Laboratory and may be shared also with the nearest National Animal Health Laboratory Network (NAHLN) laboratory for testing. The probability of observation is based on the frequency that a producer observes his animals (which is a daily occurrence in a feedlot but somewhat rare for animals on pasture), the percent of his herd that he observes, and the chance that a sick animal is recognized. In this section, the effect of changing the parameters related to observation and reporting is explored one component at a time. In the section that follows, other possible systems (that do not involve the producer) for surveillance and detection of FMD are described and explored.

6.3.4.1 Changing the Probability that a Sick Animal Would be Observed

Once sick animals begin to show signs of sickness, it is possible that a producer will observe those signs. In the model used in the Updated SSRA, the probability to observe a sick animal and notice that it is sick is a function of the production type (which determines how often a producer sees his animals and what proportion are seen) and a scalar that represents the producer's ability to recognize the signs of FMD as extraordinary. In this analysis, the effect of changing the observation function was studied to determine how sensitive model outputs are to this function, and to understand the possible benefit of education campaigns that enable producers to better recognize the signs of FMD, or incentivize them to observe a larger portion of their herds more frequently. In Figure 6.3.4-1, the probability that a producer can observe and recognize the signs of FMD is increased and decreased by up to four-fold. Note that changing the probability of observation has a significant effect on outbreaks that have not reached their maximum size (cow-calf p50 and feedlot p5) but only a minor effect on outbreaks that are very large (cow-calf p95 and feedlot p50).

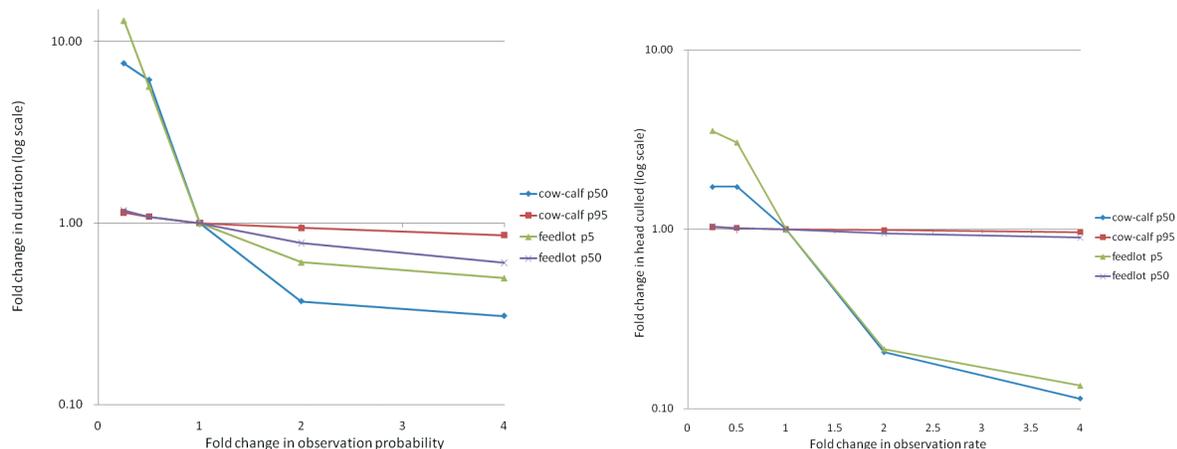


Figure 6.3.4-1: Effect of Changing the Observation Probability for Two Premises Types and NAADSM Outputs

The left panel shows the change in duration, the right panel shows the change in head culled.

6.3.4.2 Improving the Probability that a Sick Animal is Reported to a Veterinarian

Once a sick animal is observed, a producer may ignore the signs, may try to treat the animal himself (or kill the animal), or may report the illness to a veterinarian. The probability that a producer would call a veterinarian immediately is different for each premises type as determined by interviews conducted by the Updated SSRA team (20% of cow-calf operators would call a veterinarian immediately, whereas a third of feedlot operators would call a veterinarian immediately). Several measures could increase the probability that a producer would call a veterinarian quickly. An education campaign that focused on the signs and potential impact of FMD would decrease the chance that a producer would attempt to treat FMD himself. Similarly, educating more producers that free veterinarian visits are provided if FMD is suspected may improve the chance that a veterinarian would be called for some production types (like small ruminant facilities, in which the value of the animal is less than the cost of a visit by a veterinarian). In Figure 6.3.4-2, below, the benefit of increasing the probability that a veterinarian is called quickly is shown. The word “half” denotes a system in which half of all producers (regardless of facility type) immediately call a veterinarian whereas “majority” denotes a system in which the same percent of producers who do not call a veterinarian immediately now do (for example, if only 30% of feedlot owners would normally call a veterinarian immediately, 30% of owners would NOT call a veterinarian in the majority system). Note that increasing the probability that a veterinarian is called quickly drops the consequences of an outbreak for all but the largest outbreaks. For large outbreaks, the probability that an outbreak would reach maximum size is reduced (not shown).

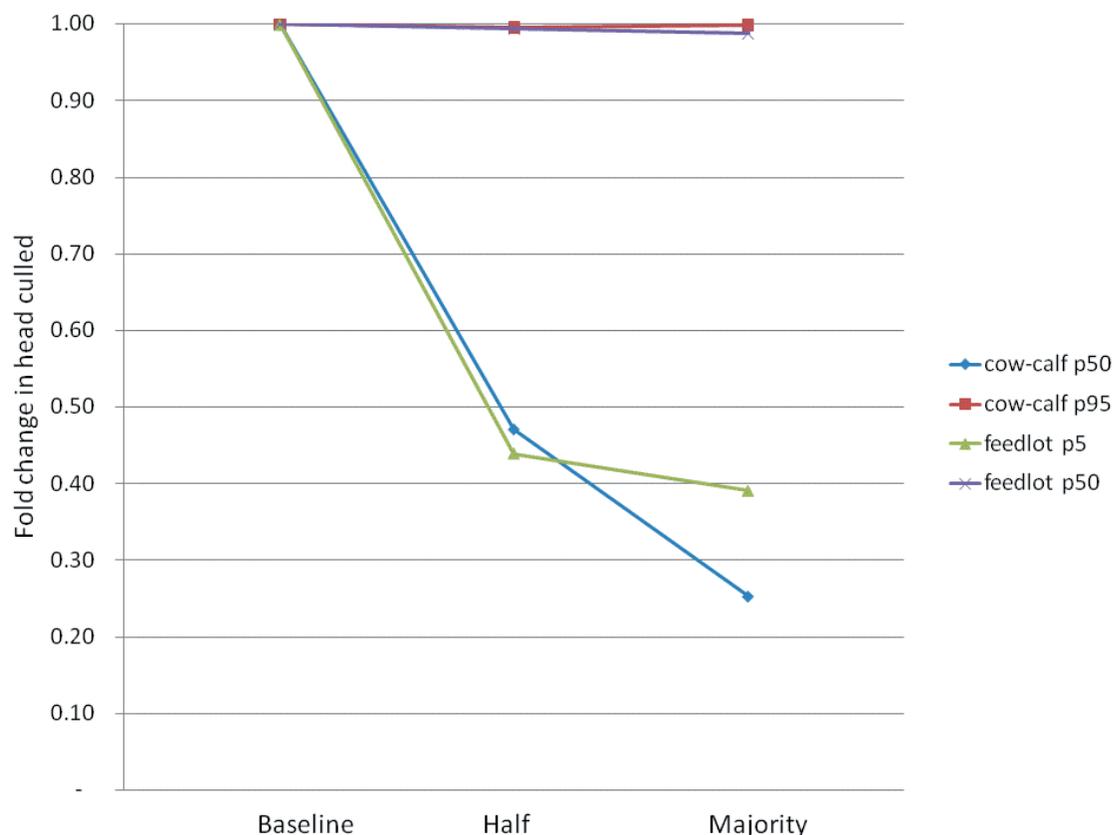


Figure 6.3.4-2: The Effect of Improving the Probability that a Producer Calls a Veterinarian Soon After Observing Signs of FMD Relative to the Baseline Probability

“Half” is used for a system in which half the producers (regardless of production type) immediately call a veterinarian. “Majority” is used for a system in which now the majority of producers immediately call a veterinarian (the percent is specific to the production type). In a majority system, if 30% of producers would call a veterinarian immediately in the baseline, 30% would NOT call a veterinarian immediately (70% would call immediately).

6.3.4.3 Air Samplers, Sentinel Animals, and Active Surveillance

The studies above explored the benefit of educating producers on the importance of observing their animals frequently and reporting suspicious signs to a veterinarian as soon as possible. However, other systems could be deployed that do not involve participation by producers. In the results section, the benefit of detecting a release of FMD before the first animal falls ill was shown to be significant (compare events that release 10^8 PFU of FMDv surreptitiously, versus a self-announcing event— like an earthquake). The NBAF could hire animal disease diagnosticians to visit susceptible herds regularly and perform diagnostic tests or look for suspicious signs. These veterinarians would need to physically travel to farms each day in order to visually examine animals for symptoms of FMD or to take samples. Ideally this approach would decrease the delay between animal infection and detection of FMD.

SMEs caution that producers may resist routine inspection and be alarmed by constant surveillance. To improve producer acceptance of the strategy, it has been suggested that producers could be incentivized with free routine veterinary services from these personnel. Even with incentives, it might be necessary to make inspection mandatory in order to achieve 100% compliance among producers. This strategy also raises concerns about biosecurity. Although more farm visits by animal health professionals may increase the likelihood of recognizing an FMD outbreak early, it also introduces the risk that a veterinarian will inadvertently spread FMDv from an infected farm to an unexposed farm. This risk increases significantly as the number of farms that each veterinarian visits each day increases; considering the large number of farms in the areas surrounding the NBAF, each veterinarian would have to visit multiple farms each day to make this strategy feasible. Moreover, it is unlikely that a veterinarian who is visiting a herd for a limited time would observe the few animals that may actually be showing signs of disease within a large herd. Pooled veterinary samples could increase the number of animals effectively screened by surveillance, but the reach will still not be total. Ultimately, concerns about producer acceptance and cross-contamination are likely to eliminate routine inspection from consideration as a surveillance strategy.

Air samplers could be used for extremely early detection of outbreaks caused by aerosol releases from the NBAF (such as an event caused by the total failure of the HEPA filtration system). Even though laboratory experiments have demonstrated the collection and detection of FMDv from the air, no system currently exists for the constant surveillance of air samples for FMDv. To explore the possible benefit of developing and deploying a system that could detect airborne FMDv, the largest surreptitious aerosol release was modeled (lack of HEPA filtration in the animal room - Event AA10) and across all meteorological conditions, the dose received at any point near the NBAF was determined. Four locations (at the compass points in the areas of highest time-integrated concentration of FMDv) were selected as possible locations for the placement of an air sampler. Then, the dose these air samplers would receive across all meteorological conditions was calculated assuming that they can entrain 100 liters per minute (L/min) or 1,000 L/min of air. For the purposes of this analysis, it was assumed that the air samplers would capture all virus particles presented to it at this entrainment rate, and that all virus particles could be recovered from the samples and used in a diagnostic assay (in the normal operation of similar systems, some of the sample is not recoverable from the capture matrix and only some of the sample is used in each assay). As mentioned in the results, more than 90% of these releases related to Event AA10 cause an infection in at least one premises, so this event would be a high priority for an air sampling system to detect. However, the four-sampler system, even if it is assumed that the assay used on the air samples can detect as little as 1 PFU, performs poorly (Table 6.3.4-1). Only if perfect capture and recovery of a sample and an assay limit of detection of 1 PFU are assumed, does the chance of detection of aerosol releases approach 10%. Given that air samplers and detection assays do not yet exist with these performance characteristics, and the locations of the air samplers were chosen based on the high concentration of FMDv at those locations, the deployment of an air sampler system is likely to not be beneficial. This conclusion is undergirded by the fact that this aerosol release event contributes only a

little to the risk space, and that the cost of false positives from an air sampling system have not been considered.

Table 6.3.4-1: The Probability of Detection of an Aerosol Release that Causes a Downwind Infection as a Function of Entrainment Rate of an Air Sampler and the Limit of Detection of the Assay Used on the Air Sample

Entrainment Rate	Percent of releases that cause at least one infection detected assuming a 1 PFU limit of detection	Percent of releases that cause at least one infection detected assuming a 10 PFU limit of detection
100 liters/min	1%	0%
1,000 liters/min	9%	1%

The poor performance of an air sampling system could be predicted by the nature of an FMD outbreak caused by an aerosol. The downwind infections are caused by a very dilute aerosol of a pathogen with a very small median infectious dose covering an area that contains many hundred susceptible animals and, importantly, the infection of just one animal is enough to cause the outbreak. For a network of air samplers to detect an aerosol that may cause an infection, it must entrain about the same amount of air as all the animals exposed to the aerosol combined, and the assay used on the air sample must be able to detect as little as one median infectious dose (less than 10 PFU in many cases). These requirements are beyond the capabilities of technology available today and the immediate future.

For similar reasons, sentinel animals would be of limited value. The aerosols released from the NBAF are dilute and therefore unlikely to infect a single animal placed in any location outside the NBAF. Instead, infections occur downwind because many hundred animals are exposed to dilute aerosols. Of course, one could completely surround the NBAF with a herd of several hundred cattle and take blood samples from the cattle daily but this concept stretches the notion of a sentinel herd. Moreover, the presence of a large herd of cattle on the grounds of the NBAF outside of containment may itself exacerbate the risk of an infection leaving the NBAF.

Because no system involving active surveillance, air samplers, or sentinel animals is feasible, acceptable to producers, and/or effective, the costs of these systems is not described below.

6.3.4.4 Cost of Improving Surveillance and Detection

The time delay between premises infection and FMD identification may greatly affect the duration and extent of an outbreak. Improved disease surveillance could reduce this delay. Producer awareness is paramount to FMD identification, particularly for the index case, as producers are typically the only ones who interact with their animals on a routine basis.

Producer awareness training sessions (roughly 90 minutes long) serve as a review of local emergency plans and can be leveraged to increase producers' awareness of FAD. Although producers are highly likely to notice disease symptoms in their animals, the first and most obvious symptoms of FMD are

similar to those observed for several other diseases (fever, general depression, reduced interest in feed and water). Therefore, producer sessions focus on improving producers' ability to distinguish between FMD and more benign illnesses that producers can safely treat; importantly, emphasis is also placed on encouraging producers to report suspicious conditions quickly. Estimated costs to conduct producer awareness sessions in counties across various areas around the NBAF are shown in Table 6.3.4-2. The costs for producer sessions cover trainer salaries, room rental, meals for attending producers, and materials including handouts, but do not include costs to cover travel to the training session or reimburse producers for their time. When similar courses were offered in the past few years, typically 50 producers from each county participated. The number of producers captured for the cost in the table below, therefore, is simply 50 for each county. If even part of a county was captured by a radius around the NBAF, it was counted in this analysis even if the majority of the county was outside the radius.

Radius Around NBAF	Counties	Producers	Cost
10 Kilometers	2	100	\$8,000
20 Kilometers	4	200	\$16,000
50 Kilometers	13	650	\$52,000
100 Kilometers	29	1,450	\$116,000
All of Kansas	105	5,250	\$420,000

Even though it was conservatively assumed that only 50 producers per county would be reached by each session, feedback from sessions has indicated that follow-up sessions in subsequent years would attract greater numbers of producers through word of mouth. Also, while 50 producers show up in person, attendees historically have taken home multiple copies of educational materials from the session and distributed them to neighbors.

At the producer awareness sessions, producers are given a laminated quick-reference sheet to keep in their house or barn which lists a short, bulleted list of reportable conditions that should prompt a call to a private or state veterinarian (e.g., "blisters or vesicular/ulcerated lesions on skin or mucous membranes"). This reference sheet also contains a list of important contacts including web addresses and phone numbers for local and state veterinarians. Producer awareness session costs (Table 6.3.4-2) include the cost of the laminated handouts, but an alternative to conducting training in every county would be distribution of these reference sheets through mail without in-person interaction. The cost to mail these sheets to every farm within various areas around the NBAF are shown in Table 6.3.4-3.

Table 6.3.4-3: Costs to Print and Mail Laminated Agricultural Emergency Quick-Reference Sheets to Producers Within Various Areas Around the NBAF

Radius Around NBAF	Farms	Handout Cost	Handout + Postage Cost
10 Kilometers	62	\$50	\$75
20 Kilometers	227	\$200	\$300
50 Kilometers	1,629	\$1,200	\$2,000
100 Kilometers	7,356	\$6,000	\$9,000

One example of an emergency reference distribution strategy is a telephone book advertisement; this strategy has been employed by the Wolf Creek Generating Station in the past to ensure that basic emergency plan details and contact numbers are available to households. Kansas's 105 counties are served through 40 different Yellow Pages telephone book regions. Based on recent price quotes, the estimated annual costs to place fold-out front inside cover ("gatefold") advertisements in Yellow Page phone books serving various areas around the NBAF are shown in Table 6.3.4-4.

Table 6.3.4-4: Costs to Place Emergency Reference Gatefold Inserts in Yellow Page Phone Books Serving Various Regions Around the NBAF

Radius Around NBAF	Counties Included	Phone Book Regions	Annual Cost
10 Kilometers	2	2	\$31,000
20 Kilometers	4	4	\$62,000
50 Kilometers	13	6	\$94,000
100 Kilometers	29	13	\$203,000
All of Kansas	105	40	\$624,000

Although producer awareness training can take place in the absence of a county emergency plan, SMEs advise that establishing and reviewing county plans encourages producer familiarization with important contacts and significantly increases effectiveness of awareness training. A county emergency planning session typically precedes a producer awareness session. In a county emergency planning session, 15 to 25 county stakeholders participate in an all-day process to develop a written plan for agricultural emergencies. Participants typically include emergency management coordinators, law enforcement, first responders, and local veterinarians. The goal of the planning session is to identify important contacts and to outline roles and responsibilities of different stakeholders, including producer expectations. Estimated costs to conduct emergency planning sessions in counties across various areas around the NBAF are shown in Table 6.3.4-5. These costs cover trainer salaries, room rental, and materials, but do not cover the salaries of attendees or travel costs.

Table 6.3.4-5: Costs to Conduct County-Level Emergency Planning Sessions Across Various Areas Around the NBAF

Radius Around NBAF	Counties Included	Cost
10 Kilometers	2	\$7,000
20 Kilometers	4	\$14,000
50 Kilometers	13	\$46,000
100 Kilometers	29	\$102,000
All of Kansas	105	\$368,000

Combined costs for county planning sessions and producer awareness sessions across various areas around the NBAF are shown in Table 6.3.4-6. As above, we assumed that 50 producers would attend the session per county based on historical rates.

Table 6.3.4-6: Costs to Conduct Both County Planning and Producer Awareness Sessions Across Various Areas Around the NBAF

Radius Around NBAF	Counties Included	Producers Included	Cost
10 Kilometers	2	100	\$15,000
20 Kilometers	4	200	\$30,000
50 Kilometers	13	650	\$100,000
100 Kilometers	29	1450	\$220,000
All of Kansas	105	5250	\$790,000

When considering the potential benefit of these measures, it is important to understand where an outbreak is likely to strike first. That is, the awareness campaigns should include the vast majority of possible locations that could be the site of the first infection. For most waste scenarios (except for the release event that occurs at the landfill) and all but the most catastrophic aerosol release scenarios, almost all locations affected are within 10 kilometers of the NBAF. For the transference release events, however, the initial infection can occur quite far from the NBAF. In Table 6.3.4-7, the percentage of starting locations in the transference events and their distance from the NBAF is shown. This analysis demonstrates that although an education campaign that includes only producers within 100 kilometers of the NBAF is less than half the cost of a campaign that covers all of Kansas, it is likely to miss up to a quarter of the possible starting locations due to transference events. If transference events are considered to be the main driver of risk, this shortcoming is not worth the cost savings afforded.

Table 6.3.4-7: Percentage of Initial Infections Caused by Transference Events as a Function of Distance From the NBAF

Radius Around NBAF	% of Transference Starts
0-10 Kilometers	10%
10-20 Kilometers	11%
20-50 Kilometers	22%
50-100 Kilometers	34%
>100 Kilometers	23%

6.3.5 Conclusions

These results demonstrate that investments to achieve the predicted culling capacity are critical for FMD outbreak mitigation, and that further investments to improve culling capacity would be beneficial no matter how large the outbreak is or where it begins. Investments that reduce the amount of direct and indirect contact between infected and susceptible farms after an outbreak are also beneficial in reducing the extent of outbreaks, and also reducing the probability that an outbreak would become very large.

Despite the fact that early detection of an outbreak can greatly mitigate its effects, air samplers, sentinel herds, and active surveillance are of limited value because these systems are unlikely to signal that an outbreak has (or will) occur given the releases modeled from the NBAF. However, producer education campaigns that incentivize producers to observe their animals for suspicious signs, enable them to recognize the signs of FMD as suspicious, and encourage them to call a veterinarian when the signs are first observed, could significantly reduce the impact of an outbreak. Given that an outbreak due to transference events could happen anywhere in Kansas, it is unwise to focus any informational system on just the region around the NBAF.

6.3.6 Other Sensitivity Analysis

In this section, we explore how the change of parameters that are not applicable to improved outbreak detection or control measures affects the analysis. This analysis informs how much confidence can be placed in the results as absolute reflections of the impact of an FMD outbreak given that some of the modeling parameters are based on scanty evidence. As discussed, epidemiological models are best used to understand *relative* risk and *relative* benefit of risk mitigation measures because inaccuracies in a model are reflected in the baseline and experimental cases, largely cancelling each other out.

6.3.6.1 Effect of Aerosol Dose Threshold

In the Updated SSRA, a livestock premises was considered to be the possible starting place for a location if the dose received by the animals in that premises passed a particular threshold. This threshold is not a static value, but a function of the number of animals in the premises and the animal type (which dictates the dose due to the species-specific minute-tidal volumes and the specific dose-response curve used). However, the experimental dose-response data that supports the dose-response curve are generated by doses far above the dose typically received by animals in this study, so there is significant uncertainty related to the appropriateness of these dose-response thresholds. As described in the methods section, the baseline threshold uses the probability that at least one animal in a cattle or small ruminant facility inhales at least 1 PFU (the swine threshold is based on probit analysis because the doses that have a nonzero probability of infection are greater than 1 PFU). In this section, the effect of the threshold being a factor of two greater or lesser than this amount (the probability that at least one animal inhales at least 0.5 PFU to 2 PFU) is explored. Also, the use of a threshold based on at least one animal inhaling a “minimum infectious dose” is explored to determine how a higher threshold would reduce the risk of aerosols of FMDv.

For small aerosol releases, there is a very small effect of lowering the infection threshold (Figure 6.3.6-1). For a release outside of containment (left panel), the probability of getting at least one infection from the release increases from 0.4% to 1.2%. For a release in containment when HEPA filtration is not functioning, the probability of getting at least one infection increases from 0.1% to 0.4%. The maximum number of premises simultaneously infected in both cases increases from one to two. If the threshold were lower (based on the minimum infectious dose, for example), no infections would occur from a release of this size under any meteorological condition.

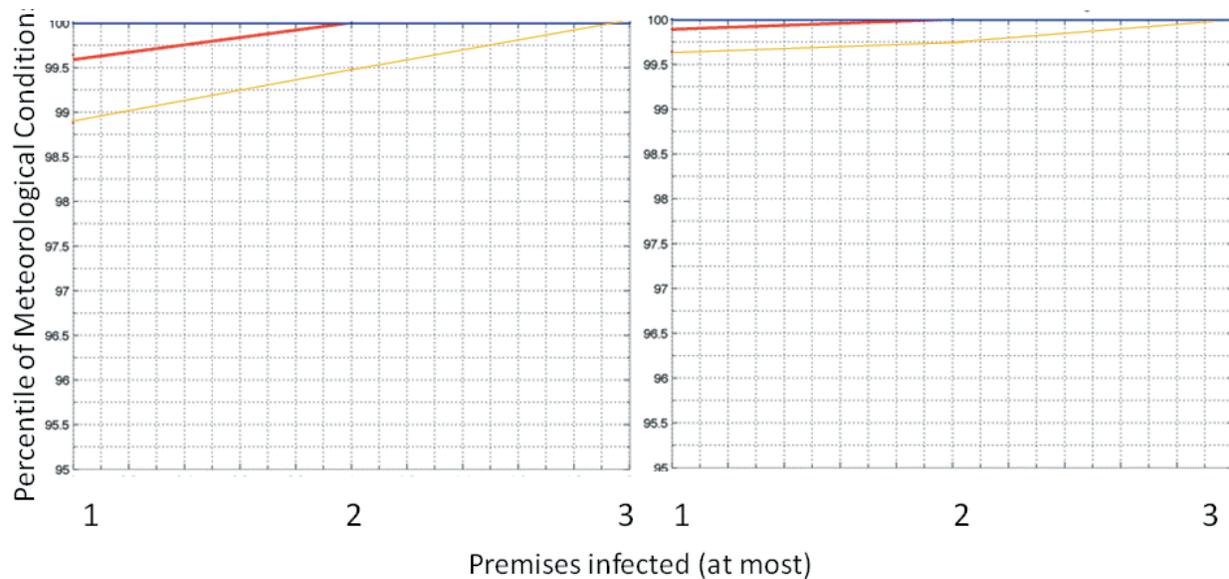


Figure 6.3.6-1: Effect of Changing the Aerosol Infection Threshold on the Number of Premises Initially Infected for a Release Outside of Containment (left) and a Release in Containment where HEPA Filtration is Not Operating (right)

The y-axis shows the percentile of meteorological conditions in which that number of premises (or fewer) are infected. The red line is the baseline threshold, the orange line shows a 2x lower threshold. The blue line that runs across the top of the graph (no infections under any meteorological condition) uses a threshold based on the minimum infectious dose for each animal.

For larger aerosol releases (such as the complete failure of the HEPA system in the BSL3 animal room), the decrease of the infection threshold also has a very small effect (Figure 6.3.6-2). Decreasing the baseline threshold by a factor of two increases the probability that an infection would occur in at least one premises from roughly 95% to 98%. For meteorological conditions that lead to the infection of multiple premises, the lower threshold increases the number of premises initially infected by about 50%. As shown in the results section, there is a correlation between the impact of the outbreak and the number of premises initially infected. However, an outbreak starting in a single important location (like a large feedlot) can have the same impact as an outbreak simultaneously starting in 10 smaller locations. Increasing the infection threshold by using the minimum infectious dose decreases the probability of at least one premises becoming infected from 95% at the baseline to roughly 60%.

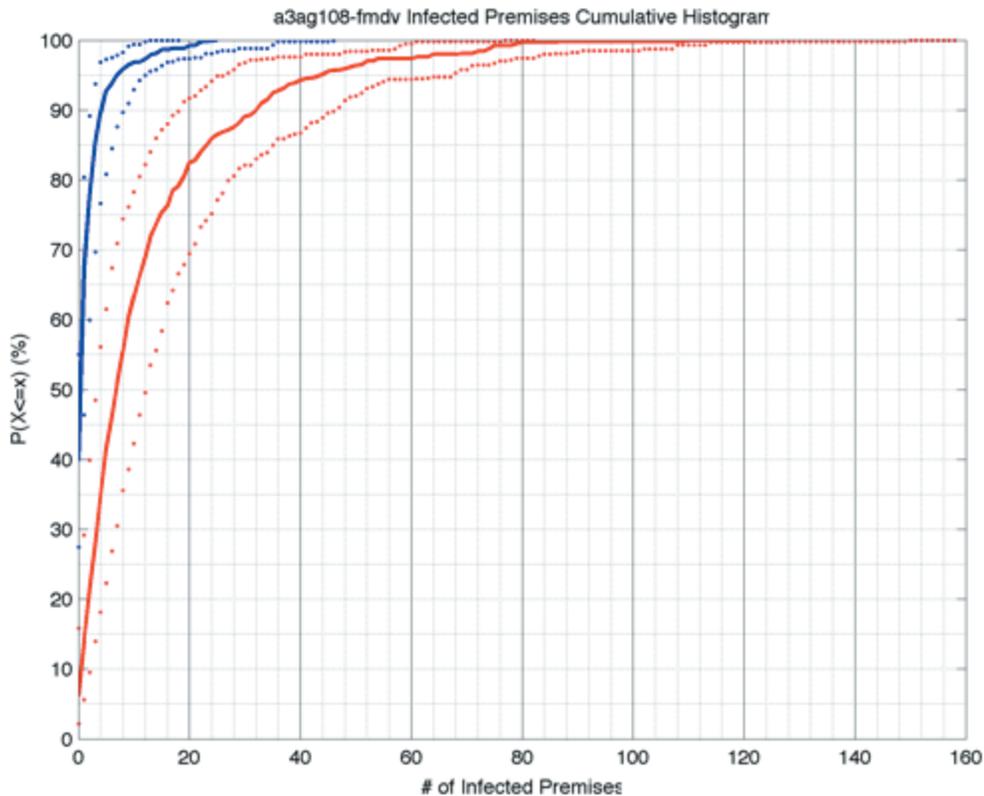


Figure 6.3.6-2: Effect of Changing the Aerosol Infection Threshold on the Number of Premises Initially Infected for a Release Due to Lack of HEPA Filtration in the BSL3 Animal Room

The y-axis shows the percentile of meteorological conditions in which that number of premises (or fewer) are infected. The red line is the baseline threshold, the blue line is based on the minimum infectious dose, and the dotted lines show thresholds two-fold greater or lesser.

Even for extremely large aerosol releases, there is a minimal effect of changing the infection threshold. Figure 6.3.6-3 shows the results for two tornado scenarios (with the release of 10^8 PFU (left panel) and 10^{10} PFU (right panel)). In the smaller release, the probability of infection of at least one premises increases from 95% to nearly 100%, whereas in the larger release, all tornados cause at least one infection. Regarding the number of initially infected premises, in a smaller release that number typically doubles if the infection threshold is halved (which, as discussed is not as consequential compared to *which* premises are infected), whereas in larger releases, the number of premises initially infected increases by only about 10%. Using the threshold based on the minimum infectious dose also does not significantly alter the picture (the probability of at least one infection only changes in the smaller release and drops from 95% to 65% in this case).

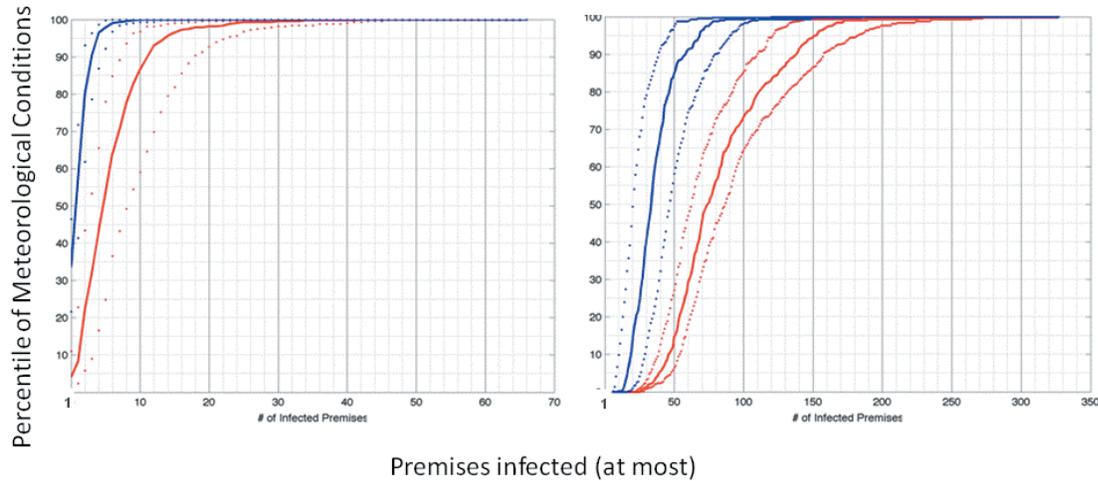


Figure 6.3.6-3: Effect of Changing the Aerosol Infection Threshold on the Number of Premises Initially Infected for a Release Due to a Tornado. (The left panel is the release of 10^8 PFU and the right panel is the release of 10^{10} PFU)

The y-axis shows the percentile of meteorological conditions in which that number of premises (or fewer) are infected. The red line is the baseline threshold, the blue line is based on the minimum infectious dose, and the dotted lines show thresholds two-fold greater or lesser.

This analysis demonstrates that the initiation of outbreaks due to aerosol releases is relatively insensitive to the threshold used, within a factor of two. The use of the lower threshold based on the chance that a herd would inhale at least 1 PFU (the baseline threshold) may overestimate the risk of FMDv aerosols if the minimum infectious dose reflects a real biological concept.

6.3.6.2 Effect of Direct Contact Rates

Although there are good primary data supporting direct contact rates for some premises types (such as the backyard premises developed in this study), the data supporting other contact rates are tenuous (such as those supporting contact rates from goat facilities). For this reason, the effects of using direct contact rates that were two-fold greater or lesser than the baseline were explored. Outbreak duration and head culled is shown as a function of the direct contact rates used in Figure 6.3.6-4. All values are given as a fold increase or decrease over the value using the baseline indirect contact rates.

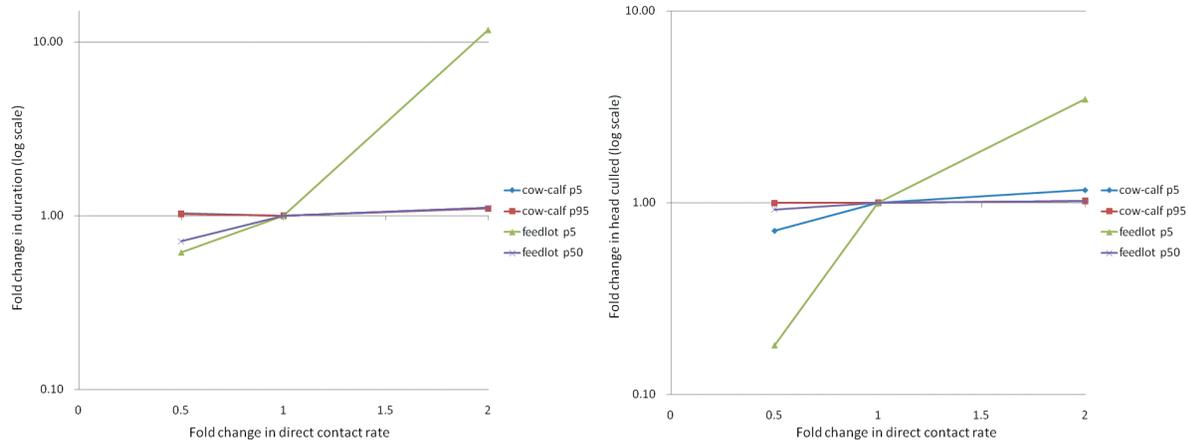


Figure 6.3.6-4: Effect of Doubling or Halving the Direct Contact Rate on Outbreak Duration (left) or Head Culled (right) Compared to Baseline

The y-axis shows the fold increase or decrease in the duration or head culled over baseline in log scale.

The effect of changing the direct contact rate for all premises types is relatively modest with few exceptions. In general, the duration or consequences change by less than 30% for a two-fold change in the direct contact rate. However, for a few premises and outputs (like the feedlot starting location and the p5 output), the extent and duration can change by ten-fold.

6.3.6.3 Effect of Indirect Contact Rates

The evidence basis for indirect contact rates is more tenuous than that supporting direct contact rates. This paucity of evidence is partially due to the variety of services that a livestock premises can receive that contribute to the indirect contact rate (veterinary services, hoof trimming, husbandry services, etc). Also, underpinning the indirect contact rates is the number of premises that would be visited in a timeframe after visiting an infected premises and the degree to which the service provider adheres to biosanitary guidelines. For this reason, the effects of using indirect contact rates that were two-fold greater or lesser than the baseline were explored. Outbreak duration and head culled is shown as a function of the indirect contact rates used in Figure 6.3.6-5. All values are given as a fold increase or decrease over the value using the baseline indirect contact rates.

As shown, the effect of changing the indirect contact rates is significant across almost all starting locations, vaccination strategies, or NAADSM outputs considered. In many cases, outbreak duration changes by more than an order of magnitude. Regarding duration, if a *reduction* in the indirect contact rate does not significantly curtail the outbreak, the *increase* in contact rates typically increases the duration significantly (and vice-versa). Generally, this effect is due to outbreaks that are already short or long before the indirect contact rate was changed, which affords less opportunity to increase or decrease the duration further. Regarding head culled, *increases* in contact rates can increase the impact for all but the smallest outbreaks (cow-calf p5) by about a factor of three, whereas *decreases* in the

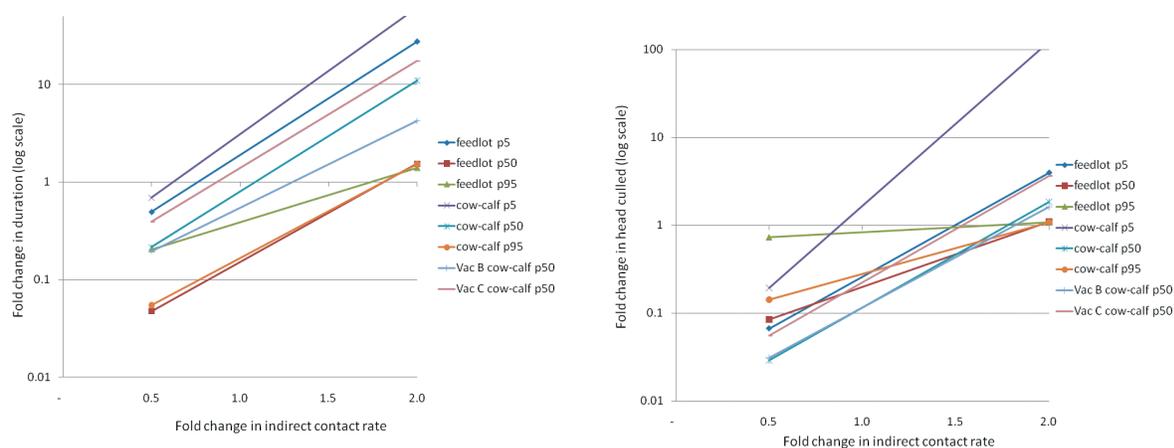


Figure 6.3.6-5: Effect of Doubling or Halving the Indirect Contact Rate on Outbreak Duration (left) or Head Culled (right) Compared to Baseline

The y-axis shows the fold increase or decrease in the duration or head culled over baseline in log scale.

indirect contact rates can decrease the impact by more than an order of magnitude. The fact that increased contact rates do not more significantly exacerbate the outbreak is probably due to the fact that large outbreaks are already limited by a lack of susceptible animals to infect.

6.3.6.4 Conclusions

These analyses demonstrate that caution should be used when using the results to predict the absolute impact and duration of an outbreak of FMD in the US. The contact rates used in NAADSM are based on limited data and the results are sensitive to small changes (a factor of two) in these values. The sensitivity of the results to these parameters demonstrates how important the collection of additional primary data is to reduce the effect of uncertainty.

That being said, uncertainties in the starting location of the outbreak and in the modeling output itself (both largely functions of aleatory, or irreducible, uncertainty) produce greater variance in possible results (outbreaks caused by release events can be as small as a few thousand animals to more than 30 million culled). This variance is caused by factors such as the meteorological conditions that prevail when a release happens, or if the infection starts in a herd owned by a producer who will call a veterinarian upon the recognition of strange signs in his animals, or the timing of an animal shipment relative to the spread of the illness. This is all to say that the range in possible results presented for the impact of an outbreak is still representative of the likely impact of the disease, even given significant uncertainty in the modeling parameters.

These analyses also demonstrate that the modeling results are best used comparatively. The relative impact of releases caused by different events can still be compared, as can the relative benefit of adopting enhanced detection or mitigation measures.

7. Economic Assessment

7.1 Objective

The Economic Assessment task evaluated producer and consumer welfare impacts to the agricultural sector resulting from unintentional releases of FMD, projected the costs and disruptions to non-agricultural activities in the epidemiologically impacted region, and assessed the costs of response — surveillance, quarantine, appraisal, euthanasia, disposal, clean-up and disinfection, vaccination, and indemnity payments — traditionally associated with risk scenarios and disease outbreaks. Significant changes to the Economic Assessment since the 2010 SSRA include 1) extending the simulation period (the updated model is simulated over 10 years as opposed to 5 years in the 2010 SSRA), 2) updating price forecasts, and 3) reporting additional consequences within each event to better reflect uncertainty. Given the first two changes described above, the consumer and producer welfare outputs reported below are improved. Results reported in this section are conditional upon a release and/or outbreak of FMD occurring, the associated epidemiological output reported in Section 6, and other assumptions documented below. The economic consequences reported in this Section are then used as inputs for Section 8, Risk Calculations.

7.2 Technical Approach

The primary modeling approach used to determine the economic effects on agricultural producers and consumers included but was not limited to the following market sectors of significance: beef, swine, dairy cattle, sheep, grain, and forages at the national levels. The general methodology relied on the use of a partial equilibrium, multi-market model of the livestock and grain sectors supplemented with a regional input-output economic model to account for regional impacts on the nonagricultural sectors [following Pendell et al., 2007]. Input-output models provide measures of short-run impacts across broad sectors of the economy. Assessment of a finer level of fidelity is facilitated with the use of partial equilibrium and/or multi-market models [Rich, Winter-Nelson, and Miller, 2005].

A partial equilibrium, multi-market, microeconomic model provided the appropriate level of fidelity to assess consequences for the 2010 SSRA and the Updated SSRA, beginning with livestock and grain production to meat processing through the supply chain and onto domestic and international customers. Changes in producer and consumer welfare presented in the report provide a comprehensive measure of the market changes for all products in the livestock and grain sectors along the entire supply chain [Just, Hueth, and Schmitz, 2004]. Assessing the grain sector is important as it provides input (i.e., feed) to the livestock sector. Information on the direct cost to the government was drawn from recent economic literature and combined with output from the epidemiological model and market data to calculate government costs. The additional impact on businesses in allied nonagricultural sectors was assessed using the Bureau of Economic Analysis' RIMSII (Regional Input Output Modeling System).

Given the wide range of potential outcomes from, and inherent uncertainty in, an FMD outbreak, economic consequences were assessed to represent a range of the distribution of outcomes provided by the epidemiological model. As in the 2010 SSRA, economic consequences are reported for the distribution of outcomes at the p5 level (meaning 5% of the epidemiological model outcomes resulted in lower epidemiological outputs, at the pp50 (median), and at the pp95 level (meaning 95% of the epidemiological model outcomes resulted in lower epidemiological outputs). In effect this provides lower, average, and upper measures of economic consequences that may arise from an FMD outbreak. To better reflect uncertainty and carry uncertainty thorough the economic model, additional consequences are reported for the p5, p50, and p95 outcomes. These outcomes are representative of uncertainty inherent in the different starting locations for infection.

7.2.1 Regional Background

The primary region of focus for the economic assessment includes Kansas, Nebraska, Oklahoma, Colorado, Missouri, Iowa, and Texas. In this region, livestock is economically important (see Table 7.2.1-1).

From 2008 USDA/NASS data, cattle and calves are the most valuable agricultural commodity in four states in the study. Nebraska, Kansas, Texas, and Colorado are ranked in the top five for cattle on feed. However, hogs are recognized as one of the top five commodities in seven of the states. Dairy is also significant percentage of state farm receipts in the region.

Additional background on the economic value of livestock sectors in the regions of interest is provided in Table 7.2.1-1. These data were taken from USDA/NASS reports and summarize the estimated gross income generated by beef cattle and swine in 2009. The final column reports the value of milk produced for the same year. In most states, income from beef cattle clearly dominates gross for swine which is second in magnitude.

Table 7.2.1 1: Regional Economic Value of Livestock Sectors			
State	Beef Cattle Gross Income	Swine Gross Income	Milk Production Value of Milk Produced
(Millions)			
Primary Region			
CO	\$ 2,624	\$137	\$364
IA	\$ 2,478	\$ 4,429	\$578
KS	\$ 5,558	\$365	\$348
MO	\$ 1,273	\$766	\$204
NE	\$ 6,250	\$652	\$161
OK	\$ 2,318	\$508	\$152
TX	\$6,957	\$131	\$1,159

Sources: <http://usda.mannlib.cornell.edu/usda/current/MeatAnimPr/MeatAnimPr-04-28-2011.pdf> and <http://usda.mannlib.cornell.edu/usda/current/MilkProdDi/MilkProdDi-04-29-2010.txt>

7.2.2 Special Considerations

7.2.2.1 Trade Bans

The OIE requires immediate notification from member countries when listed or emerging diseases [OIE, 2009] are reported. Member countries can self declare freedom of a country, zone, or compartment from an OIE listed disease. However, OIE does not recognize self declaration for Bovine Spongiform Encephalopathy (BSE), FMD, Rinderpest and Contagious Bovine Pleuropneumonia. If a notification is made for a particular disease, immediate international and domestic trade restrictions are likely for specific species and their products.

FMD

The U.S. has been an FMD-free country since 1929.

FMD is an OIE listed and notifiable disease. Agricultural sectors with high probability of immediate international trade restrictions after notification include cattle, swine, sheep, and goats. Chapter 8.5 of the OIE Terrestrial Animal Health Code provides protocol for FMD.

Article 8.5.8 outlines the guidelines for Recovery of Free Status:

When an FMD outbreak or FMD infection occurs in an FMD free country or zone where vaccination is not practiced, one of the following waiting periods is required to regain the status of FMD free country or zone where vaccination is not practiced: a) 3 months after the last case where a stamping-out policy and serological surveillance are applied in accordance with Articles 8.5.40. to 8.5.46.; or b) 3 months after the slaughter of all vaccinated animals where a stamping-out policy, emergency vaccination and serological surveillance are applied in accordance with Articles 8.5.40. to 8.5.46.; or c) 6 months after the last case or the last vaccination (according to the event that occurs the latest), where a stamping-out policy, emergency vaccination not followed by the slaughtering of all vaccinated animals, and serological surveillance are applied in accordance with Articles 8.5.40. to 8.5.46., provided that a serological survey based on the detection of antibodies to nonstructural proteins of FMD demonstrates the absence of infection in the remaining vaccinated population. Where a stamping-out policy is not practiced, the above waiting periods do not apply, and Article 8.5.2. or 8.5.4. applies.

7.2.2.2 Effective Trade Bans

In addition to trade bans specified by national and international standards, an important consideration is an effective trade ban. Effective trade bans reflect the changes in commerce (e.g., consumer behavior) that can augment the impacts of actual trade bans or cause significant economic disruption in the absence of any officially mandated ban. Effective trade bans can be persistent over long periods of time. For example, while many countries have lifted trade bans on U.S. beef products, until recently Japan imposed trade restrictions on U.S. beef imports due to the three BSE cases in the U.S. from 2003 to 2006.

7.3 Methods

7.3.1 Partial Equilibrium Model for the Agricultural Sector

The current study utilized an updated version of the Paarlberg, Seitzinger, Lee, and Mathews' partial equilibrium model [Paarlberg, 2008] to assess the economic impacts of the livestock and grain sectors. Although other economic models for disease outbreaks exist for the U.S. [Pendell et al., 2007; Zhao et al., 2006], the Paarlberg [2008] model is the most comprehensive economic model available to complete the analysis for the Updated SSRA. Similar to Rich and Winter-Nelson [2007], who assessed FMD outbreaks in South America, it incorporates both spatial and temporal dimensions - as well as farm and trade policy information - necessary to appropriately model impacts of disease outbreaks in livestock. Major updates of the Paarlberg, Seitzinger, Lee, and Mathews model since the 2010 SSRA include 1) extending the simulation period (the updated model is simulated over 10 years as opposed to 5 years in the 2010 SSRA) and 2) updating price forecasts. Given these changes, the reported changes in consumer and producer welfare given below are improved.

The modeling framework integrated the North American Animal Disease-Spread Model (NAADSM) epidemiological model results (i.e., supply shocks) as input into the economic components to estimate the economic impacts of outbreaks of FMD. It assessed the effects of a disease outbreak on major agricultural sectors—livestock and crops—along vertical market chains, for agricultural inputs (wheat, coarse grains, rice, soybeans, soybean meal, soybean oil, forage and pasture), production (cattle, hogs, poultry, lamb and sheep, dairy, and eggs), processing (beef and cattle, pork and hogs, lamb and sheep, poultry and birds), and consumption (beef, pork, poultry, lamb and sheep, dairy, eggs, rice, coarse grains, wheat, soybean oil); and it projected the impacts of the disease outbreak over 40 calendar quarters. Of particular importance to the 2010 SSRA and Updated SSRA, this model allowed the opportunity to assess impacts of FMD supply shocks on the beef cattle, dairy cattle, swine, and grains sectors for domestic and international markets, as well as the feed sector. It also allowed for the flexibility to include domestic consumer shocks and adjustment of the duration and magnitude of trade bans specific to a species of livestock or crop. Complete documentation of the model is provided in Paarlberg et al. [Paarlberg, 2008].

A brief overview of the data, parameters, and inputs (e.g., supply, demand, and trade shocks) used to implement the model is provided below.

7.3.1.1 Data

This section contains a summary of the data used in the model taken from Paarlberg [2008]. Quarterly supply, use, and price data were primarily sourced from the Livestock Marketing Information Center (LMIC). However, the LMIC database does not include data for some crops and trade. Quarterly supply, use, and price data for coarse grains, wheat, and rice came from situation reports prepared by the Economic Research Service of the U.S. Department of Agriculture (USDA/ERS, Outlook series). Quarterly supply and use tables for the soybean complex prepared by ERS cover the later years. Forage prices are from the LMIC database. Total quarterly use was generated by feed balance equations from which data

on animal numbers were combined with standard feeding practices to produce quarterly amounts of forage and pasture. Production of hay, corn silage, and sorghum silage was reported by the National Agricultural Statistics Service, U.S. Department of Agriculture. Uncut grazed pasture was imputed for quarters 2 and 3. Trade data were derived from LMIC and ERS reports, as well as the U.S. Customs through the Foreign Agricultural Service, U.S. Department of Agriculture. Policy information affecting the crop components of the model came from various sources; including Provisions of the Federal Agriculture Improvement and Reform Act of 1996 [Nelson & Schertz, 1996] and the 2002 Farm Act [Westcott et al., 2002].

7.3.1.2 Parameters

Model parameters included livestock-feed balance information, revenue and factor shares, and elasticities. The livestock-feed balance information, revenue shares, and factor shares were retained as defined in the Paarlberg et al. [Paarlberg, 2008]. The retail elasticity values (provided in Table 7.3.1-1) for final meat demand for beef, pork, and poultry [Tonsor, Mintert, and Schroeder, 2010], lamb, [Shiftlett et al., 2007] and milk [Zheng and Kaiser, 2008] were updated for this study. Substitution elasticities for derived demand and trade elasticities remained unchanged.

Table 7.3.1-1: Retail Demand Elasticities for Agricultural Commodities

Retail Elasticities	Beef	Pork	Poultry	Lamb	CGrain	Wheat	Rice	Milk	Soyoil	Eggs
Beef	-0.4219	0.0295	-0.1100	0.789	0	0	0	0	0	0
Pork	0.0151	-0.7397	0.0131	0	0	0	0	0	0	0
Poultry	-0.0414	0.0082	-0.0985	0.263	0	0	0	0	0	0
Lamb	0.789	0	0.263	-1.052	0	0	0	0	0	0
CGrain	0	0	0	0	-0.3	0	0	0	0	0
Wheat	0	0	0	0	0	-0.309	0.036	0	0	0
Rice	0	0	0	0	0	0.229	-0.328	0	0	0
Milk	0	0	0	0	0	0	0	-0.301	0	0
Soyoil	0	0	0	0	0	0	0	0	-0.314	0
Eggs	0	0	0	0	0	0	0	0	0	-0.1103

Price Expectations

The model required an assumption about livestock grower expectations regarding prices and future returns. In this study, producer decisions regarding livestock production were adjusted, to the outbreak, by equating expected future returns to current returns for livestock (i.e., naïve expectations) [Paarlberg et al., 2009]. Naïve price expectations were assumed for all scenarios.

7.3.1.3 Economic Shocks

An FMD outbreak will result in supply shocks (resulting from culling of animals and movement restrictions), international demand shocks (resulting from trade bans or restrictions), and domestic demand shocks (resulting from adverse reaction from consumers to the outbreak). The supply shocks (i.e., the number of depopulated animals) were derived from the epidemiological disease spread models for FMD and were integrated into the quarterly economic model as percent changes in quantity. Economic impacts for the agricultural sector were determined by summing the quarterly impacts to

producer and consumers to determine the economic impacts of the FMD outbreaks. The model solved for the percent changes in the endogenous variables (prices and quantities) for each quarter and each agricultural sector. The percent changes were applied to a baseline defined by the observed data for the first quarter of 2009 through the fourth quarter of 2018. Thus, actual market price and quantity movements during the period were reflected in the baseline.

Supply Shocks

In particular, the data from NAADSM were used to calculate the expected number of animals for each scenario. The production types used in NAADSM were adjusted to allow for use in the partial equilibrium economic model. Table 7.3.1-2 lists the animal population by production type across each state. Additional information used was the number of herds by production type across each state (Table 7.3.1-3). The production types required by the partial equilibrium economic model are beef cattle, dairy, slaughter cattle, swine and sheep. The production types in Table 7.3.1-2 and Table 7.3.1-3 were adjusted as follows: Cow-Calf + Beef (backyard) = beef cattle; Dairy = dairy; Feedlot (small) + Feedlot (large) = beef slaughter; Swine (small) + Swine (large) + Swine (backyard); Goats + Sheep + Small ruminants (backyard) = sheep.

Table 7.3.1-2: Number of Animals in Impacted Region

	CO	IA	MO	NE	OK	TX	KS
Cattle Population							
Cow-calf	786,095	1,646,253	3,747,572	3,448,357	2,612,850	9,429,452	3,772,864
Dairy	192,636	360,452	24,517	48,016	117,545	1,288,896	345,191
Feedlot (small)	544,576	1,788,490	61,917	284,722	1,158,614	65,935	952,305
Feedlot (large)	106,250	25,608	21,501	1,659,594	1,306,828	4,984,694	3,360,890
Beef (backyard)	32,228	26,780	63,691	15,808	68,043	309,223	27,154
Swine Population							
Swine (small)	219	174,397	98,442	68,500	18,318	30,218	47,308
Swine (large)	48,234	24,387,168	3,073,406	2,211,421	2,307,588	2,291,419	168,480
Swine (backyard)	4,681	3,072	7,968	451,879	11,321	16,078	2,915
Small Ruminant Population							
Goats	41,271	50,461	90,986	32,665	115,689	1,098,525	47,320
Sheep	500,046	203,745	74,573	74,445	71,007	1,037,594	103,815
Small ruminants (backyard)	11,019	9,250	13,519	3,954	14,100	55,921	5,500
Total	2,267,255	28,675,676	7,278,092	8,299,361	7,801,903	20,607,955	8,833,742

Table 7.3.1-3: Number of Herds in Impacted Region

	CO	IA	MO	NE	OK	TX	KS
Cattle Facilities							
Cow calf	6,433	16,047	45,030	15,849	32,506	104,819	22,977
Dairy	392	2,391	13	483	970	255	1,061
Feedlot (small)	2,405	6,561	896	1,718	8,039	410	2,485
Feedlot (large)	168	7	4	287	912	198	221
Beef (backyard)	4,151	3,870	8,433	1,999	9,765	40,603	3,723
Swine Facilities							
Swine (small)	11,571	1,390	954	587	353	440	529
Swine (large)	19	8,658	749	1,379	234	57	722
Swine (backyard)	898	526	1,420	310	2,219	3,974	526
Small Ruminant Facilities							
Goats	1,532	1,451	3,202	781	4,152	19,832	1,377
Sheep	834	2,794	1,506	974	1,080	5,564	766
Small ruminants (backyard)	1,891	1,526	2,261	636	2,405	9,585	969
Total	30,294	45,221	64,468	25,003	62,635	185,737	35,356

Tables 7.3.1-4 and 7.3.1-5 report the average number of animals and herds culled by event, respectively. Tables 7.3.1-6 and 7.3.1-7 report the average number of animals and herds that were vaccinated by event, respectively. Numbers are reported at the p5, p50, and p95 epidemiological output levels across p5, p50, and p95 location quartiles. In all FMD outbreaks, emergency vaccination was assumed, which is discussed in more detail in the outcomes section below. In the economic modeling, two emergency vaccinations scenarios are assumed: vaccinate-to-kill and vaccinate-to-live. For releases <180 days (corresponding to small to medium size releases), the vaccinate-to-kill scenario was assumed where all vaccinated animals were assumed to be culled. For large releases (corresponding to >180 days), vaccinated cattle were assumed to remain in the cattle inventory. Depending on the scenario (vaccinate-to-kill or vaccinate-to-live), the average numbers of animals culled and/or animals vaccinated reported below were used in calculating the supply shock. Additionally, the average number of animals culled, herds culled, animals vaccinated, and herds vaccinated were used in estimating the governmental costs, which are discussed in the Government Costs section.

The events modeled in this section of the Updated SSRA include: Liquid A, Liquid B, Liquid C, Liquid D, Non Containment Aerosol (OA), Solid Waste Transfer Station, Solid Waste Landfill, Transference, Tornado Medium, Tornado High, and Earthquake High. Only one aerosol event (Non Containment Aerosol (OA)) is reported throughout Section 7 because the probability of a complete HEPA failure in any of the rooms is less than 1×10^{-30} . Thus, an infection due to a complete HEPA failure from a room within containment (given the fully redundant in-series HEPA filtration caisson designed for the NBAF) is

considered to be a non-credible event. For more discussion on the events modeled in this section, see Sections 4, 5 and 6.

Uncertainty due to starting location is explored more rigorously in the Updated SSRA (see Section 6 for more discussion). For each release event (e.g., Liquid A, Liquid B, etc.), all plausible operations (e.g., cow-calf operations, dairy operations, etc.) were modeled as if each operation housed the index case. NAADSM provided distributions of outcomes (i.e., for number of animals and herds culled, number of animals and herds vaccinated, and duration) for each index case. The median output (p50) from NAADSM for each index case was then ranked by the severity of the outbreak (animals culled) to generate distributions of output (e.g., a distribution representing the number of animals culled). From that process, the p5, p50, and p95 epidemiological outputs (i.e., number of animals and herds culled, number of animals and herds vaccinated, and duration) were reported and used in the economic modeling. As an example, consider the p5/p5 Liquid A event. The 1st p5 represents the p5 outcome in the distribution of culled animals, which was in fact the p50 outcome of a NAADSM distribution for a specific location. The 2nd p5 value refers to the p5 value of the distribution from the NAADSM specific run for a location.

Table 7.3.1-4: Average Number of Animals Culled by Event

Event	Output/Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Liquid A	p5/p5	0	0	0	0	420
	p5/p50	Same as p5/p5				
	p5/p95	325	0	0	0	368
	p50/p5	281,165	2,987	4,990	34,438	778
	p50/p50	1,407,022	46,711	61,234	1,877,824	10,019
	p50/p95	5,016,130	104,194	378,189	5,671,386	117,671
	p95/p5	3,531,717	0	0	2,611,594	0
	p95/p50	10,325,521	200,151	586,754	8,635,918	65,032
	p95/p95	11,237,180	274,031	1,036,983	14,165,009	72,064
Liquid B	p5/p5	No animals are culled				
	p5/p50	No animals are culled				
	p5/p95	21,640	25	0	0	0
	p50/p5	1,093,786	5,667	6,507	105,646	608
	p50/p50	2,707,326	53,592	81,606	2,012,587	12,884
	p50/p95	5,864,177	140,795	399,528	6,376,951	119,768
	p95/p5	3,548,413	0	0	2,504,141	0
	p95/p50	10,333,905	276,457	807,009	14,758,579	73,298
	p95/p95	12,324,616	338,167	1,175,595	13,440,254	72,937
Liquid C	p5/p5	1,829,839	13,364	7,943	326,985	1,124
	p5/p50	1,959,298	14,402	8,533	343,449	1,404
	p5/p95	2,348,555	23,932	34,666	427,103	6,964
	p50/p5	3,398,057	0	0	2,704,690	-
	p50/p50	5,743,865	48,144	61,455	4,576,511	9,932
	p50/p95	10,021,556	135,128	480,488	11,288,636	119,160

Table 7.3.1-4: Average Number of Animals Culled by Event

Event	Output/Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
	p95/p5	10,885,503	331,760	662,427	12,857,564	117,029
	p95/p50	10,178,781	400,735	717,828	12,975,372	79,092
	p95/p95	12,204,497	515,729	1,065,325	12,763,388	78,731
Liquid D	p5/p5	37,360	175	549	0	0
	p5/p50	Same p5/p5				
	p5/p95	Same p5/p5				
	p50/p5	3,493,968	0	0	2,312,375	0
	p50/p50	5,643,774	48,144	339,799	6,166,558	9,930
	p50/p95	9,839,354	211,945	656,095	10,314,686	116,893
	p95/p5	9,909,678	148,286	471,819	11,788,616	113,209
	p95/p50	10,477,046	223,173	562,915	13,857,934	73,298
	p95/p95	12,502,762	338,167	910,412	13,645,950	72,937
	Non Containment Aerosol (OA)	p5/p5	13,665	0	88	0
p5/p50		44,905	1,038	678	16,463	4,511
p5/p95		767,388	10,305	29,982	162,219	1,042
p50/p5		537,320	3,789	1,452	53,757	435
p50/p50		2,998,536	52,026	63,523	3,856,818	10,418
p50/p95		7,943,054	289,095	552,631	10,131,995	66,806
p95/p5		11,035,317	154,198	758,512	13,547,509	111,235
p95/p50		10,357,307	276,457	837,208	14,633,068	73,298
p95/p95		12,354,311	338,167	1,161,410	13,453,333	72,937
Solid Waste Transfer Station	p5/p5	No animals are culled				
	p5/p50	No animals are culled				
	p5/p95	No animals are culled				
	p50/p5	0	0	0	0	57
	p50/p50	Same as SolNear p50/p5				
	p50/p95	Same as SolNear p50/p5				
	p95/p5	919,930	2,529	24,087	34,670	170
	p95/p50	1,331,756	82,912	107,000	6,514,340	9,930
p95/p95	6,709,688	240,757	724,320	7,407,941	13,144	
Solid Waste Landfill	p5/p5	0	0	0	79	0
	p5/p50	Same as p5/p5				
	p5/p95	Same as p5/p5				
	p50/p5	112,393	584	509	4,705	0
	p50/p50	Same as p50/p5				
	p50/p95	Same as p50/p5				
	p95/p5	3,448,426	0	0	2,451,985	0
	p95/p50	8,981,519	219,310	796,615	11,284,442	73,223
	p95/p95	12,325,686	287,617	1,184,355	12,165,037	72,937
Transference	p5/p5	207,849	793	224	10,252	5
	p5/p50	283,757	838	224	11,910	5
	p5/p95	811,038	13,413	14,663	89,342	5,798

Table 7.3.1-4: Average Number of Animals Culled by Event

Event	Output/Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
	p50/p5	3,417,986	0	0	2,596,428	0
	p50/p50	3,417,986	0	0	2,596,428	0
	p50/p95	4,322,953	60,553	158,820	2,207,841	10,731
	p95/p5	10,013,500	101,207	420,751	10,640,659	116,893
	p95/p50	11,082,943	154,198	675,692	13,799,764	111,235
	p95/p95	10,391,913	223,173	763,259	13,784,818	73,298
Tornado Medium	p5/p5	100	0	0	0	0
	p5/p50	162,482	6,841	824	6,315	58
	p5/p95	434,185	12,417	3,152	46,349	88
	p50/p5	67,685	1,076	233	218	6
	p50/p50	385,273	8,925	1,464	52,160	231
	p50/p95	2,284,809	16,100	71,254	2,312,449	718
	p95/p5	540,627	892	298	71,473	91
	p95/p50	3,516,750	9,860	259,998	2,038,729	0
Tornado High	p95/p95	4,079,713	206,022	142,676	5,607,018	13,765
	p5/p5	3,421,445	0	0	2,547,784	0
	p5/p50	3,401,560	1,038	590	2,852,239	143
	p5/p95	3,797,229	6,240	10,249	2,905,886	5,719
	p50/p5	3,379,717	0	0	2,759,748	0
	p50/p50	3,755,606	147	504	2,599,759	0
	p50/p95	8,512,799	101,207	375,891	8,396,696	116,893
	p95/p5	3,582,124	1,158	0	2,416,037	0
	p95/p50	4,217,057	80,383	82,913	9,253,821	9,760
Earthquake High	p95/p95	9,574,132	238,228	713,783	10,055,838	12,974
	p5/p5	100	0	0	0	0
	p5/p50	163,992	2,098	1,663	9,871	402
	p5/p95	3,532,616	4,443	7,966	2,370,853	5,584
	p50/p5	56,015	416	371	25	400
	p50/p50	555,397	5,497	2,242	139,437	260
	p50/p95	4,887,743	57,520	227,186	6,484,685	12,416
	p95/p5	500,798	39	2,362	179,010	84
	p95/p50	3,145,183	2,250	99,488	1,893,028	620
p95/p95	9,414,254	238,228	956,821	9,923,546	12,974	

Table 7.3.1-5: Average Number of Herds Culled by Event

Event	Output/ Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Liquid A	p5/p5	0	0	0	0	4
	p5/p50	Same as p5/p5				
	p5/p95	2	0	0	0	2
	p50/p5	53	21	18	14	14
	p50/p50	482	397	254	642	251
	p50/p95	1,395	1,099	558	2,380	773
	p95/p5	672	0	0	775	0
	p95/p50	2,508	2,358	354	2,995	530
	p95/p95	4,831	2,831	1,011	4,818	602
Liquid B	p5/p5	No animals are culled				
	p5/p50	No animals are culled				
	p5/p95	3	1	0	0	0
	p50/p5	149	58	33	43	23
	p50/p50	653	448	298	700	293
	p50/p95	1,685	1,554	583	2,596	952
	p95/p5	802	0	0	673	0
	p95/p50	4,350	3,140	1,428	4,942	852
	p95/p95	4,885	3,238	1,589	4,001	611
Liquid C	p5/p5	240	96	67	96	59
	p5/p50	266	108	71	103	68
	p5/p95	401	179	104	157	95
	p50/p5	314	0	0	817	0
	p50/p50	1,569	395	266	1,457	260
	p50/p95	4,835	1,496	736	3,812	929
	p95/p5	3,606	2,181	1,172	4,002	1,034
	p95/p50	3,836	3,089	1,298	4,265	1,160
	p95/p95	4,473	3,789	1,396	3,688	919
Liquid D	p5/p5	8	1	2	0	0
	p5/p50	Same p5/p5				
	p5/p95	Same p5/p5				
	p50/p5	507	0	0	576	0
	p50/p50	1,336	395	668	2,538	259
	p50/p95	4,221	1,374	1,022	3,405	759
	p95/p5	3,019	1,588	569	4,204	865
	p95/p50	4,558	2,538	1,026	4,717	852
	p95/p95	5,195	3,238	1,124	4,140	611
Non Containment Aerosol (OA)	p5/p5	4	0	2	0	3
	p5/p50	23	12	6	6	10
	p5/p95	174	91	74	93	75
	p50/p5	97	29	14	25	9
	p50/p50	666	425	285	1,969	273
	p50/p95	3,687	1,373	854	3,282	516

Table 7.3.1-5: Average Number of Herds Culled by Event

Event	Output/ Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Solid Waste Transfer Station	p95/p5	3,975	1,630	1,398	4,333	726
	p95/p50	4,318	3,140	1,536	4,874	852
	p95/p95	4,842	3,238	1,622	4,019	611
	p5/p5	No animals are culled				
	p5/p50	No animals are culled				
	p5/p95	No animals are culled				
	p50/p5	0	0	0	0	2
	p50/p50	Same as p50/p5				
	p50/p95	Same as p50/p5				
p95/p5	98	12	9	16	9	
p95/p50	947	744	420	3,202	387	
p95/p95	1,888	2,347	540	2,563	394	
Solid Waste Landfill	p5/p5	0	0	0	1	0
	p5/p50	Same as p5/p5				
	p5/p95	Same as p5/p5				
	p50/p5	23	7	4	8	0
	p50/p50	28	8	4	8	0
	p50/p95	507	177	177	1,631	243
	p95/p5	436	0	0	667	0
	p95/p50	2,488	2,501	1,157	4,164	848
	p95/p95	4,668	2,749	1,636	3,645	611
Transference	p5/p5	27	3	3	4	1
	p5/p50	45	4	3	5	1
	p5/p95	200	57	45	66	32
	p50/p5	355	0	0	748	0
	p50/p50	801	481	329	731	314
	p50/p95	4,706	1,078	604	3,658	759
	p95/p5	4,080	1,630	1,137	4,469	726
	p95/p50	4,366	2,538	1,258	4,689	852
	p95/p95	5,003	3,238	1,356	4,112	611
Tornado Medium	p5/p5	1	0	0	0	0
	p5/p50	49	8	5	8	7
	p5/p95	100	26	20	34	13
	p50/p5	15	6	3	2	1
	p50/p50	80	17	17	24	13
	p50/p95	254	83	62	1,638	39
	p95/p5	78	11	4	12	10
	p95/p50	642	17	375	485	-
	p95/p95	1,643	692	448	2,212	412

Table 7.3.1-5: Average Number of Herds Culled by Event

Event	Output/ Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Tornado High	p5/p5	378	0	0	781	0
	p5/p50	267	12	4	917	7
	p5/p95	374	39	31	958	21
	p50/p5	285	0	0	874	0
	p50/p50	1,098	2	2	789	0
	p50/p95	2,693	1,078	554	3,240	759
	p95/p5	795	2	0	722	0
	p95/p50	2,191	732	411	4,083	378
	p95/p95	3,106	2,335	598	3,403	385
Earth quake High	p5/p5	1	0	0	0	0
	p5/p50	39	12	11	10	7
	p5/p95	587	21	14	608	13
	p50/p5	12	1	3	1	6
	p50/p50	100	51	22	52	19
	p50/p95	1,862	451	568	2,986	291
	p95/p5	21	1	2	2	2
	p95/p50	402	17	16	1,331	9
	p95/p95	2,854	2,335	991	3,262	385

Table 7.3.1-6: Average Number of Animals Vaccinated by Event

Event	Output/Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Liquid A	p5/p5	9,715	19,755	1,366	39,670	353
	p5/p50	Same as p5/p5				
	p5/p95	1,413	6,744	527	2,144	77
	p50/p5	250,581	230,995	34,791	243,504	9,445
	p50/p50	2,170,147	1,857,445	430,031	21,125,076	271,355
	p50/p95	3,413,318	7,958,069	874,911	24,485,887	1,055,746
	p95/p5	806,896	3,242,510	70,142	807,516	143,412
	p95/p50	6,160,027	17,726,317	1,389,259	16,711,992	1,628,937
	p95/p95	7,397,719	21,232,129	1,503,064	28,048,690	2,135,396
Liquid B	p5/p5	No animals are culled				
	p5/p50	No animals are culled				
	p5/p95	1,513	6,642	525	1,944	445
	p50/p5	558,237	572,587	30,573	701,383	32,083
	p50/p50	2,674,860	2,468,126	504,503	21,585,087	310,240
	p50/p95	3,830,901	10,242,637	877,355	26,840,569	1,166,088
	p95/p5	919,314	3,224,388	139,881	801,670	145,166
	p95/p50	8,682,751	20,620,026	1,714,854	29,677,167	1,936,414

Table 7.3.1-6: Average Number of Animals Vaccinated by Event

Event	Output/Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Liquid C	p95/p95	7,911,697	21,792,460	1,650,836	31,526,353	2,148,883
	p5/p5	718,399	1,110,880	55,361	798,098	54,190
	p5/p50	1,026,275	1,239,544	102,055	1,529,460	62,912
	p5/p95	1,346,620	1,766,203	114,639	3,467,722	98,120
	p50/p5	596,762	2,589,713	45,196	478,265	110,315
	p50/p50	3,305,075	6,016,542	544,996	21,609,580	472,858
	p50/p95	5,436,058	17,234,084	998,463	26,998,213	1,552,662
	p95/p5	7,242,609	13,215,181	1,445,698	30,993,191	1,470,616
	p95/p50	8,230,482	15,891,991	1,732,547	27,864,582	1,724,521
	p95/p95	7,859,740	19,624,102	1,701,731	31,770,895	2,056,375
Liquid D	p5/p5	25,517	41,701	564	12,354	1,725
	p5/p50	Same p5/p5				
	p5/p95	Same p5/p5				
	p50/p5	626,036	2,510,603	72,836	799,457	101,413
	p50/p50	3,502,292	8,736,740	602,201	22,947,146	531,521
	p50/p95	5,377,071	15,013,031	1,031,659	25,614,427	1,420,816
	p95/p5	5,786,866	14,336,317	1,223,407	29,601,103	1,443,185
	p95/p50	8,145,342	17,843,514	1,576,792	27,254,970	1,809,123
	p95/p95	7,774,600	21,575,625	1,545,976	31,161,283	2,140,977
	Non Containment Aerosol (OA)	p5/p5	5,048	30,848	1,104	3,672
p5/p50		115,651	134,906	25,423	731,283	9,009
p5/p95		465,865	1,235,676	53,852	921,923	64,157
p50/p5		177,582	364,830	16,911	451,631	24,521
p50/p50		2,960,231	5,099,550	515,408	22,353,735	411,781
p50/p95		4,941,577	14,733,683	875,965	25,788,110	1,148,413
p95/p5		7,288,962	15,182,268	1,359,066	30,865,915	1,552,347
p95/p50		8,317,797	20,559,373	1,650,610	29,879,112	1,923,440
p95/p95		7,906,093	21,591,189	1,615,099	31,643,619	2,138,106
Solid Waste Transfer Station	p5/p5	No animals are culled				
	p5/p50	No animals are culled				
	p5/p95	No animals are culled				
	p50/p5	2,349	13,369	1,013	9,029	842
	p50/p50	Same as p50/p5				
	p50/p95	Same as p50/p5				
	p95/p5	434,626	293,225	17,287	260,048	21,942
	p95/p50	2,500,414	4,798,143	363,934	24,759,996	379,225
	p95/p95	4,692,520	11,346,626	1,232,826	26,423,089	1,304,613

Table 7.3.1-6: Average Number of Animals Vaccinated by Event

Table 7.3.1-6: Average Number of Animals Vaccinated by Event						
Event	Output/Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Solid Waste Landfill	p5/p5	1,602	4,544	144	965	207
	p5/p50	Same as p5/p5				
	p5/p95	Same as p5/p5				
	p50/p5	24,376	72,114	7,752	72,221	4,896
	p50/p50	63,239	83,918	7,937	203,389	6,392
	p50/p95	803,578	3,144,337	164,638	990,925	401,298
	p95/p5	482,878	2,029,165	56,193	747,991	87,367
	p95/p50	6,412,917	15,198,101	1,539,292	25,933,785	1,581,391
	p95/p95	7,630,600	18,792,848	1,573,471	29,132,876	1,986,083
Transference	p5/p5	24,472	33,938	1,289	21,058	4,156
	p5/p50	141,976	86,811	3,089	150,330	6,392
	p5/p95	744,111	662,275	70,573	2,443,715	50,374
	p50/p5	692,486	2,573,193	48,822	568,146	110,748
	p50/p50	3,452,187	3,080,166	559,902	22,002,431	335,381
	p50/p95	5,494,909	15,502,989	1,033,836	25,232,099	1,425,357
	p95/p5	7,026,349	15,253,943	1,298,846	30,119,740	1,546,958
	p95/p50	8,236,661	18,135,449	1,599,610	27,766,499	1,806,057
	p95/p95	7,865,919	21,867,560	1,568,794	31,672,812	2,137,911
Tornado Medium	p5/p5	1,413	6,744	527	2,144	445
	p5/p50	107,167	159,402	3,139	64,254	13,685
	p5/p95	160,128	360,948	21,940	447,817	18,649
	p50/p5	19,191	68,994	2,173	62,493	2,134
	p50/p50	248,092	314,456	14,575	369,864	10,239
	p50/p95	913,385	3,653,868	88,232	1,599,140	133,543
	p95/p5	206,368	291,284	14,770	384,252	15,943
	p95/p50	1,057,129	3,355,533	119,643	1,277,361	130,273
	p95/p95	3,392,730	5,633,262	503,143	27,090,641	396,274
Tornado High	p5/p5	581,040	2,563,305	50,015	826,824	109,144
	p5/p50	672,299	2,817,234	66,321	1,137,185	112,406
	p5/p95	1,118,966	3,164,052	96,510	2,704,629	140,056
	p50/p5	753,106	2,772,602	70,235	538,916	98,617
	p50/p50	912,234	4,253,702	73,533	961,011	166,595
	p50/p95	4,317,099	12,922,165	935,192	24,917,275	1,246,109
	p95/p5	866,156	3,418,977	73,107	1,137,993	142,008
	p95/p50	3,029,146	9,656,230	401,631	25,220,883	569,723
	p95/p95	5,261,933	16,096,332	1,278,449	26,985,036	1,476,384

Table 7.3.1-6: Average Number of Animals Vaccinated by Event

Event	Output/Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Earthquake High	p5/p5	1,413	6,744	527	2,144	445
	p5/p50	70,458	166,092	6,665	149,079	7,304
	p5/p95	968,400	2,563,836	117,759	2,592,842	127,589
	p50/p5	26,048	38,913	2,146	6,273	3,457
	p50/p50	166,300	361,080	20,233	378,045	27,925
	p50/p95	2,900,707	9,604,415	436,668	24,480,645	561,954
	p95/p5	248,809	24,849	32,276	496,211	729
	p95/p50	1,187,166	3,632,630	100,180	2,298,256	126,464
	p95/p95	5,683,675	15,992,548	1,353,455	27,425,919	1,484,720

Table 7.3.1-7: Average Number of Herds Vaccinated by Event

Event	Output/ Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Liquid A	p5/p5	16	105	5	36	13
	p5/p50	Same as p5/p5				
	p5/p95	3	46	3	7	6
	p50/p5	242	2,062	90	207	228
	p50/p50	5,760	21,837	2,127	9,026	5,856
	p50/p95	8,884	88,918	2,759	13,490	19,405
	p95/p5	2,002	23,865	580	1,255	2,358
	p95/p50	9,024	199,412	2,204	14,032	34,508
	p95/p95	20,075	255,017	4,230	21,508	47,491
Liquid B	p5/p5	No animals are culled				
	p5/p50	No animals are culled				
	p5/p95	4	46	2	5	8
	p50/p5	567	4,918	196	395	584
	p50/p50	6,265	27,599	2,303	9,519	6,798
	p50/p95	9,711	118,803	2,874	15,369	23,232
	p95/p5	1,942	24,239	649	1,356	2,504
	p95/p50	20,083	246,372	4,270	21,004	44,568
	p95/p95	21,259	257,372	4,596	23,060	48,145

Table 7.3.1-7: Average Number of Herds Vaccinated by Event

Event	Output/ Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Liquid C	p5/p5	1,087	8,743	417	721	1,070
	p5/p50	1,465	9,937	534	1,154	1,333
	p5/p95	2,072	14,754	626	2,221	2,074
	p50/p5	1,537	18,300	396	922	1,795
	p50/p50	8,139	52,766	2,709	10,515	9,046
	p50/p95	19,582	193,196	4,140	19,256	33,418
	p95/p5	18,847	150,193	4,597	18,351	29,594
	p95/p50	18,406	192,935	4,270	18,373	38,607
	p95/p95	20,358	241,316	4,501	22,467	46,802
Liquid D	p5/p5	33	247	4	23	34
	p5/p50	Same as p5/p5				
	p5/p95	Same as p5/p5				
	p50/p5	1,674	16,815	544	1,062	1,775
	p50/p50	9,254	67,191	3,079	11,963	10,758
	p50/p95	19,118	163,458	4,400	17,755	29,942
	p95/p5	11,954	150,730	3,676	17,644	26,580
	p95/p50	19,170	209,371	4,121	18,826	39,731
	p95/p95	21,122	257,752	4,352	22,920	47,926
Non Containment Aerosol (OA)	p5/p5	16	337	12	17	31
	p5/p50	363	1,353	119	439	256
	p5/p95	903	13,236	361	960	1,832
	p50/p5	353	3,198	151	308	394
	p50/p50	7,225	40,806	2,344	10,637	8,128
	p50/p95	17,839	159,524	4,252	17,084	27,939
	p95/p5	19,836	166,390	4,688	18,904	30,932
	p95/p50	19,995	246,437	4,364	21,122	44,559
	p95/p95	21,347	257,513	4,592	23,020	48,140
Solid Waste Transfer Station	p5/p5	No animals are culled				
	p5/p50	No animals are culled				
	p5/p95	No animals are culled				
	p50/p5	8	155	8	17	32
	p50/p50	Same as p50/p5				
	p50/p95	Same as p50/p5				
	p95/p5	341	1,818	103	180	278
	p95/p50	7,608	36,972	2,467	11,348	7,552
	p95/p95	8,742	136,392	2,815	15,650	30,192

Table 7.3.1-7: Average Number of Herds Vaccinated by Event

Event	Output/ Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Solid Waste Landfill	p5/p5	5	69	4	6	12
	p5/p50	Same as p5/p5				
	p5/p95	Same as p5/p5				
	p50/p5	57	782	44	80	84
	p50/p50	128	919	47	145	117
	p50/p95	2,138	21,610	292	1,745	4,055
	p95/p5	1,354	17,535	537	1,053	1,841
	p95/p50	11,367	167,389	3,693	16,317	32,706
	p95/p95	20,586	219,215	4,683	20,755	43,379
Transference	p5/p5	43	306	16	18	58
	p5/p50	141	560	29	155	110
	p5/p95	1,218	5,444	324	1,526	962
	p50/p5	1,581	17,621	439	941	1,738
	p50/p50	6,669	30,717	2,400	9,685	7,275
	p50/p95	19,010	166,238	3,975	17,545	29,832
	p95/p5	19,580	166,561	4,686	18,563	30,910
	p95/p50	19,415	209,086	4,241	18,853	39,894
	p95/p95	21,367	257,467	4,472	22,947	48,089
Tornado Medium	p5/p5	3	46	3	7	8
	p5/p50	181	1,139	35	95	127
	p5/p95	422	3,157	155	357	372
	p50/p5	58	488	16	42	46
	p50/p50	375	2,662	136	274	317
	p50/p95	1,641	21,211	353	1,535	2,370
	p95/p5	363	2,051	103	194	269
	p95/p50	2,127	24,727	824	1,468	2,534
	p95/p95	8,699	42,060	2,714	12,986	8,240
Tornado High	p5/p5	1,622	18,676	412	1,058	1,812
	p5/p50	1,848	20,112	394	1,400	1,943
	p5/p95	2,423	22,719	490	2,329	2,400
	p50/p5	1,597	19,025	301	967	1,690
	p50/p50	2,438	32,449	611	1,621	3,086
	p50/p95	11,329	126,174	3,210	15,088	22,706
	p95/p5	2,014	25,341	549	1,436	2,340
	p95/p50	9,881	74,715	2,872	12,896	10,743
	p95/p95	11,086	173,798	3,288	17,278	33,501

Table 7.3.1-7: Average Number of Herds Vaccinated by Event

Table 7.3.1-7: Average Number of Herds Vaccinated by Event						
Event	Output/ Location	Production Type				
		Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Earthquake High	p5/p5	3	46	3	7	8
	p5/p50	143	1,408	61	151	180
	p5/p95	2,195	19,775	695	2,008	2,296
	p50/p5	59	447	21	33	47
	p50/p50	430	3,538	165	343	476
	p50/p95	9,934	74,919	3,158	13,230	10,949
	p95/p5	24	102	7	24	18
	p95/p50	1,824	19,913	251	1,995	2,227
	p95/p95	11,300	173,031	3,582	17,445	33,593

Table 7.3.1-8 reports the supply shocks used in this study. In the vaccinate-to-kill scenarios, the supply shocks were calculated by taking the number of culled and vaccinated animals divided by the total number of animals by production type. In the vaccinate-to-live scenarios, all supply shocks were calculated by taking the number of culled animals divided by the total number of animals by production type.

Table 7.3.1-8: Supply Shocks

Event	Output/ Location	Duration (days)	Production Type				
			Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Liquid A	p5/p5	20	-0.03%	-0.05%	-0.03%	-0.04%	-0.01%
	p5/p50	20	Same as p5/p5				
	p5/p95	21	-0.01%	-0.02%	-0.01%	0.00%	-0.01%
	p50/p5	67	-1.65%	-0.60%	-0.89%	-0.31%	-0.16%
	p50/p50	424	-4.30%	-0.11%	-1.45%	-4.35%	-0.21%
	p50/p95	473	-15.41%	-0.25%	-9.10%	-6.47%	-2.42%
	p95/p5	328	-10.77%	0.00%	0.00%	-2.95%	0.00%
	p95/p50	492	-31.64%	-0.46%	-13.65%	-9.80%	-1.35%
	p95/p95	533	-34.38%	-0.63%	-26.06%	-16.08%	-1.43%
Liquid B	p5/p5	0	No animals are culled				
	p5/p50	0	No animals are culled				
	p5/p95	15	-0.07%	-0.02%	-0.01%	0.00%	-0.01%
	p50/p5	78	-5.13%	-1.48%	-0.83%	-0.91%	-0.52%
	p50/p50	424	-8.34%	-0.13%	-1.90%	-4.50%	-0.25%
	p50/p95	473	-8.34%	-0.13%	-1.90%	-4.50%	-0.25%
	p95/p5	335	-18.04%	-0.34%	-9.59%	-7.27%	-2.45%
	p95/p50	492	-31.82%	-0.63%	-18.81%	-16.74%	-1.49%
	p95/p95	533	-37.78%	-0.77%	-29.09%	-15.23%	-1.46%

Table 7.3.1-8: Supply Shocks

Event	Output/ Location	Duration (days)	Production Type				
			Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Liquid C	p5/p5	188	-7.84%	-2.79%	-1.44%	-1.27%	-1.00%
	p5/p50	188	-9.20%	-3.12%	-2.49%	-2.12%	-1.14%
	p5/p95	188	-11.41%	-4.49%	-3.35%	-4.41%	-1.80%
	p50/p5	280	-10.36%	0.00%	0.00%	-3.06%	0.00%
	p50/p50	424	-17.56%	-0.12%	-1.45%	-7.40%	-0.21%
	p50/p95	473	-30.65%	-0.32%	-11.44%	-12.82%	-2.44%
	p95/p5	492	-33.37%	-0.77%	-15.79%	-14.61%	-2.38%
	p95/p50	492	-31.37%	-0.93%	-16.98%	-14.73%	-1.59%
	p95/p95	533	-37.45%	-1.19%	-26.91%	-14.47%	-1.56%
Liquid D	p5/p5	25	-0.20%	-0.11%	-0.02%	-0.01%	-0.03%
	p5/p50	25	Same as p5/p5				
	p5/p95	25	Same as p5/p5				
	p50/p5	261	-10.72%	0.00%	0.00%	-2.61%	0.00%
	p50/p50	424	-17.37%	-0.12%	-7.63%	-7.02%	-0.21%
	p50/p95	473	-30.16%	-0.49%	-15.26%	-11.72%	-2.40%
	p95/p5	492	-30.29%	-0.34%	-11.23%	-13.40%	-2.31%
	p95/p50	492	-30.29%	-0.34%	-11.23%	-13.40%	-2.31%
	p95/p95	533	-30.29%	-0.34%	-11.23%	-13.40%	-2.31%
Non Containment Aerosol (OA)	p5/p5	28	-0.058%	-0.079%	-0.027%	-0.004%	-0.094%
	p5/p50	48	-0.499%	-0.348%	-0.581%	-0.846%	-0.216%
	p5/p95	180	-3.827%	-3.163%	-1.877%	-1.226%	-1.073%
	p50/p5	83	-2.221%	-0.943%	-0.409%	-0.572%	-0.398%
	p50/p50	424	-9.274%	-0.127%	-1.501%	-4.406%	-0.214%
	p50/p95	473	-24.276%	-0.665%	-13.280%	-11.506%	-1.373%
	p95/p5	492	-33.792%	-0.354%	-17.591%	-15.389%	-2.280%
	p95/p50	492	-31.879%	-0.635%	-19.392%	-16.601%	-1.488%
	p95/p95	533	-37.862%	-0.774%	-28.713%	-15.252%	-1.455%
Solid Waste Transfer Station	p5/p5	0	No animals are culled				
	p5/p50	0	No animals are culled				
	p5/p95	0	No animals are culled				
	p50/p5	24	-0.01%	-0.03%	-0.02%	-0.01%	-0.01%
	p50/p50		Same as p50/p5				
	p50/p95		Same as p50/p5				
	p95/p5	90	-4.21%	-0.76%	-0.92%	-0.33%	-0.35%
	p95/p50	492	-4.11%	-0.19%	-2.56%	-7.42%	-0.16%
	p95/p95	533	-20.54%	-0.55%	-18.66%	-8.43%	-0.22%

Table 7.3.1-8: Supply Shocks

Event	Output/ Location	Duration (days)	Production Type				
			Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Solid Waste Landfill	p5/p5	13	0.00%	-0.01%	0.00%	0.00%	0.00%
	p5/p50		Same as p5/p5				
	p5/p95		Same as p5/p5				
	p50/p5	48	-0.42%	-0.19%	-0.18%	-0.09%	-0.08%
	p50/p50	147	-0.57%	-0.22%	-0.19%	-0.24%	-0.10%
	p50/p95	473	-6.12%	-0.03%	-2.46%	-2.53%	-1.03%
	p95/p5	275	-10.56%	0.00%	0.00%	-2.76%	0.00%
	p95/p50	492	-27.67%	-0.50%	-18.44%	-12.81%	-1.49%
	p95/p95	533	-37.76%	-0.66%	-29.25%	-13.79%	-1.46%
Transference	p5/p5	35	-0.72%	-0.09%	-0.03%	-0.04%	-0.07%
	p5/p50	48	-1.32%	-0.22%	-0.07%	-0.18%	-0.10%
	p5/p95	420	-12.48%	-0.02%	-0.23%	-3.22%	-0.09%
	p50/p5	266	-10.45%	0.00%	0.00%	-2.93%	0.00%
	p50/p50	424	-13.34%	-0.15%	-3.67%	-4.72%	-0.22%
	p50/p95	473	-30.61%	-0.24%	-10.07%	-12.08%	-2.40%
	p95/p5	492	-33.91%	-0.35%	-15.84%	-15.67%	-2.28%
	p95/p50	492	-31.93%	-0.51%	-17.76%	-15.64%	-1.49%
	p95/p95	533	-38.00%	-0.77%	-27.69%	-15.39%	-1.46%
Tornado Medium	p5/p5	6	0.00%	-0.02%	-0.01%	0.00%	-0.01%
	p5/p50	34	-0.84%	-0.43%	-0.09%	-0.08%	-0.22%
	p5/p95	41	-1.85%	-0.95%	-0.56%	-0.56%	-0.30%
	p50/p5	30	-0.27%	-0.18%	-0.05%	-0.07%	-0.03%
	p50/p50	56	-1.97%	-0.83%	-0.36%	-0.48%	-0.17%
	p50/p95	473	-7.06%	-0.04%	-1.64%	-2.66%	-0.01%
	p95/p5	75	-0.84%	-0.43%	-0.09%	-0.08%	-0.22%
	p95/p50	349	-10.78%	-0.02%	-6.53%	-2.31%	0.00%
	p95/p95	533	-12.58%	-0.51%	-3.36%	-6.39%	-0.23%
Tornado High	p5/p5	240	-10.43%	0.00%	0.00%	-2.88%	0.00%
	p5/p50	252	-10.37%	0.00%	-0.01%	-3.22%	0.00%
	p5/p95	252	-11.60%	-0.02%	-0.23%	-3.28%	-0.09%
	p50/p5	272	-10.30%	0.00%	0.00%	-3.12%	0.00%
	p50/p50	424	-11.40%	0.00%	-0.01%	-5.16%	0.00%
	p50/p95	473	-26.04%	-0.24%	-9.05%	-9.54%	-2.40%
	p95/p5	333	-10.93%	0.00%	0.00%	-2.73%	0.00%
	p95/p50	492	-12.85%	-0.18%	-2.02%	-10.52%	-0.16%
	p95/p95	533	-29.21%	-0.55%	-18.43%	-11.42%	-0.22%

Table 7.3.1-8: Supply Shocks

Event	Output/ Location	Duration (days)	Production Type				
			Beef Slaughter Cattle	Beef Cows	Dairy	Swine	Sheep
Earthquake High	p5/p5	6	0.00%	-0.02%	-0.01%	0.00%	-0.01%
	p5/p50	33	-0.73%	-0.43%	-0.19%	-0.18%	-0.12%
	p5/p95	243	-11.24%	-0.19%	-6.42%	-2.68%	-0.09%
	p50/p5	28	-0.25%	-0.10%	-0.06%	-0.01%	-0.06%
	p50/p50	62	-2.24%	-0.94%	-0.50%	-0.59%	-0.45%
	p50/p95	473	-14.85%	-0.14%	-5.25%	-7.37%	-0.25%
	p95/p5	84	-2.33%	-0.06%	-0.77%	-0.76%	-0.01%
	p95/p50	492	-9.60%	-0.01%	-2.22%	-2.17%	-0.01%
	p95/p95	533	-28.78%	-0.55%	-23.92%	-11.27%	-0.22%

Consumer Shocks

Although FMD poses little, if any, human health concerns, there are anticipated decreases in consumer demand. As such, consumer demand shocks were incorporated to allow variations in the level of consumer perception of food quality from a hypothetical FMD event [Piggott and Marsh, 2004]. These parameters indicate the share of the population cutting consumption of a final good and provide a policy instrument by which to manage impacts on final demand. There have been no FMD events on the U.S. mainland in recent history that provides data on consumer responsiveness, so it is necessary to draw information from other events and from other countries to provide reasonable and plausible guidelines for parameter choices. Various studies have quantified the impact of consumer demand in the U.S. to livestock disease outbreaks. Piggott and Marsh [2004], using quarterly annual data from 1982 to 1999 for the U.S., reported that the impact on beef demand to public food safety information was statistically significant, but on average small and short lived (i.e., a shock of 1 quarter after the event). Beef demand decreased as much as 5.9% in one quarter to public food safety information over the period from 1982 to 1999. Marsh, Schroeder, and Mintert [2004] examined consumer responses to meat product recalls in the United States. Meat product recalls included - but were not limited to - Salmonella, Listeria, E. coli O157:H7, Staphylococcus, Trichinae, Hepatitis A, and other contaminants. They reported that the impact on beef demand to meat recalls was statistically significant. On average the impact was small and short lived, but the likelihood of larger responses coincided with larger recalls. Coffey et al. [2005] provided a summary of survey results from different sources related to BSE announcements. They reported that across five different surveys that between 14 and 29 percent of respondents reported reducing their beef consumption. Survey results from Thilmany, Umberger, and Ziehl [2004] concluded that the BSE incident generated a 13% demand reduction. Several studies have examined response to BSE using weekly grocery store scanner data. Kuchler and Tegene [2006] used weekly sales from 1998 to 2004 to examine the impact of the BSE case in 2003. For the Washington State BSE case, they find the impact on fresh beef purchase to be short-lived with week 1 purchase to be 32.6% lower and week 2 purchase to be 18.7% lower. Schlenker and Villas-Boas [2009], using transaction level data, reported that sales (not demand) fell 21% during the first 35 days following the announcement of BSE. Losses recovered to about a 10% decline by day 90. While informative as to the

duration of consumer shock, scanner data is not based on statistically drawn sample, which makes the magnitude of the shock less useful for analyzing current market conditions [Hahn et al., 2009].

FMD outbreaks have been experienced in other countries, including the UK in 2001. Consumers in the UK decreased their average weekly per capita carcass meat consumption from 235 grams in 2001 to 229 grams in 2002 (or 2.7%). Consumption in the UK recovered to pre-outbreaks levels by 2006 [UK DEFRA, updated 1/14/2010]. A survey of European citizens in March and April 2006 questioned over 25,000 EU citizens on avian influenza, reporting that 50% of those questioned did not believe that eating meat from vaccinated birds carries no risk to human health [Scudamore 2007]. Although these results represent stated and not actual outcomes, the findings suggest consumers can be concerned about consumption of meat and other products from vaccinated animals.

Given the above information, demand shocks were specified for FMD across the events. Based on the epidemiological output (see Tables 7.1.3-4 and 7.1.3-6) smaller (larger) outbreaks coincided with outbreaks that lasted shorter (longer) than 1 quarter. Consequently, following a small FMD outbreak (lasting less than one quarter), it was assumed that 5% of people would refrain from consuming beef, pork, and lamb while 2.5% would stop consuming milk and dairy products during the outbreak. In the second quarter, consumer demand for beef, pork and lamb declined by 2.5% and was fully recovered (i.e., 0% decline) for dairy and milk products (see Table 7.3.1-9 for an example, Liquid A p5/p5). It was assumed that consumer demand for meat products would be fully recovered by the third quarter.

In outbreaks lasting more one quarter (which corresponded to larger outbreaks), it was assumed that 10% of consumers would refrain from consuming beef, pork and lamb while 5% would stop consuming milk and dairy products during the outbreak. Following the outbreak, it was assumed that consumer demand would decrease by 5% for one quarter and 2.5% for another quarter for beef, pork, and lamb. Consumer demand for dairy and milk products would decline by 2.5% for 1 quarter following the outbreak (see Table 7.3.1-9 for an example, Liquid A p50/p50).

These assumptions are supported by the quantitative findings of the studies discussed above. They are also consistent with previous modeling efforts to estimate economic consequences of FMD outbreaks. Paarlberg et al. [2003] assume 5% of the consumers no longer eat beef and veal when examining FMD outbreaks in the United States. Zhao et al. [2006] use a 5% decrease in domestic demand when simulating FMD events in the United States. Nogueira et al. [2011] applied a 5% decrease in domestic demand when simulating FMD outbreaks in Mexico. Tozer et al. [2011] applied a 5% decrease in domestic demand when simulating FMD outbreaks in Australia.

Table 7.3.1-9: Demand Shocks

Event	Output/Location	Outbreak	End of Outbreak +1	End of Outbreak +2	End of Outbreak +3	End of Outbreak +4	End of Outbreak +5	End of Outbreak +6
Liquid A	p5/p5	-5.0%	-2.5%	0.0%	0.0%	0.0%	0.0%	0.0%
Liquid A	p50/p50	-10.0%	-10.0%	-10.0%	-10.0%	-10.0%	-5.0%	-2.50%

Trade Shocks

The magnitude and duration of trade shocks assumed for this study were based on observations from previous events in, and studies about, the U.S. and across the world. In 2003 and 2004, due to isolated incidences of BSE, the U.S. and Canada faced complete bans on beef in major overseas markets while beef and cattle imports and exports continued among the North America Free Trade Agreement countries (Canada, Mexico, and the United States) under a variety of restrictions [Blayney, 2005]. The U.S. has experienced a long recovery relative to pre-outbreak trade status as a result the isolated BSE events. U.S. beef exports, as a percentage of beef production was 9.6% in 2003, dropped dramatically to 1.9% in 2004, and recovered to 7.1% in 2008 [USDA-ERS].

A review of the economic literature on previous events and research is useful in identifying plausible time lengths defining trade bans for FMD scenarios. The EU imposed a one year ban on the UK following its 2001 FMD outbreak. Rich and Winter-Nelson [2007] studied FMD outbreaks during 2000-2001 in the southern cone of South America, reporting short lived impacts on exports to Argentina, Brazil, and Uruguay. In modeling exercises, they assumed exports to fully resume sixteen weeks after the end of the outbreak was declared. Randolph et al. [2005] examined FMD outbreaks in Zimbabwe, and assumed a 12 month export ban. Nogueira et al. [2011] and Tozer et al. [2011] apply 1 to 2 year trade bans for hypothetical FMD outbreaks in Mexico and Australia, respectively. Although the actual length of export restrictions will depend upon the actual product, disease, trade agreements, and countries involved, these observations provide informative guidelines for the economic model assumptions and simulations.

Based on the above information trade shocks were constructed in the following manner. First, 95% of all U.S. exports of beef, pork, lamb meat, cattle, swine, and sheep were halted during the full quarter of the outbreak and for one quarter after the last case appears. This assumes some processed/cooked beef is still exported after the outbreak. Interrupting exports for one quarter beyond the end of the outbreak (and for two quarters beyond the end of the outbreak when emergency vaccination is practiced and not followed by slaughter) was consistent with OIE guidelines and practices (Chapter 8.5) during FMD outbreaks [OIE, 2009]. Second, after the additional quarter ended with no FMD reported, it was assumed that U.S. exports of the embargoed products gradually recovered over the subsequent quarters towards the baseline levels. Full recovery was assumed to occur in approximately two years (immediately following one full quarter after the outbreak is contained) as defined in Table 7.3.1-10. For FMD, the duration of the outbreak becomes a critical element in determining the economic effects from trade disruptions.

Table 7.3.1-10: Percentage Change Of International Trade Following FMD Outbreaks by Event

Event	Output/ Location	Initial Outbreak	Ongoing Outbreak	Post Outbreaks								
		Qtr 0	Qtr +1	Qtr +2	Qtr +3	Qtr +4	Qtr +5	Qtr +6	Qtr +7	Qtr +8	Qtr +9	Qtr +10
Liquid A	p5/p5	-95%	-95%	-85%	-70%	-50%	-40%	-30%	-20%	-10%	-5%	0%

7.3.1.4 Outcomes

Consumer and Producer Welfare

The model provided estimates of changes in per capita consumer welfare between the baseline case with no FMD outbreak and one of the previously defined outbreak events. The economic welfare of consumers was measured by the difference between what consumers were willing to pay and what they must pay for each unit consumed. The changes in consumer welfare were adjusted by the consumer welfare foregone by non-consuming individuals.

Producer welfare was represented by changes in quasi-profits and captured by returns to capital and management (not sales). Producer welfare measured welfare changes along the supply change including meat processing, egg and layers, dairy cattle and milk, beef cattle, swine, lambs and sheep, crops and soybeans. Producer welfare was adjusted for the value of animals lost due to the FMD outbreak and for the indemnification payment to producers. Indemnification payments compensate producers for asset losses incurred due to lost animals, and were assumed to be a transfer from the government to the producer.

The results were generated under two emergency vaccination scenarios: 1) vaccinate-to-kill and 2) vaccinate-to-live. For small to medium sized releases (<180 days), the vaccinate-to-kill scenario was assumed where all removed animals culled or vaccinated were assumed to be depopulated. This is incorporated into the study by extending the decline in international trade by 95% for one quarter beyond the end of the outbreak (i.e., an outbreak lasting one quarter would result in a decline of 95% of trade for two quarters). For large releases (>180 days), vaccinated cattle were assumed to remain in the cattle inventory. The vaccinate-to-live scenarios extend the export ban for two quarters beyond the end of the outbreak (i.e., an outbreak that last four quarters would result in a decline of 95% of trade for six quarters). Consumer demand and trade shocks for both are defined above. Regionalization/zoning was not assumed for the vaccinate-to-kill and the vaccinate-to-live scenarios. Rather, uniform trade bans for the entire U.S. were applied for both. See Tozer et al. [2011] for additional details on the economic consequences of regional and uniform trade ban policies from FMD outbreaks. Furthermore, no adjustments were imposed on the model related to changes in slaughter capacity or changes in capital investment in the livestock sector. The performer acknowledges that there are limitations with these assumptions. For example, vaccinate-to-slaughter or mixed strategies are also plausible alternatives. Response to a FMD outbreak will likely include a combination of culling, vaccinate-to-kill, and vaccinate-to-slaughter depending on the factors such as the animal species affected, geographic area, number of infected animals, trade restrictions, proximity of processing plants, etc.

7.3.2 Regional Non-Agricultural Impacts

Input-output modeling can be traced back to the Nobel Prize winning work of Leontief [1936] [Irwin, Issermann, Kilkenny, and Partridge, 2007]. The input-output model is a system of linear equations that describe the circular flow of income and product throughout an economy. A key issue in economic impact analysis is defining the region of interest. The more narrowly defined a region the greater degree

income will 'leak' out of the region and fail to further affect the region's economy. Likewise one must understand the concept of an economic multiplier which measures the effect of an economic shock (either positive or negative) on a specific sector of the economy. Multipliers are in general greater than 1.0 as they measure a total effect which subsumes indirect effects relative to the direct effects alone. The economic impact of a shock in one industry on other industries in the region will depend on the degree of economic dependence or interaction that exists between those industries. Thus, an industry using locally-produced inputs would have more effect on an economy than an industry that does not. Agricultural economists have applied input-output modeling to rural issues and improved the technique. For example, Little and Doeksen [1968] devised a procedure to measure leakages from the local economy and Heady and Sonka [1974] combined input-output and math programming. For many years survey-based input-output modeling was utilized and was extremely expensive. Eventually, researchers turned to governmental income accounting data [Round 1983]. While various input-output models arose during this period, two systems, developed with initial government funding, have continued to be expanded and refined. The first, developed by the Bureau of Economic Analysis is RIMSII (Regional Input-Output Modeling System), is the approach used in the Updated SSRA. The second is IMPLAN (Impact Analysis for Planning), originally developed by the Forest Service, which is now privately-maintained. Note that these models assume a simple production relationship and do not capture substitution effects that may occur during an economic shock (especially a longer lasting shock). However, estimates of these effects are a significant additional computational burden and not readily available.

The livestock sectors affected by an outbreak are directly linked to both input and output markets. Production inputs such as feed, fuel, and fertilizer are directly purchased by livestock producers. Similarly, the animals produced by various farm types may move from farm to farm, or as a finished animal or product moves into the agribusiness value chain for processing. While clear direct market chain relationships exist, the effects of which are captured by the partial equilibrium model for the agricultural sector, there are also well-known indirect effects on a local economy when an economic enterprise increases or decreases production. For example, a processing plant will create employment and those employees are likely to purchase a wide variety of goods and services such as medical care, entertainment and other goods that are not directly related to the manufacturing plant. Thus, the regional impacts of an economic shock were evaluated separately because of the localized effects. These impacts may be contrasted with the broader economy consumer demand and trade shocks resulting from an outbreak.

For the non-agricultural impacts, input-output industrial multipliers were obtained from the Bureau of Economic Analysis (BEA) and these data were chosen because they provided a well accepted and validated methodology to evaluate these impacts. Moreover, the multipliers were readily available with flexibility to define the states defined in the primary and secondary regions in the study. The outcomes of the RIMSII model compare favorably to alternative regional economic models. Specifically, a RIMSII, which combines BEA's national I-O table, integrates the input and output relationships of approximately 500 U.S. industries and regional economic accounts. The final-demand multipliers for output are used in

this analysis to estimate the indirect economic activity generated by a specific economic activity in a region (with the producer and consumer welfare measures of the partial equilibrium model capturing the direct effects on the agricultural sector). Thus, the intent of using the RIMSII data was to measure the effects of an FMD event on the non-agricultural regional economy. Calculations were structured to remove duplication or double counting of losses. Three livestock sectors were broken out to individual indirect effects – beef cattle, dairy and milk production, and other livestock including sheep. Three indirect effects were evaluated in the primary modeling region: first, the effect of culling and destroying animals on the non-agricultural regional economy (e.g. retail trade); second, the economic implication of a travel ban that would limit recreational and non-essential travel in and out of a region; and third, the indirect effects from the stimulus to the region created by the expenditures during government clean-up efforts. The effects of travel bans are composed of transit and ground transportation; spectator sports; hotels and motels; and food and drink services. To some extent, the government expenditures and purchases of goods and services while performing a clean-up will stimulate the regional economy.

One critical aspect of using regional input-output models to quantify economic impacts is clearly defining the region of interest as the multipliers capture the associated economic activity of a specific industry in a region. If the region is too tightly defined there is ‘leakage’ of economic activity out of the region that is not represented. An important attribute of RIMSII is the flexibility to define regions in terms of any combination of contiguous counties. For this analysis, the primary economic region was composed of seven states - Kansas, Nebraska, Missouri, Iowa, Texas, Oklahoma, and Colorado. Thus, as production returns to pre-release conditions, the indirect effects to this region dissipate.

Because of government indemnification for culled cattle in an FMD event, it is assumed that a farm will resume production after stop movement and quarantines are lifted and the owner is compensated for his losses. After a return to production, the farm would resume its previous contributions to the economic activity in the region.

The economic impact from the loss in travel expenditures can be measured using RIMSII [Mak, 1989]. Total domestic travel expenditures for overnight trips and day trips of over 50 miles in 2007 were obtained from the U.S. Statistical abstract produced by the U.S. Census Bureau. These data are reported on a state-by-state basis. However, the RIMSII data separates the economic effects of various forms of travel (Table 7.3.2-1). Thus, using data on the percentage allocations of travel expenditures from the Bureau of Labor Statistics, expenditures were allocated by category for each state in the study region (U.S. BLS).

Table 7.3.2-1: Allocation of Travel Expenditure by Category (%)

Air Transportation	Transit and Ground Passenger Transportation	Spectator Sports	Hotels and Motels, Including Casino Hotels	Food Service
29.10	13.95	10.80	19.08	27.08

The magnitude of the travel sector in the study states are reported in Table 7.3.2-2.

Table 7.3.2-2: Travel Expenditures by State and Subcategory					
State	Air Transportation	Transit and Ground Passenger Transportation	Spectator Sports	Hotels and Motels, Including Casino Hotels	Food Service
	(Millions)				
Texas	\$12,593	\$ 6,037	\$ 4,674	\$8,255	\$ 11,717
Colorado	\$ 3,741	\$ 1,793	\$ 1,388	\$2,452	\$3,480
Iowa	\$ 1,824	\$ 874	\$677	\$1,195	\$1,697
Kansas	\$ 1,520	\$729	\$564	\$996	\$1,414
Missouri	\$ 3,374	\$1,618	\$1,252	\$2,212	\$3,139
Nebraska	\$1,082	\$519	\$ 402	\$709	\$ 1,007
Oklahoma	\$ 1,707	\$ 818	\$ 634	\$1,119	\$ 1,588
Core total	\$ 25,841	\$12,388	\$9,591	\$ 16,939	\$ 24,043

While not insignificant, travel and tourism is not a dominate sector in the primary region. Kansas, Nebraska, and Oklahoma each constitute less than 1% of the U.S. domestic travel visits and expenditures (3.1% combined). Travel and tourism are more important in Texas, Colorado and Missouri which contribute 6.7%, 2% and 1.8% of domestic travel visits and expenditures, respectively. Tourism expenditure reduction in the UK following the FMD outbreak in 2001 was 13% [Blake et al., 2002]. This study assumes that travel will be less affected than in the UK because tourism in the UK involves significant rural tourism. Thus, a maximum of 8% annualized reduction on travel within a state is assumed. That is if an outbreak last one year, a state's travel would be reduced by 8%. It also appears likely that in major outbreaks travel restrictions to non-agricultural events will be lifted after two quarters so a maximum reduction of 4% of annual travel is realized. For outbreaks of less than two quarters, the travel reduction computed from the number of days the outbreak lasts as a percentage of a full year's reduction.

Government Costs

Government costs included in this study were appraisal, euthanasia, disposal, cleaning and disinfection, surveillance, indemnification, vaccination, and quarantine. Indemnification costs reflect the value of culled animals in the first quarter prior to an FMD release using LMIC price data. Costs per animal and herd are based on published literature [Pendell, 2006; Elbakidze et al., 2009] and other assumptions are provided in Table 7.3.2-3. Indemnification costs per animal were calculated at average market prices. Non-indemnification government costs per animal are consistent in magnitude with those reported by Abdalla et al. [2005].

Table 7.3.2-3: Government Cost Used in Calculations

	Cow Calf	Dairy	Feedlot	Swine	Sheep
Cost of appraisal for slaughter (\$/Herd) ^{a*}	95.35	95.35	238.37	95.35	95.35
Cost of cleaning and disinfection (\$/herd) ^{a*}	1,776.4	3,762.8	11,173.75	1,279.81	1,776.40
Fixed costs of surveillance (\$/herd) ^{b**}	225.70	225.70	225.70	225.70	225.70
Variable costs of surveillance (\$/visit) ^{b**}	84.64	84.64	112.85	84.64	84.64
Quarantine costs(\$/animal/day) ^{b**}	1.41	1.41	1.41	1.41	1.41
Euthanasia (\$/animal) ^{a*}	27.91	5.70	5.79	27.91	4.10
Carcass disposal (\$/animal) ^{a*}	14.97	2.24	2.08	2.89	14.97
Fixed costs of vaccination (\$/herd) ^{b**}	338.55	564.25	902.80	654.25	338.55
Variable costs of vaccination (\$/animal) ^{b**}	6.77	6.77	6.77	6.77	6.77

* ^a Pendell, D.L. [2006] inflated to 2009 dollars.

**^b Elbakidze, L. et al. [2009]. Assumed 3 surveillance visits per herd inflated to 2009 dollars.

Note: Assumed 28 day quarantine period with all susceptible premises in each state incurring quarantine. Assumed 3 surveillance visits.

7.4 Results Summary

The subsections below summarize the model outputs for the scenarios of epidemiological significance and economic impact. The producer and consumer welfare effects monetize the changes in the well-being of producers and consumers of agricultural products. The total impact for a scenario was determined as the sum of agricultural producer and consumer welfare plus the government indemnification and non-indemnification expenditures. These results were then added to the non-agricultural sector results for the total impact. Reported scenarios with outbreak lengths greater than or equal to two quarters were modeled as vaccinate-to-live scenarios, while the remaining scenarios were modeled as vaccinate-to-kill.

It is important to first provide some general observations regarding the welfare assessments of FMD releases. First, the combined sum of producer and consumer welfare dominates the economic impacts arising from government costs and regional non-agricultural impacts. Second, results indicate that for small and medium sized outbreaks, agricultural producer welfare effects are several times larger than the consumer welfare effects. Producer effects are always negative due to lost output and reduced prices. While producers are burdened with losses, consumers are better off with reduced prices. However, in some cases where supply shocks are small or localized, positive consumer welfare changes could outweigh producer losses (see Paarlberg [2008], Nogueira et al. [2011], and Tozer et al. [2011] for further discussion of such cases). In other words, if adverse consumer reaction to a disease outbreak is small, it is possible for consumers of agricultural products to benefit from a small FMD outbreak because bans on agricultural exports lead to oversupply and reduce domestic meat and dairy prices; these price reductions benefit consumers. For large outbreaks, consumers and producers welfare measures are large and negative. Third, government cost of indemnification and non-indemnification costs are, in general, much lower than the changes in agricultural producer and consumer welfare. Fourth, in every

case, the regional non-agricultural effect is negative as the government indemnification replaces the value of lost animals, but not the full economic impact they have on the region.

7.4.1 Economic Impacts

The results summarized in Table 7.4.1-1 by event indicate the total losses range from about 16 billion dollars to 140 billion dollars in damage. To better reflect uncertainty from the epidemiological model the results are reported at the p5, p50, and p95 epidemiological output levels across p5, p50, and p95 location quartiles. For example, p5/p50 implies the p5 epidemiological output quartile and the p50 location quartile. The economic impacts reported below are consistent with other studies, Paarlberg et al. [2003] and Zhao et al. [2006], who examined FMD outbreaks for the U.S. beef cattle sector. Producers share the largest burden in losses. Consumers realize negative or positive effects primarily contingent upon the size of the outbreak, export losses, and assumed demand shocks. Indeed, for events with smaller supply shocks and lower assumed consumer demand reaction, consumers benefit from the outbreak due to lower prices. Regional non-agricultural losses ranged from under 1 to over 6 billion dollars across the scenarios. Government indemnification (non-indemnification) costs range from \$0.004 billion to nearly \$10 billion (\$0.001 billion to over \$5 billion). The information reported in Table 7.4.1-1 summarizes the cumulative economic impact across the entire study period for the specified scenarios. However, consequences of disease outbreaks are inherently dynamic in nature with benefits and costs accruing differently to producers and consumers over time; this interplay has important policy implications [Zhao et al., 2006]. To better illustrate the changes in producer and consumer welfare relative to baseline levels over time and along the supply chain, Figures 7.4.1-1 and 7.4.1-2 are provided for the Liquid A p5/p5 event (results for other cases are mostly qualitatively similar, but do vary according to the degree of the outbreak).

Figure 7.4.1-1 shows the decomposition of changes in producer welfare for meat processing, egg and layers, dairy cattle and milk, beef cattle, swine, lambs and sheep, crops and soybeans. Outcomes related to goats are combined into sheep and lamb for the purposes of the economic assessment. Focusing on livestock, swine facilities, beef cattle operations, and meat processing are immediately impacted after an outbreak and realize the largest and longest economic distortions. Dairy cattle and milk also are immediately impacted, but to a much lesser degree as consumer confidence is quickly restored and because of the smaller number of dairies in the primary region. Crops exhibit a large negative effect primarily because of demand for feed grains. Lamb and sheep, eggs and layers, and soybean processing are unaffected by the outbreak. As trade restrictions are lifted, changes in producer welfare become positive due to reduced herd sizes and higher prices. By the end of the study period, changes in producer welfare are converging to zero, implying markets are returning to baseline levels. Although periods exist where producer welfare was negative and positive for different sectors, the cumulative change in total producer welfare is negative across all sectors as reported in Table 7.4.1-1.

Figure 7.4.1-2 illustrates changes in total producer and consumer welfare over the study period for the Liquid A p5/p5 event. During the outbreak, changes in consumer and producer welfare are negative. However, after the outbreak is contained, because of lower prices and recovery of consumer demand, consumers become better off. Producers remain worse off until trade restrictions are almost fully

removed. After which, both changes in consumer and producer welfare converge to zero. As reported in Table 7.4.1-1, the cumulative change in producer welfare is negative while change in consumer welfare is positive for this scenario.

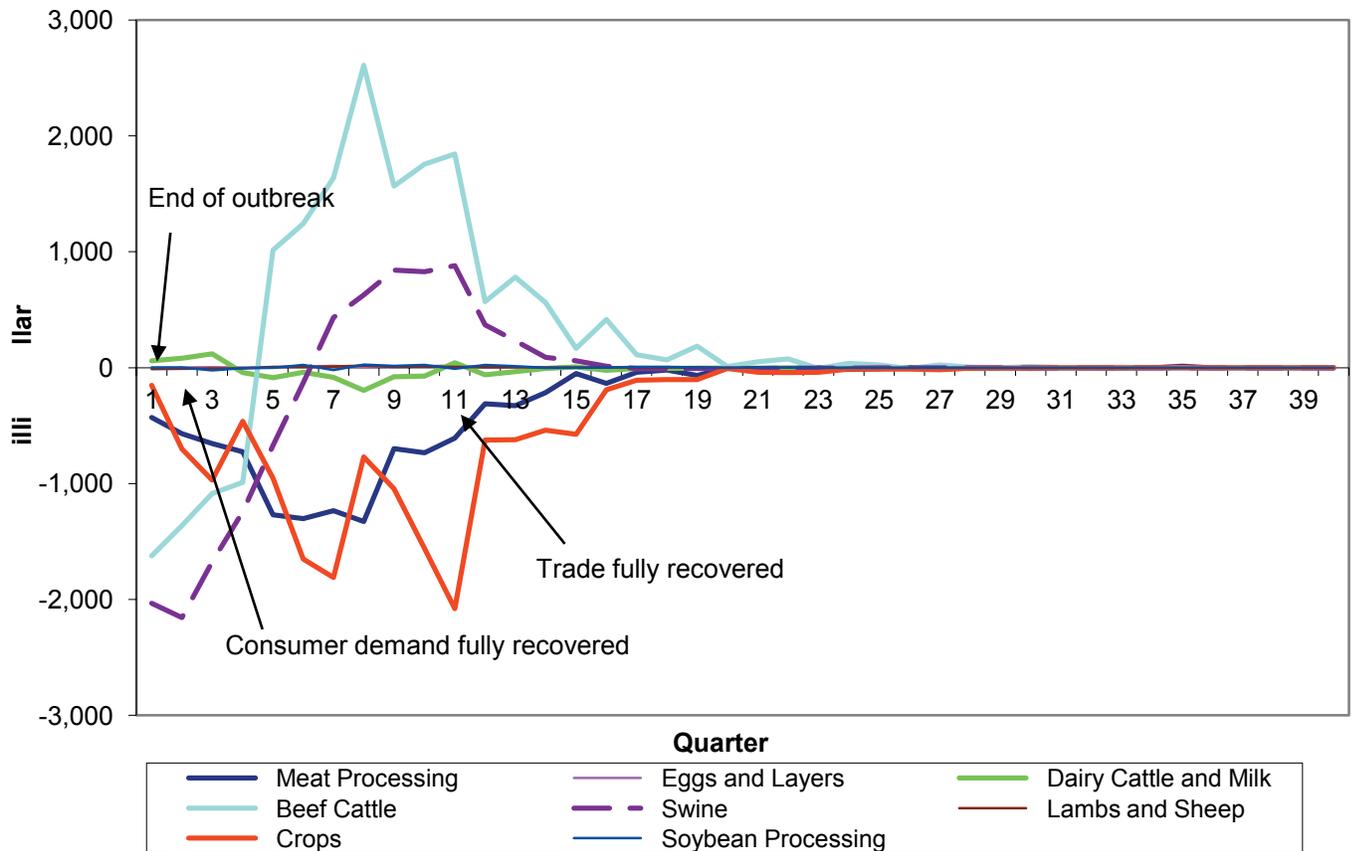


Figure 7.4.1-1: Changes in Producer Welfare by Commodity Throughout the Study Period for Liquid A p5/p5

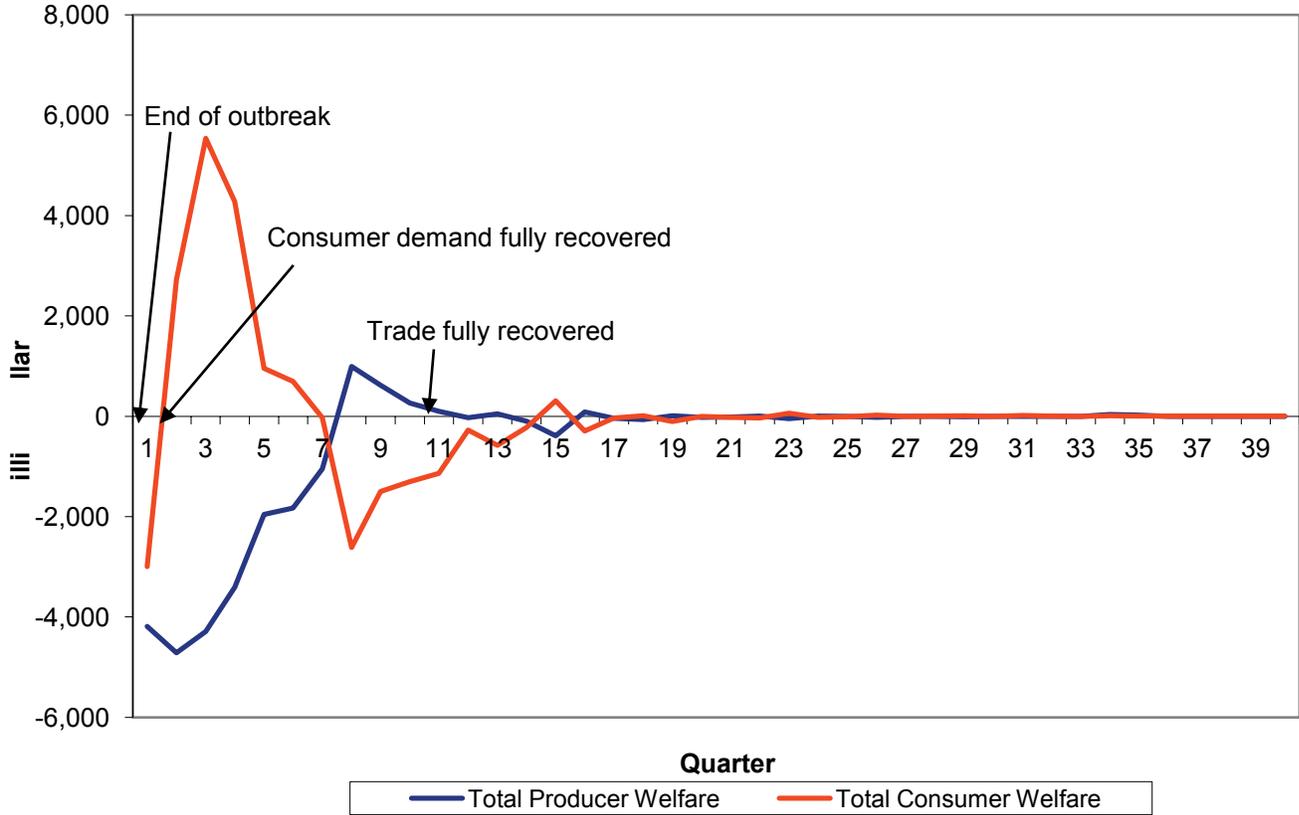


Figure 7.4.1-2: Changes in Producer and Consumer Welfare Throughout the Study Period for Liquid A p5/p5

Table 7.4.1-1: Economic Impacts Summary (Millions)

Event	Output/ Location	Agricultural Producer Welfare	Agricultural Consumer Welfare	Govt Costs Indemnification	Govt Costs Non Indemnification	Regional Non Agricultural Impacts	Total Impact
Liquid A	p5/p5	-\$19,918	\$3,478	\$21	\$7	-\$42	-\$16,510
	p5/p50	Same as p5/p5					
	p5/p95	-\$19,931	\$3,479	\$6	\$1	-\$31	-\$16,490
	p50/p5	-\$19,545	\$3,649	\$518	\$103	-\$360	-\$16,877
	p50/p50	-\$57,571	-\$52,646	\$1,082	\$1,524	-\$979	-\$113,801
	p50/p95	-\$64,546	-\$60,713	\$4,003	\$2,811	-\$4,621	-\$136,694
	p95/p5	-\$47,574	-\$43,750	\$2,323	\$770	-\$1,575	-\$95,992
	p95/p50	-\$61,490	-\$59,488	\$7,786	\$3,892	-\$1,681	-\$134,337
	p95/p95	-\$61,106	-\$59,105	\$9,053	\$5,333	-\$3,414	-\$138,011
Liquid B	p5/p5	No Culled Animals					
	p5/p50	Same as p5/p5					
	p5/p95	-\$19,920	\$3,489	\$18	\$3	-\$39	-\$16,492
	p50/p5	-\$18,752	\$4,061	\$1,414	\$288	-\$1,143	-\$17,536
	p50/p50	-\$56,869	-\$51,990	\$1,903	\$1,730	-\$3,726	-\$116,218
	p50/p95	-\$64,027	-\$60,322	\$4,614	\$3,216	-\$4,152	-\$136,332
	p95/p5	-\$47,578	-\$43,436	\$2,322	\$771	-\$831	-\$94,938
	p95/p50	-\$61,231	-\$58,915	\$8,377	\$5,387	-\$2,433	-\$136,343
	p95/p95	-\$60,679	-\$58,701	\$9,844	\$5,604	-\$4,061	-\$138,889
Liquid C	p5/p5	-\$27,506	-\$25,631	\$2,280	\$458	-\$3,162	-\$59,037
	p5/p50	-\$27,171	-\$25,492	\$2,728	\$586	-\$6,096	-\$62,073
	p5/p95	-\$26,370	-\$25,366	\$3,645	\$902	-\$6,638	-\$62,922
	p50/p5	-\$39,474	-\$33,193	\$2,250	\$702	-\$897	-\$76,516
	p50/p50	-\$54,971	-\$51,563	\$3,903	\$2,423	-\$3,736	-\$116,596
	p50/p95	-\$61,404	-\$59,904	\$7,589	\$4,497	-\$4,454	-\$137,848
	p95/p5	-\$60,828	-\$58,987	\$8,604	\$4,788	-\$3,292	-\$136,499
	p95/p50	-\$61,335	-\$58,521	\$8,179	\$4,842	-\$3,498	-\$136,375
	p95/p95	-\$60,637	-\$58,318	\$9,760	\$5,435	-\$3,806	-\$137,956
Liquid D	p5/p5	-\$19,881	\$3,498	\$63	\$11	-\$98	-\$16,555
	p5/p50	Same as p5/p5					
	p5/p95	Same as p5/p5					
	p50/p5	-\$39,447	-\$32,646	\$2,300	\$690	-\$692	-\$75,776
	p50/p50	-\$55,119	-\$51,165	\$4,248	\$2,791	-\$2,978	-\$116,300
	p50/p95	-\$61,696	-\$59,464	\$7,644	\$4,217	-\$4,283	-\$137,304
	p95/p5	-\$61,344	-\$59,843	\$7,606	\$4,480	-\$3,036	-\$136,310
	p95/p50	-\$61,027	-\$59,130	\$8,140	\$4,982	-\$3,647	-\$136,925
	p95/p95	-\$60,328	-\$58,937	\$9,721	\$5,575	-\$4,063	-\$138,624
Non Containment Aerosol (OA)	p5/p5	-\$19,909	\$3,480	\$30	\$6	-\$50	-\$16,516
	p5/p50	-\$19,733	\$3,483	\$259	\$103	-\$179	-\$16,791
	p5/p95	-\$28,154	-\$26,128	\$1,594	\$373	-\$2,827	-\$59,076
	p50/p5	-\$19,349	\$3,697	\$691	\$154	-\$438	-\$16,935
	p50/p50	-\$56,573	-\$51,877	\$2,187	\$2,097	-\$2,440	-\$115,175

Table 7.4.1-1: Economic Impacts Summary (Millions)

Event	Output/ Location	Agricultural Producer Welfare	Agricultural Consumer Welfare	Govt Costs - Indemnification	Govt Costs - Non Indemnification	Regional Non- Agricultural Impacts	Total Impact
	p50/p95	-\$62,610	-\$60,274	\$6,424	\$3,984	-\$2,600	-\$135,892
	p95/p5	-\$60,842	-\$59,389	\$8,693	\$4,954	-\$3,063	-\$136,941
	p95/p50	-\$61,238	-\$58,965	\$8,416	\$5,367	-\$3,718	-\$137,704
	p95/p95	-\$60,646	-\$58,723	\$9,850	\$5,600	-\$4,645	-\$139,464
Solid Waste Transfer Station	p5/p5	No Culled Animals					
	p5/p50	No Culled Animals					
	p5/p95	No Culled Animals					
	p50/p5	-\$19,954	\$3,521	\$11	\$3	-\$8	-\$16,455
	p50/p50	Same as p50/p5					
	p50/p95	Same as p50/p5					
	p95/p5	-\$19,093	\$4,010	\$1,049	\$180	-553	-\$16,866
	p95/p50	-\$68,027	-\$59,273	\$1,461	\$2,255	-\$2,806	-\$133,822
	p95/p95	-\$65,048	-\$58,791	\$5,484	\$3,512	-\$3,423	-\$136,257
Solid Waste Landfill	p5/p5	-\$19,932	\$3,480	\$4	\$1	-\$4	-\$16,461
	p5/p50	Same as p5/p50					
	p5/p95	Same as p5/p50					
	p50/p5	-\$19,827	\$3,521	\$138	\$29	-\$149	-\$16,622
	p50/p50	-\$19,785	\$3,533	\$182	\$47	-\$678	-\$17,159
	p50/p95	-\$66,426	-\$61,255	\$1,454	\$644	-\$1,414	-\$131,192
	p95/p5	-\$39,465	-\$32,990	\$2,263	\$666	-\$973	-\$76,357
	p95/p50	-\$62,233	-\$59,273	\$7,255	\$4,330	-\$2,646	-\$135,736
	p95/p95	-\$60,804	-\$58,791	\$9,728	\$5,181	-\$3,677	-\$138,181
Transference	p5/p5	-\$19,796	\$3,576	\$163	\$27	-\$163	-\$16,573
	p5/p50	-\$19,660	\$3,646	\$320	\$62	-\$310	-\$16,706
	p5/p95	-\$58,229	-\$52,239	\$521	\$270	-\$1,982	-\$113,241
	p50/p5	-\$39,473	-\$33,066	\$2,252	\$702	-\$983	-\$79,396
	p50/p50	-\$55,919	-\$51,213	\$3,107	\$2,348	-\$1,627	-\$79,622
	p50/p95	-\$61,445	-\$59,895	\$7,457	\$4,241	-\$4,087	-\$137,125
	p95/p5	-\$60,726	-\$59,506	\$8,662	\$4,925	-\$3,062	-\$136,881
	p95/p50	-\$61,238	-\$59,170	\$8,269	\$5,028	-\$3,128	-\$136,833
	p95/p95	-\$60,544	-\$58,966	\$9,850	\$5,621	-\$3,543	-\$138,523
Tornado Medium	p5/p5	-\$19,931	\$3,479	\$5	\$1	-\$10	-\$16,469
	p5/p50	-\$19,708	\$3,561	\$264	\$50	-\$167	-\$16,627
	p5/p95	-\$19,413	\$3,639	\$630	\$144	-\$297	-\$16,844
	p50/p5	-\$19,851	\$3,500	\$98	\$21	-\$81	-\$16,551
	p50/p50	-\$19,421	\$3,675	\$608	\$133	-\$323	-\$16,810
	p50/p95	-\$66,220	-\$61,132	\$1,632	\$710	-\$618	-\$130,312
	p95/p5	-\$19,372	\$3,728	\$660	\$140	-\$376	-\$16,822
	p95/p50	-\$47,844	-\$43,097	\$2,549	\$786	-\$1,226	-\$95,502
	p95/p95	-\$64,881	-\$61,073	\$3,174	\$2,623	-\$2,129	-\$133,879
Tornado	p5/p5	-\$39,496	-\$33,174	\$2,252	\$706	-\$802	-\$76,431

Table 7.4.1-1: Economic Impacts Summary (Millions)

Event	Output/ Location	Agricultural Producer Welfare	Agricultural Consumer Welfare	Govt Costs - Indemnification	Govt Costs - Non Indemnification	Regional Non- Agricultural Impacts	Total Impact
High	p5/p50	-\$39,560	-\$33,108	\$2,264	\$763	-\$1,176	-\$76,871
	p5/p95	-\$39,262	-\$33,009	\$2,522	\$918	-\$3,131	-\$78,842
	p50/p5	-\$39,478	-\$33,220	\$2,243	\$725	-\$760	-\$76,425
	p50/p50	-\$56,074	-\$52,452	\$2,585	\$1,228	-\$2,622	-\$114,960
	p50/p95	-\$62,412	-\$60,102	\$6,327	\$3,670	-\$4,147	-\$136,657
	p95/p5	-\$47,557	-\$43,605	\$2,350	\$786	-\$2,204	-\$96,503
	p95/p50	-\$64,450	-\$61,619	\$3,396	\$3,041	-\$2,281	-\$134,787
	p95/p95	-\$62,056	-\$59,981	\$7,410	\$4,290	-\$3,828	-\$137,565
Earthquake High	p5/p5	-\$19,931	\$3,479	\$5	\$1	-\$334	-\$16,793
	p5/p50	-\$19,721	\$3,539	\$255	\$56	-\$474	-\$16,966
	p5/p95	-\$39,437	-\$32,636	\$2,355	\$809	-\$2,702	-\$77,939
	p50/p5	-\$19,874	\$3,507	\$75	\$13	-\$359	-\$16,814
	p50/p50	-\$19,347	\$3,698	\$701	\$157	-\$917	-\$17,424
	p50/p95	-\$64,413	-\$61,699	\$3,794	\$2,834	-\$1,066	-\$133,806
	p95/p5	-\$19,503	\$3,783	\$557	\$128	-\$699	-\$17,104
	p95/p50	-\$65,699	-\$61,550	\$2,296	\$790	-\$1,292	-\$131,627
	p95/p95	-\$62,359	-\$59,852	\$7,532	\$4,326	-\$1,930	-\$135,998

7.4.2 Discussion and Implications

The economic consequence values reported in 7.4.1-1 need to be carefully and appropriately interpreted. The values are calculated conditional on the realizations of the epidemiological output for selected scenarios from Section 6, as well as other model assumptions and parameters. The economic consequences are also conditioned on the event that a release and/or outbreak has occurred. Section 8 reports the expected economic consequences not conditioned on the event that release and/or outbreak occurs.

This section reports two vaccination strategies, vaccinate-to-live and vaccinate-to-kill. It does not represent a definitive study of optimal vaccination strategies for FMD, which is outside the scope of the Updated SSRA. However, it does provide some insight into implications of the two strategies. One important assumption in defining the vaccinate-to-live versus vaccinate-to-kill strategies was the number of days of the outbreak (<180 days vs. >180 days). There are implications of this assumption. For example, if vaccinate-to-kill was chosen for an outbreak longer than 180 days, then there would be more animals culled. It would most likely result in larger supply shocks, and larger negative changes in producer welfare. In addition, the trade ban would be shortened by one quarter, per OIE suggested guidelines. This would most likely reduce negative impacts on producers, but may have a mixed impact on consumers. In regards to the government expenditures, there would be higher expenses due to appraisal of herds for culling, cleaning and disinfecting, euthanasia, and carcass disposal; however, there would be no costs associated with vaccination. Overall, because a response to a FMD outbreak will likely include a combination of culling, vaccinate-to-kill, and vaccinate-to-slaughter, important tradeoffs arise

and the total economic consequences are unclear. This calls for a more comprehensive analysis of the vaccination policies, which can more fully and completely address the tradeoffs.

8. Risk Calculations

This section of the Updated SSRA develops a quantitative assessment of the probabilities and economic consequences associated with the potential loss of containment of FMDv from the NBAF over the 50-year operating lifetime of the facility. This analysis is an update of the 2010 SSRA, which used a scenario-based assessment of risk and presented risk values as the product of the probability of a release and the economic consequence of a release separately for selected release scenarios at a single point in time. The approach used for the initial SSRA utilized conservative estimates of release probabilities and source terms to provide worst-case estimates of risk. This approach allowed scenarios to be ranked in a way that would inform design decisions. However, uncertainty associated with the risk values was not included quantitatively, and the risk values did not lend themselves to the computation of cumulative risk across scenarios or years. Based on feedback from the NAS SSRA Committee, the Updated SSRA presents cumulative probability and risk values across events and over the 50-year operating lifetime of the NBAF, along with quantitative estimates of uncertainty.

In this Updated SSRA, risks are again characterized by estimating probabilities and associated economic consequences for potential FMDv loss-of-containment events, and risk values are presented as the product of the probability of a release and the economic consequence of a release. Probabilities, risk values, and associated uncertainties are presented separately for each of the modeled FMDv loss-of-containment events. In addition, probabilities, risk values, and associated uncertainties are computed cumulatively across events and over time.

FMDv loss-of-containment events included in this assessment are described in detail in Section 4. Most of the loss-of-containment events were derived using fault tree analysis. A separate fault tree was constructed for each relevant combination of originating location (BSL-3Ag animal holding rooms (AHRs), BSL-3Ag necropsy suite, BSL-3E and “Special Procedures” (SP) rooms, or non-containment areas) and release pathway (aerosol, solid waste, liquid waste, or transference). For the transference pathway, multiple loss-of-containment fault trees were generated for each originating location, one corresponding to each applicable mode of transference (e.g., respiratory, hand, foot, body, or fomite). The detailed loss-of-containment fault trees are presented in Section 4.5 and each depicts a series of potential actions, errors, or containment system or process failures that could lead to a loss of FMDv containment. Within each fault tree, each unique outcome represents a separate loss-of-containment event that is mutually exclusive of all other events within the same fault tree (i.e., at a given point in time, only one potential outcome is realized). The resulting events comprise 140 of the 142 loss-of-containment events included in this Updated SSRA. Two additional events were not modeled through a fault-tree analysis: tornado events and earthquakes. These events are catastrophic events that involve loss of containment from multiple originating locations and through multiple pathways. Details related to these two events are described in Section 4.6.

Section 8.1 presents event-specific risk calculations. In Section 8.2, the event-specific risks are ranked and discussed. Section 8.3 presents cumulative risks, both across events and over time.

8.1 Loss-of-Containment Event-Specific Risk Calculations

The risk calculations presented in this section were computed separately for each loss-of-containment fault tree. Within each fault tree, the risks and associated uncertainties were first computed for each individual outcome; risks and uncertainties were then aggregated over all outcomes within a given fault tree.

Section 8.1.1 describes the general risk and uncertainty calculation approach. Section 8.1.2 presents risk calculations for the fault trees corresponding to aerosol releases, Section 8.1.3 solid-waste events, Section 8.1.4 liquid-waste events, and Section 8.1.5 transference events.

8.1.1 Risk and Uncertainty Calculation Approach

8.1.1.1 Input Parameters

There are three parameters presented in Section 4.5 associated with each outcome in each fault tree that are relevant to the risk calculations:

- P_{loss} is the probability of a given loss-of-containment outcome.¹ The probability of each loss-of-containment outcome is computed based on the probabilities associated with each step in the sequence that leads to that outcome. For each fault tree, the sum of the individual outcome probabilities is equal to 1. The stochastic variability associated with P_{loss} is based on a binomial distribution and is computed as $\sigma_{P_{loss}} = \sqrt{(1 - P_{loss})P_{loss}}$.
- Q represents the amount of viable FMDv involved in each loss-of-containment outcome. Q values are determined based on the amount of material present at the originating location, reduced as appropriate by the success or failure of each containment system or process corresponding to the outcome. Low, medium, and high Q values are computed for each loss-of-containment outcome, and typically represent the 5th percentile, the mean, and the 95th percentile of FMDv involved in the loss or release and are labeled as Q_L , Q_M , and Q_H . The specific basis for each range of Q values is explained in Sections 4.4 and 4.6; in all cases the ranges are based on empirical data and reflect stochastic variation in the amount of material that may be present at a given point in time when a release occurs.
- R_O is the number of opportunities per year corresponding to each fault tree. For example, for the BSL-3Ag AHR aerosol release fault tree, R_O represents the total number of days and rooms per year that FMDv-infected animals may be present. For a given day and room in which FMDv-infected animals are present, one (and only one) of the outcomes associated with the BSL-3Ag AHR aerosol release fault tree will be realized. In most cases, in addition to a point estimate for R_O , an estimate of the stochastic variation associated with R_O was computed (σ_R , the estimated standard deviation associated with R_O).

¹ In some fault trees, one or more outcomes may be considered to be “no loss” outcomes. In order to be complete, all outcomes were included.

In addition to the parameters above, which were derived and presented in Section 4, two additional parameters associated with each outcome for each fault tree that are key to risk calculations include the following:

- P_i is the conditional probability that a given loss-of-containment outcome results in at least one infection (i.e., an index case). The approaches for estimating P_i vary by pathway and are described in more detail in subsequent sections. Regardless of the pathway, for each event, a separate estimate for P_i is computed for each Q value (Q_L , Q_M , and Q_H). The resulting conditional probabilities are listed as: P_{iL} , P_{iM} , and P_{iH} . The value P_{iL} is associated with Q_L , which represents the 5th percentile of possible Q values associated with a given loss-of-containment outcome. In other words, 5% of the time that a loss of containment occurs, the amount of FMDv involved in the release will be Q_L or less and the probability of an infection event is P_{iL} . Similarly, 5% of the time that a loss of containment occurs, the amount of FMDv involved in the release will be Q_H or higher and the probability of an infection event is P_{iH} . The remaining 90% of the time that a loss of containment occurs, the amount of FMDv involved in the release is assumed to be Q_M and the probability of an infection event is P_{iM} . As a result, the estimate for P_i is obtained as follows:

$$P_i = 0.05P_{iL} + 0.90P_{iM} + 0.05P_{iH}$$

The stochastic variability associated with P_i is based on a binomial distribution and is computed as $\sigma_{P_i} = \sqrt{(1 - P_i)P_i}$.

8.1.1.2 Event-Specific Risk Values and Associated Uncertainties

For each individual outcome, the input parameters described above were used as input into the following risk calculations:

- F_{loss} is the expected frequency (per year) at which a given loss-of-containment outcome will occur. It is computed as the product of the probability that the loss-of-containment outcome will occur, given a single opportunity (P_{loss}) and the number of opportunities per year (R_O). The uncertainty is based on the uncertainty (stochastic variation) associated with R_O as well as the stochastic variability in P_{loss} . The equations for F_{loss} and the associated uncertainty are:

$$F_{loss} = P_{loss}R_O$$

$$\sigma_{F_{loss}} = F_{loss} \left(\frac{\sigma_{P_{loss}}^2}{P_{loss}^2} + \frac{\sigma_{R_O}^2}{R_O^2} \right)^{1/2}$$

- P_{event} is the probability that a given loss-of-containment outcome will occur *and* will result in an infection event (given a single opportunity). It is computed as the probability that the loss-of-containment will occur (P_{loss}) times the conditional probability that an infection event will occur given that the release event occurred (P_i). Because P_{loss} is a point estimate, the uncertainty in P_{event} is based on the uncertainty associated with P_i . The equation for P_{event} is:

$$P_{event} = P_{loss}P_i$$

The stochastic variability associated with P_{event} is based on a binomial distribution and is computed as $\sigma_{P_{event}} = \sqrt{(1 - P_{event})P_{event}}$.

- F_{event} is the expected frequency (per year) at which a given loss-of-containment outcome will occur *and* will result in an infection event. It is computed as the product of the frequency of the loss-of-containment outcome and the conditional probability that the loss will result in an infection (P_i). The equations for F_{event} and the associated uncertainty are:

$$F_{event} = F_{loss}P_i$$

$$\sigma_{F_{event}} = F_{event} \left(\frac{\sigma_{F_{loss}}^2}{F_{loss}^2} + \frac{\sigma_{P_i}^2}{P_i^2} \right)^{1/2}$$

- C_{event} is the estimated economic consequence, given that the loss-of-containment outcome is realized *and* at least one infection event ensues. For each outcome that may result in at least one infection event, three separate series of economic models are performed, one corresponding to the 5th, 50th, and 95th percentile outbreaks (see Section 6 for a description of the epidemiological modeling that provided the input into the economic modeling and Section 7 for the detailed economic modeling results). For each event, the estimated C_{event} value and the associated standard deviation, $\sigma_{C_{event}}$, are computed by assigning appropriate weighting values to each individual economic outcome and computing the resulting mean and standard deviation. The standard deviation reflects both stochastic variability and uncertainty. Note that if the conditional probability of an infection for a given Q value is zero, the corresponding consequence is not modeled and the corresponding C_{event} and $\sigma_{C_{event}}$ terms are set equal to zero.
- $Risk_{event}$ is the expected economic consequence associated with a given infection event. It is computed as the expected frequency (per year) at which the loss-of-containment outcome will occur and will result in an infection event, times the expected economic consequence if an infection does occur. The equations for $Risk_{event}$ and the associated uncertainty are as follows:

$$Risk_{event} = F_{event}C_{event}$$

$$\sigma_{Risk_{event}} = Risk_{event} \left(\frac{\sigma_{F_{event}}^2}{F_{event}^2} + \frac{\sigma_{C_{event}}^2}{C_{event}^2} \right)^{1/2}$$

8.1.1.3 Event-Tree Risk Values and Associated Uncertainties

As noted above, the potential infection events are derived based on the loss-of-containment fault trees presented in Section 4.5 (which are organized by release pathway and originating location). For each tree (referred to as an event tree in subsequent discussions), the following aggregate risk calculations are performed:

- P_{tree} is the total probability over all possible events within the event tree that an infection will occur (given a single opportunity). For each event tree, P_{tree} is computed as:

$$P_{tree} = \sum_{k=1}^n (P_{event})_k$$

where k is the k^{th} event in the event tree and n is the number of unique events associated with the tree. This equation is based on the assumption that each outcome in the fault tree is mutually exclusive. The associated uncertainty is computed as:

$$\sigma_{P_{tree}} = \left(\sum_{k=1}^n (\sigma_{P_{event}}^2)_k \right)^{1/2}$$

- F_{tree} is the expected frequency (per year) at which any event within the event tree will occur and will result in an infection. It is the product of the opportunities per year and P_{tree} , as defined above. The equations for F_{tree} and the associated uncertainty are:

$$F_{tree} = R_0 P_{tree}$$

$$\sigma_{F_{tree}} = F_{tree} \left(\frac{\sigma_{P_{tree}}^2}{P_{tree}^2} + \frac{\sigma_{R_0}^2}{R_0^2} \right)^{1/2}$$

- C_{tree} is the expected economic consequence associated with the event tree, given that an event in the tree occurs and results in an infection. It is the weighted average of the consequences associated with each of the mutually exclusive outcomes that comprise the tree. The equations for C_{tree} and the associated uncertainty are:

$$C_{tree} = \sum_{k=1}^n \left(\frac{P_{event}}{P_{tree}} C_{event} \right)_k$$

$$\sigma_{C_{tree}} = \left\{ \sum_{k=1}^n \left(\frac{P_{event}^2}{P_{tree}^2} \sigma_{C_{event}}^2 \right)_k \right\}^{1/2}$$

- $Risk_{tree}$ is the expected economic consequence associated with the event tree. It is the sum of the risks associated with the mutually exclusive events that comprise the event tree. The equations for $Risk_{tree}$ and the associated uncertainty are:

$$Risk_{tree} = \sum_{k=1}^n (Risk_{event})_k$$

$$\sigma_{Risk_{tree}} = \left\{ \sum_{k=1}^n (\sigma_{Risk_{event}}^2)_k \right\}^{1/2}$$

8.1.2 Aerosol Events

Four aerosol fault trees are presented in Section 4.5: one associated with the BSL-3Ag AHRs; one associated with the BSL-3Ag necropsy suite; one associated with BSL-3E/ BSL-3E SP rooms; and one associated with aerosol releases from non-containment areas. Each fault tree enumerates a series of potential HEPA filter failures and models the probability associated with each potential series of failures and the resulting potential release amounts (Q values).

For each aerosol loss-of-containment outcome, the low, medium, and high Q values presented in Section 4.5 served as input into fate and transport modeling, which is described in detail in Section 5. The output from each aerosol fate and transport model was in turn used as input into epidemiological modeling, which is described in Section 6. For each unique possible aerosol loss-of-containment outcome and for each unique Q value associated with each aerosol loss of containment, an estimate of the conditional probability that the release will result in an infection, or P_i , is output from the epidemiological modeling. The three P_i values for each event associated with the low, medium, and high Q values for that event are P_{iL} , P_{iM} , and P_{iH} , respectively.

In addition, for each event that resulted in a nonzero probability of an infection, the epidemiological modeling also resulted in a set of potential infection scenarios that served as input for the economic modeling, which is described in Section 7. In turn, three sets of economic output were generated for each event – one set corresponding to the 5th, 50th, and 95th percentiles of outbreak scenarios. For each event, the 5th, 50th, and 95th percentiles of possible economic outcomes were provided in the economic modeling output. These percentiles were used to assign weights to each potential economic outcome, and thereby compute C_{event} and $\sigma_{C_{event}}$. For example, for the 5th and 95th percentiles of economic outcomes associated with the 5th and 95th percentile outbreaks, weights of 2.5×10^{-3} were assigned (0.05 times 0.05); for the 50th percentile of economic outcomes associated with the 5th and 95th percentile outbreaks, weights of 4.5×10^{-2} were assigned (0.9 times 0.05). Similarly, for the 5th and 95th percentiles of economic outcomes associated with the 50th percentile outbreak, weights of 4.5×10^{-3} were assigned and for the 50th percentile of economic outcomes associated with the 50th percentile outbreak, a weight of 8.1×10^{-1} was assigned.

For three of the four aerosol fault trees considered (i.e., all but the non-containment area fault tree), only one specific case yielded a nonzero P_i value. Specifically, for all rooms within containment, only a complete HEPA failure would result in a possible infection, and then only if the highest Q term modeled were present when the failure occurred. Because the probability of a complete HEPA failure in any of the rooms is less than 1×10^{-30} , an infection due to a complete HEPA failure from a room within containment (given the fully redundant in-series HEPA filtration caisson designed for the NBAF), no subsequent economic modeling or risk calculations were performed for these events. A detailed discussion of the basis for the HEPA failure calculations is provided in Section 4.2.1. The epidemiological output for the HEPA failure events is described in Section 6.2.3.

The detailed input parameters for each of the four aerosol event trees are presented in Appendix A8 (Risk Calculation Supporting Material), along with the results of the event-specific and event-tree-specific risk calculations. A summary of the resulting risk values are presented in Tables 8.1.2-1 through 8.1.2-4.

Table 8.1.2-1: BSL-3Ag AHR Aerosol Event Tree (AA) Risk Calculations								
Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
AA1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AA2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AA3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AA4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AA5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AA6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AA7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AA8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AA9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AA10	4.70E-36	2.17E-18	8.15E-33	8.15E-16	Not Included Based on Frequency < 1x10 ⁻³⁰			
AA11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	4.70E-36	2.17E-18	8.15E-33	8.15E-16	Not Included – No Credible Events			

Table 8.1.2-2: Necropsy Suite Aerosol Event Tree (NA) Risk Calculations								
Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
NA1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NA2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NA3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NA4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NA5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NA6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NA7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NA8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NA9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NA10	5.00E-39	7.07E-20	2.11E-37	2.11E-20	Not Included Based on Frequency $< 1 \times 10^{-30}$			
NA11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	5.00E-39	7.07E-20	2.11E-37	2.11E-20	Not Included – No Credible Events			

Table 8.1.2-3: BSL-3E/ BSL-3E SP Aerosol Event Tree (EA) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr^{-1})		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
EA0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EA10	1.00E-41	3.16E-21	5.25E-37	1.17E-18	Not Included Based on Frequency $< 1 \times 10^{-30}$			
EA11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr^{-1})		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	1.00E-41	3.16E-21	5.25E-37	1.17E-18	Not Included – No Credible Events			

Table 8.1.2-4: Non-Containment Aerosol Event Tree (OA) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
OA1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
OA2	3.98E-10	1.99E-05	1.99E-07	1.42E-04	\$108,001	\$29,924	\$0.02	\$15.30
OA3	3.98E-13	6.31E-07	1.99E-10	4.46E-06	\$108,001	\$29,924	<\$0.01	\$0.48
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	3.98E-10	1.99E-05	1.99E-07	1.42E-04	\$108,001	\$29,894	\$0.02	\$15.31

8.1.3 Solid Waste Events

Four solid waste fault trees are presented in Section 4.5: one associated with the BSL-3Ag AHRs; two associated with the BSL-3Ag necropsy suite; and one associated with BSL-3E/ BSL-3E SP rooms. For each room type, one fault tree enumerates a series of potential autoclave and/or incinerator failures and models the probability associated with each potential series of failures and the resulting potential release amounts (Q values). In addition, for the necropsy suite, there is an additional fault tree associated with carcass and tissue disposal outcomes.

For each solid waste loss-of-containment outcome, the low, medium, and high Q terms presented in Section 4.5 served as input into fate and transport calculations, which were used to determine the probability of two potential infection scenarios: (1) an infection occurring at a facility located between the NBAF and the Riley County Transfer Station, or (2) an infection occurring at a facility between the transfer station and the landfill (Hamm Quarry). Epidemiological models and subsequent economic models were run for each of these two potential starting locations (referred to as Site 1 and Site 2). These models resulted in the following parameters, which served as input into the risk calculations: P_{iL} , P_{iM} , and P_{iH} for Site 1, and P_{iL} , P_{iM} , and P_{iH} for Site 2 (where the L, M, and H values below correspond to the Q_L , Q_M , and Q_H values respectively).

In order to generate a single probability of infection value for each outcome, the following equations were applied:

$$P_{i1} = 0.05(P_{iL}(\text{Site1})) + 0.90(P_{iM}(\text{Site1})) + 0.05(P_{iH}(\text{Site1}))$$

$$P_{i2} = 0.05(P_{iL}(\text{Site2})) + 0.90(P_{iM}(\text{Site2})) + 0.05(P_{iH}(\text{Site2}))$$

$$P_i = 1 - \prod_{k=1}^2 (1 - P_{ik})$$

Three sets of economic output values were generated for each site – one set corresponding to the 5th, 50th, and 95th percentiles of outbreak scenarios. In turn, for each site and outbreak scenario, the 5th, 50th, and 95th percentiles of possible economic outcomes were provided in the economic modeling output. These percentiles were used to assign weights to each of the nine modeled economic outcomes for each site, and thereby compute C_{Sitek} and $\sigma_{C_{Sitek}}$ for each site. The same weighting approach as was applied to aerosol events was applied to solid waste events (see Section 8.1.2).

The overall estimate of the economic consequence for a given solid waste event was computed based on the probability that each site would be affected, relative to P_i (which is the probability that an infection would begin at either site). For the potential outcome where an infection begins at both sites, the higher of the two economic consequence values (i.e., those associated with Site 2) was assumed. The following equations were applied:

$$C_{event} = \frac{P_{i1}(1 - P_{i2})}{P_i} C_{Site1} + \frac{P_{i2}}{P_i} C_{Site2}$$

$$\sigma_{C_{event}} = \left\{ \frac{P_{i1}(1 - P_{i2})}{P_i} (\sigma_{C_{Site1}}^2 + C_{Site1}^2) + \frac{P_{i2}}{P_i} (\sigma_{C_{Site2}}^2 + C_{Site2}^2) - C_{event}^2 \right\}^{1/2}$$

The detailed input parameters and the results for the calculations described above are presented in Appendix A8, along with the results of the event-specific and event-tree-specific risk calculations. A summary of the resulting risk values are presented in Tables 8.1.3-1 through 8.1.3-4. For all solid waste event trees considered in this Updated SSRA, the expected frequency of a loss that leads to an infection is less than 5×10^{-9} . If an infection due to a solid waste release were to occur, the expected economic consequence would be approximately \$25B. The risk (computed as the expected frequency of a loss leading to an infection times the consequence of an infection) is less than \$0.01M for all solid waste event trees.

Table 8.1.3-1: BSL-3Ag AHR Solid Waste Event Tree (AS) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
AS1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AS2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AS3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AS4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AS5	1.35E-16	1.16E-08	1.53E-14	3.42E-07	\$24,675	\$30,198	<\$0.01	\$0.01
AS6	9.99E-21	1.00E-10	1.13E-18	1.13E-08	\$27,843	\$33,671	<\$0.01	<\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	1.35E-16	1.16E-08	1.53E-14	3.42E-07	\$24,676	\$30,196	<\$0.01	\$0.01

Table 8.1.3-2: Necropsy Suite Solid Waste Event Tree (NSW) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
NSW1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NSW2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NSW3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NSW4	7.55E-12	2.75E-06	3.19E-10	3.19E-05	\$24,683	\$30,207	<\$0.01	\$0.79
NSW5	1.95E-16	1.04E-08	8.22E-15	1.84E-07	\$24,703	\$30,232	<\$0.01	<\$0.01
NSW6	1.00E-20	1.00E-10	4.22E-19	4.22E-09	\$27,985	\$33,811	<\$0.01	<\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	7.55E-12	2.75E-06	3.19E-10	3.19E-05	\$24,683	\$30,206	<\$0.01	\$0.79

Table 8.1.3-3: Necropsy Suite Solid Waste (Carcasses/Tissues) Event Tree (NST) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
NST1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NST2	6.77E-11	8.23E-06	2.86E-09	2.86E-04	\$25,553	\$31,231	<\$0.01	\$7.31
NST3	8.59E-12	2.93E-06	3.63E-10	3.63E-05	\$24,693	\$30,219	<\$0.01	\$0.90
NST4	1.00E-20	1.00E-10	4.22E-19	4.22E-09	\$28,004	\$33,830	<\$0.01	<\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	7.63E-11	8.74E-06	3.22E-09	2.88E-04	\$25,456	\$27,922	\$0.00	\$7.37

Table 8.1.3-4: BSL-3E/ BSL-3E SP Solid Waste Event Tree (ES) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
ES1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
ES2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
ES3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
ES4	3.76E-12	1.94E-06	9.40E-10	9.40E-05	\$24,649	\$30,166	<\$0.01	\$2.32
ES5	1.89E-16	1.37E-08	4.72E-14	1.06E-06	\$24,701	\$30,228	<\$0.01	\$0.03
ES6	9.99E-21	9.99E-11	2.50E-18	2.50E-08	\$27,797	\$33,625	<\$0.01	<\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	3.76E-12	1.94E-06	9.40E-10	9.40E-05	\$24,649	\$30,164	<\$0.01	\$2.32

8.1.4 Liquid Waste Events

Three liquid waste fault trees are presented in Section 4.5: one associated with the BSL-3Ag AHRs, one associated with the BSL-3Ag necropsy suites, and one associated with BSL-3E/ BSL-3E SP rooms. For each room type, the fault tree enumerates a series of potential disinfection and/or cook tank failures and models the probability associated with each potential series of failures and the resulting potential release amounts (Q values).

For each liquid waste loss-of-containment outcome, the low, medium, and high Q terms presented in Section 4.5 served as input into fate and transport calculations, which were used to determine the probability of four potential infection scenarios: 1) an infection occurring at a susceptible premises near the NBAF (the “Denison premises,” Premises A); 2) an infection occurring at a susceptible premises near the location of a major sewer junction (the “Marlatt premises,” Premises B); 3) an infection occurring at a premises near a surface water feature (the “Highway 905 premises,” Premises C); or 4) an infection occurring at a facility near the Big Blue River (Premises D). Epidemiological models and subsequent economic models were run for each of these four potential starting locations (referred to as Premises A through D). These models resulted in the following parameters, which served as input into the risk calculations: P_{iL} , P_{iM} , and P_{iH} for Premises A through D (where the L, M, and H values below correspond to the Q_L , Q_M , and Q_H values respectively).

In order to generate a single probability of infection value for each outcome, the following equations were applied:

$$P_{i1} = 0.05(P_{iL (PremisesA)}) + 0.90(P_{iM (PremisesA)}) + 0.05(P_{iH (PremisesA)})$$

$$P_{i2} = 0.05(P_{iL (PremisesB)}) + 0.90(P_{iM (PremisesB)}) + 0.05(P_{iH (PremisesB)})$$

$$P_{i3} = 0.05(P_{iL (PremisesC)}) + 0.90(P_{iM (PremisesC)}) + 0.05(P_{iH (PremisesC)})$$

$$P_{i4} = 0.05(P_{iL (PremisesD)}) + 0.90(P_{iM (PremisesD)}) + 0.05(P_{iH (PremisesD)})$$

$$P_i = 1 - \prod_{k=1}^4 (1 - P_{i_k})$$

Three sets of economic output values were also generated for each premises – one set corresponding to the 5th, 50th, and 95th percentiles of outbreak scenarios. In turn, for each premises and outbreak scenario, the 5th, 50th, and 95th percentiles of possible economic outcomes were provided in the economic modeling output. These percentiles were used to assign weights to each of the nine modeled economic outcomes for each site, and thereby compute $C_{PremisesK}$ and $\sigma_{C_{PremisesK}}$ for each site. The same weighting approach as was applied to aerosol and solid waste events was applied to liquid waste events (see Section 8.1.2 for details).

The overall estimate of the economic consequence for a given liquid waste event was computed based on the probability that each premises would be affected, relative to P_i (which is the probability that an infection would begin at any premises). For the potential outcome where an infection begins at multiple premises, the highest economic consequence value was assumed. Equations similar to those shown in 8.1.3 were applied to obtain C_{event} and $\sigma_{C_{event}}$.

The detailed input parameters and the results for the calculations described above are presented in Appendix A8, along with the results of the event-specific and fault-tree-specific risk calculations. A summary of the resulting risk values are presented in Tables 8.1.4-1 through 8.1.4-3. For the liquid waste event trees considered in this Updated SSRA, the expected frequency of a loss that leads to an infection is less than 1×10^{-7} in all locations. If an infection due to a liquid waste release were to occur, the expected economic consequence would be approximately \$108B. The risk (computed as the expected frequency of a liquid loss leading to an infection times the consequence of an infection) is less than or equal to \$0.01M for all locations.

Table 8.1.4-1: BSL-3Ag AHR Liquid Waste Event Tree (AL) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr^{-1})		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
AL1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AL2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AL3	6.53E-11	8.08E-06	7.41E-09	7.60E-04	\$107,485	\$31,957	<\$0.01	\$81.68
AL4	8.21E-16	2.86E-08	9.31E-14	3.02E-06	\$107,605	\$31,731	<\$0.01	\$0.32
AL5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AL6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
AL7	3.63E-12	1.91E-06	4.12E-10	1.86E-04	\$107,484	\$31,923	<\$0.01	\$20.03
AL8	4.39E-17	6.62E-09	4.98E-15	7.12E-07	\$107,641	\$31,707	<\$0.01	\$0.08
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in an Infection		Frequency of an Infection Event (yr^{-1})		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	6.89E-11	8.30E-06	7.82E-09	7.82E-04	\$107,485	\$30,321	<\$0.01	\$84.10

Table 8.1.4-2: Necropsy Suite Liquid Waste Event Tree (NL) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
NL1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NL2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NL3	7.70E-12	2.77E-06	3.25E-10	3.27E-05	\$107,202	\$31,184	<\$0.01	\$3.50
NL4	4.93E-16	2.22E-08	2.08E-14	6.62E-07	\$107,806	\$32,521	<\$0.01	\$0.07
NL5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
NL6	2.24E-09	4.74E-05	9.48E-08	3.00E-04	\$107,822	\$32,757	<\$0.01	\$32.37
NL7	9.27E-13	9.63E-07	3.92E-11	3.92E-05	\$107,806	\$31,546	<\$0.01	\$4.23
NL8	9.82E-18	3.13E-09	4.15E-16	1.31E-07	\$107,984	\$31,519	<\$0.01	\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	2.25E-09	4.75E-05	9.52E-08	3.05E-04	\$107,820	\$32,631	\$0.01	\$32.84

Table 8.1.4-3: BSL-3E/ BSL-3E SP Liquid Waste Event Tree (EL) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
EL1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EL2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EL3	4.36E-15	6.60E-08	2.29E-10	2.29E-03	\$108,052	\$31,943	<\$0.01	\$247.28
EL4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
EL5	7.14E-15	8.45E-08	3.75E-10	3.75E-03	\$107,866	\$31,315	<\$0.01	\$1.28
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	4.36E-15	6.60E-08	2.29E-10	2.29E-03	\$108,052	\$31,943	<\$0.01	\$247.28

8.1.5 Transference Events

Thirteen transference fault trees are presented in Section 4.5:

- Two transference fault trees are associated with the BSL-3Ag AHRs (one corresponding to respiratory transfer events and one to fomite transfer events);
- Three transference fault trees are associated with the BSL-3Ag necropsy suites (two corresponding to hand transference and one corresponding to transference on the body);
- Three transference fault trees are associated with the BSL-3E/BSL-3E SP rooms (two corresponding to hand transference and one corresponding to transference on the body); and
- Five transference fault trees are associated with non-containment areas (one each corresponding to hand, foot, and body transference from a spill outside of containment, as well as fomite and palm transference from contact with a leaking drain pipe below an AHR).

Each fault tree enumerates a series of potential hygiene or equipment failures resulting in an event in which material is carried from the NBAF and could potentially be transferred to susceptible species.

Each fault tree models the probability associated with each potential series of failures and the resulting potential amounts of material involved in the event (Q values).

For each individual transference event, the low, medium, and high Q terms presented in Section 4.5 served as input into Monte Carlo simulations, which are described in detail in Section 5 and were used to determine the probability of an infection. Outputs from the Monte Carlo simulations were used as input into epidemiological models and subsequent economic models. The results of the Monte Carlo and subsequent epidemiological and economic modeling include three P_i values for each event (associated with the low, medium, and high Q terms for that event, labeled P_{iL} , P_{iM} , and P_{iH} , respectively).

For all transference events, a single set of epidemiological models were run (i.e., the modeling assumed that an infection had begun due to transference; the specific mechanism by which the transference had occurred did not affect the models). The epidemiological modeling generated 5th, 50th, and 95th percentile transference outbreak scenarios, which then served as input into economic modeling. For each of the three outbreak scenarios, the economic modeling generated estimates of the 5th, 50th, and 95th percentiles of possible economic outcomes. These percentiles were used to assign weights to each potential economic outcome, and thereby compute C_{event} and $\sigma_{C_{event}}$. The same weighting approach as was applied to aerosol events was applied to transference events (see Section 8.1.2 for details).

The detailed input parameters for each of the transference event trees are presented in Appendix A8, along with the results of the event-specific and event-tree-specific risk calculations. A summary of the resulting risk values are presented in Tables 8.1.5-1 through 8.1.5-12. For all transference event trees considered in this Updated SSRA, the expected frequency of a loss that leads to an infection is approximately 1×10^{-6} . If an infection due to transference were to occur, the expected economic consequence would be approximately \$82B. The risk (computed as the expected frequency of a liquid loss leading to an infection times the consequence of an infection) is less than or equal to \$0.05M for all transference events.

Table 8.1.5-1: BSL-3Ag AHR Respiratory Transference Event Tree (ATR) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
ATR1	2.71E-17	5.20E-09	1.54E-14	2.91E-06	\$82,028	\$22,327	<\$0.01	\$0.24
ATR2	8.34E-18	2.89E-09	4.73E-15	2.59E-07	\$82,028	\$22,327	<\$0.01	\$0.02
ATR3	4.93E-21	7.02E-11	2.80E-18	2.78E-09	\$82,028	\$22,327	<\$0.01	<\$0.01
ATR4	1.60E-19	4.00E-10	9.07E-17	2.54E-09	\$82,028	\$22,327	<\$0.01	<\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in an Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	3.56E-17	5.96E-09	2.02E-14	2.92E-06	\$82,028	\$17,775	<\$0.01	\$0.24

Table 8.1.5-2: BSL-3Ag AHR Fomite Transference Event Tree (ATF) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
ATF1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
ATF2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
ATF3	4.40E-10	2.10E-05	2.50E-07	7.77E-05	\$82,028	\$22,327	\$0.02	\$6.37
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	4.40E-10	2.10E-05	2.50E-07	7.77E-05	\$82,028	\$22,327	\$0.02	\$6.37

Table 8.1.5-3: Necropsy Suite Transference (Hand) Event Tree (NTH1-6) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr^{-1})		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
NTH1	4.06E-16	2.02E-08	6.87E-14	3.26E-06	\$82,028	\$22,327	<\$0.01	\$0.27
NTH2	4.80E-12	2.19E-06	8.11E-10	1.02E-04	\$82,028	\$22,327	<\$0.01	\$8.37
NTH3	3.06E-16	1.75E-08	5.17E-14	2.83E-07	\$82,028	\$22,327	<\$0.01	\$0.02
NTH4	5.64E-13	7.51E-07	9.54E-11	3.51E-06	\$82,028	\$22,327	<\$0.01	\$0.29
NTH5	5.50E-17	7.42E-09	9.30E-15	6.02E-09	\$82,028	\$22,327	<\$0.01	<\$0.01
NTH6	9.52E-15	9.76E-08	1.61E-12	2.29E-08	\$82,028	\$22,327	<\$0.01	<\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr^{-1})		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	5.37E-12	2.32E-06	9.08E-10	1.02E-04	\$82,028	\$20,077	<\$0.01	\$8.38

Table 8.1.5-4: Necropsy Suite Transference (Hand) Event Tree (NTH7-12) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
NTH7	2.19E-18	1.48E-09	3.70E-16	1.76E-08	\$82,028	\$22,327	<\$0.01	<\$0.01
NTH8	3.43E-19	5.86E-10	5.80E-17	6.96E-10	\$82,028	\$22,327	<\$0.01	<\$0.01
NTH9	9.26E-20	3.04E-10	1.57E-17	1.81E-11	\$82,028	\$22,327	<\$0.01	<\$0.01
NTH10	1.14E-13	3.38E-07	1.93E-11	2.84E-07	\$82,028	\$22,327	<\$0.01	\$0.02
NTH11	7.33E-15	8.56E-08	1.24E-12	7.63E-09	\$82,028	\$22,327	<\$0.01	<\$0.01
NTH12	3.85E-16	1.96E-08	6.51E-14	2.61E-09	\$82,028	\$22,327	<\$0.01	<\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	1.22E-13	3.49E-07	2.06E-11	2.85E-07	\$82,028	\$20,959	<\$0.01	\$0.02

Table 8.1.5-5: Necropsy Suite Transference (Body) Event Tree (NTB) Risk Calculations								
Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
NTB1	1.22E-12	1.10E-06	2.06E-10	1.85E-04	\$82,028	\$22,327	<\$0.01	\$15.16
NTB2	2.98E-11	5.46E-06	5.03E-09	9.17E-05	\$82,028	\$22,327	<\$0.01	\$7.53
NTB3	5.53E-14	2.35E-07	9.35E-12	3.95E-06	\$82,028	\$22,327	<\$0.01	\$0.32
NTB4	3.12E-12	1.77E-06	5.27E-10	2.98E-06	\$82,028	\$22,327	<\$0.01	\$0.24
NTB5	2.04E-15	4.51E-08	3.44E-13	3.79E-08	\$82,028	\$22,327	<\$0.01	<\$0.01
NTB6	1.84E-14	1.36E-07	3.11E-12	1.31E-08	\$82,028	\$22,327	<\$0.01	<\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	3.42E-11	5.85E-06	5.78E-09	2.06E-04	\$82,028	\$19,566	<\$0.01	\$16.93

Table 8.1.5-6: BSL-3E/BSL-3E SP Transference (Hand) Event Tree (ETP0-6) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
ETP0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
ETP1	4.11E-17	6.41E-09	8.63E-13	5.76E-06	\$82,028	\$22,327	<\$0.01	\$0.47
ETP2	6.89E-14	2.63E-07	1.45E-09	6.80E-05	\$82,028	\$22,327	<\$0.01	\$5.57
ETP3	3.35E-17	5.78E-09	7.03E-13	5.21E-07	\$82,028	\$22,327	<\$0.01	\$0.04
ETP4	9.16E-15	9.57E-08	1.92E-10	2.49E-06	\$82,028	\$22,327	<\$0.01	\$0.20
ETP5	1.96E-19	4.42E-10	4.11E-15	2.00E-09	\$82,028	\$22,327	<\$0.01	<\$0.01
ETP6	2.51E-16	1.58E-08	5.27E-12	8.76E-08	\$82,028	\$22,327	<\$0.01	\$0.01
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	7.84E-14	2.80E-07	1.65E-09	6.82E-05	\$82,028	\$19,800	<\$0.01	\$5.60

Table 8.1.5-7: BSL-3E/BSL-3E SP Transference (Hand) Event Tree (ETP7-12) Risk Calculations								
Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
ETP7	1.88E-17	4.34E-09	3.95E-13	6.39E-06	\$82,028	\$22,327	<\$0.01	\$0.52
ETP8	2.35E-16	1.53E-08	4.94E-12	2.27E-06	\$82,028	\$22,327	<\$0.01	\$0.19
ETP9	4.35E-19	6.59E-10	9.13E-15	4.88E-09	\$82,028	\$22,327	<\$0.01	<\$0.01
ETP10	7.58E-13	8.71E-07	1.59E-08	9.10E-05	\$82,028	\$22,327	<\$0.01	\$7.47
ETP11	4.39E-14	2.10E-07	9.22E-10	2.87E-06	\$82,028	\$22,327	<\$0.01	\$0.24
ETP12	6.58E-16	2.56E-08	1.38E-11	5.53E-07	\$82,028	\$22,327	<\$0.01	\$0.05
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	8.03E-13	8.96E-07	1.69E-08	9.13E-05	\$82,028	\$21,116	<\$0.01	\$7.49

Table 8.1.5-8: BSL-3E/BSL-3E SP Transference (Body) Event Tree (ETB) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
ETB0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
ETB1	7.69E-15	8.77E-08	1.61E-10	8.15E-05	\$82,028	\$22,327	<\$0.01	\$6.69
ETB2	2.29E-13	4.78E-07	4.80E-09	4.47E-05	\$82,028	\$22,327	<\$0.01	\$3.67
ETB3	3.27E-15	5.72E-08	6.87E-11	5.33E-06	\$82,028	\$22,327	<\$0.01	\$0.44
ETB4	5.74E-14	2.40E-07	1.21E-09	3.51E-06	\$82,028	\$22,327	<\$0.01	\$0.29
ETB5	9.82E-17	9.91E-09	2.06E-12	4.72E-08	\$82,028	\$22,327	<\$0.01	<\$0.01
ETB6	3.18E-16	1.78E-08	6.67E-12	2.99E-07	\$82,028	\$22,327	<\$0.01	\$0.02
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	2.97E-13	5.45E-07	6.24E-09	9.32E-05	\$82,028	\$17,707	<\$0.01	\$7.64

Table 8.1.5-9: Non-Containment Transference (Hand) Event Tree (OTP) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
OTP1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
OTP2	2.38E-10	1.54E-05	1.19E-07	8.52E-05	\$82,028	\$22,327	\$0.01	\$6.99
OTP3	2.64E-13	5.13E-07	1.32E-10	2.96E-06	\$82,028	\$22,327	<\$0.01	\$0.24
OTP4	1.13E-10	1.06E-05	5.67E-08	5.68E-04	\$82,028	\$22,327	<\$0.01	\$46.61
OTP5	1.21E-13	3.48E-07	6.04E-11	1.92E-05	\$82,028	\$22,327	<\$0.01	\$1.57
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	3.51E-10	1.87E-05	1.76E-07	5.75E-04	\$82,028	\$16,732	\$0.01	\$47.16

Table 8.1.5-10: Non-Containment Transference (Foot) Event Tree (OTF) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
OTF1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
OTF2	3.10E-10	1.76E-05	1.55E-07	1.55E-03	\$82,028	\$22,327	\$0.01	\$127.51
OTF3	2.98E-13	5.46E-07	1.49E-10	4.73E-05	\$82,028	\$22,327	<\$0.01	\$3.88
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	3.10E-10	1.76E-05	1.55E-07	1.56E-03	\$82,028	\$22,306	\$0.01	\$127.56

Table 8.1.5-11: Non-Containment Transference (Body) Event Tree (OTB) Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
OTB1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
OTB2	1.07E-09	3.27E-05	5.33E-07	3.80E-04	\$82,028	\$22,327	<\$0.01	<\$0.01
OTB3	1.10E-12	1.05E-06	5.52E-10	1.24E-05	\$82,028	\$22,327	\$0.04	\$31.16
OTB4	1.37E-10	1.17E-05	6.85E-08	6.87E-04	\$82,028	\$22,327	<\$0.01	\$1.02
OTB5	1.37E-13	3.70E-07	6.84E-11	2.17E-05	\$82,028	\$22,327	\$0.01	\$56.38
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	1.20E-09	3.47E-05	6.02E-07	7.86E-04	\$82,028	\$19,927	\$0.05	\$64.45

Table 8.1.5-12: Non-Containment Transference (Fomite) Event Tree (OTFom) Risk Calculations								
Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
OTFom1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a

Table 8.1.5-13: Non-Containment Transference (Palm) Event Tree (OTPalm) Risk Calculations								
Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
OTPalm1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a
Aggregate Risk Calculations								
All Events	Probability that a Loss Occurs and Results in and Infection		Frequency of an Infection Event (yr ⁻¹)		Economic Consequence of an Infection (\$M)		Event Tree Risk (\$M)	
	P_{tree}	$\sigma_{P_{tree}}$	F_{tree}	$\sigma_{F_{tree}}$	C_{tree}	$\sigma_{C_{tree}}$	$Risk_{tree}$	$\sigma_{Risk_{tree}}$
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	n/a	n/a	n/a	n/a

8.1.6 Catastrophic Events

Two catastrophic events are considered in this risk assessment: tornados and earthquakes. Detailed discussions related to these two catastrophic events are provided in Section 4. For each of these two events, the analysis presented in Section 4 resulted in estimated probabilities of occurrence and potential release amounts (Q values).

For tornados, two scenarios were carried through fate and transport, epidemiological, and economic modeling (specifically, both a 10^8 and a 10^{10} release were modeled). As presented in Section 4, the potential release amounts (Q values) associated with a tornado event are on the order of 10^6 (for the 5th and 50th percentile values) and 10^{10} (for the 95th percentile value). For purposes of risk calculations, the P_i values and consequence estimates associated with the 10^8 models were, conservatively, given 95% weights and the P_i values and consequence estimates associated with the 10^{10} models were given 5% weights. Specifically, for tornados, P_i was computed as $P_i = 0.95P_{i(10^8)} + 0.05P_{i(10^{10})}$. Similarly, two sets of economic outputs were combined by assigning an additional weighting factor to the output values of 0.95 for the output values associated with the 10^8 model and 0.05 for the output values associated with the 10^{10} model.

For earthquakes, 10^4 , 10^5 , and 10^8 releases were included in the fate and transport and epidemiological modeling. However, because the 10^4 and 10^5 releases resulted in no probability of infection, only the 10^8 release was included in subsequent economic modeling. As presented in Section 4, the potential release amounts (Q values) associated with an earthquake event are on the order of 10^4 (for the 5th percentile value), 10^5 (for the 50th percentile value), and 10^8 (for the 95th percentile value). For purposes of risk calculations for earthquakes, the P_i values and consequence estimates were weighted as follows. P_i was computed as $P_i = 0.05P_{i(10^4)} + 0.90P_{i(10^5)} + 0.05P_{i(10^8)}$.

The input parameters and the results for the calculations described above are presented in Appendix A8. A summary of the resulting risk values are presented in Tables 8.1.6-1.

Table 8.1.6-1: Catastrophic Events Risk Calculations

Event	Probability that the Loss Occurs and Results in an Infection Event		Frequency of an Infection Event (yr^{-1})		Economic Consequence of an Infection (\$M)		Event Risk (\$M)	
	P_{event}	$\sigma_{P_{event}}$	F_{event}	$\sigma_{F_{event}}$	C_{event}	$\sigma_{C_{event}}$	$Risk_{event}$	$\sigma_{Risk_{event}}$
Tornado	6.78E-08	2.60E-04	6.78E-08	2.55E-04	\$30,105	\$33,834	<\$0.01	\$7.69
Earthquake	2.00E-05	4.47E-03	2.00E-05	1.00E-03	\$28,197	\$33,536	\$0.56	\$28.30

8.2 Risk Rankings for FMDv-Related Events

In total, twenty-six event trees (including the two catastrophic events) comprising a total of 144 events were evaluated. This section presents a comparative analysis and interpretation of the risks across the event trees and individual events comprising each tree that were considered in this Updated SSRA.

Twenty-one of the twenty-six risk trees were found to have an observable risk. Figure 8.2-1 shows the fault-tree frequencies and consequences for each of the fault trees. Note that in this figure, the frequencies and consequences are aggregated for each event tree. Individual events are not shown.

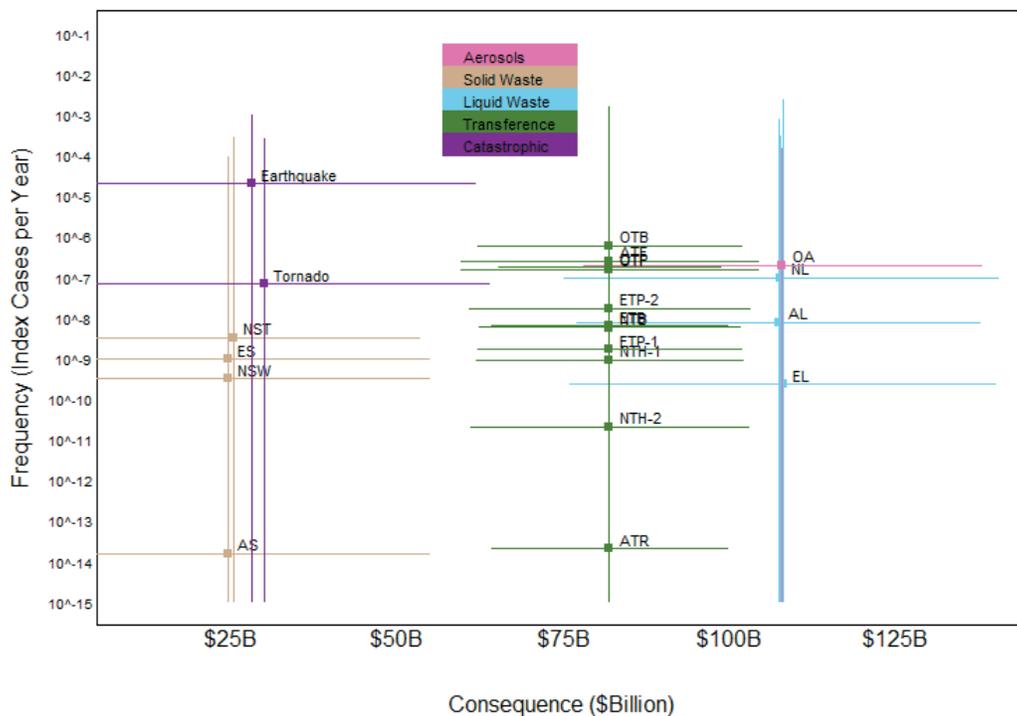


Figure 8.2-1: Frequency-Consequence Plot for All Event Trees

Table 8.2-1 presents the risks for all trees with an observed risk (i.e., the expected frequency of a release resulting in an infection times the estimated consequence if a release resulting in an infection occurs).

Table 8.2-1: Risk Values by Event Tree

Tree Name	F_{Tree} : Frequency of Loss Leading to an Infection (yr^{-1})		C_{Tree} : Economic Consequence, Conditional on an Infection Occurring (\$M)		$Risk_{Tree}$: Economic Risk Associated with the Event Tree (\$M)	
	Expected F_{Tree}	σF_{Tree}	Expected C_{Tree}	σC_{Tree}	Expected $Risk_{Tree}$	$\sigma Risk_{Tree}$
Earthquake	2.00E-05	1.00E-03	\$28,197	\$33,536	\$0.56	\$28.30
OTB	6.02E-07	7.86E-04	\$82,028	\$19,927	\$0.05	\$64.45
OA	1.99E-07	1.42E-04	\$108,001	\$29,894	\$0.02	\$15.31
ATF	2.50E-07	7.77E-05	\$82,028	\$22,327	\$0.02	\$6.37
OTP	1.76E-07	5.75E-04	\$82,028	\$16,732	\$0.01	\$47.16
OTF	1.55E-07	1.56E-03	\$82,028	\$22,306	\$0.01	\$127.56
NL	9.52E-08	3.05E-04	\$107,820	\$32,631	\$0.01	\$32.84
Tornado	6.78E-08	2.55E-04	\$30,105	\$33,834	<\$0.01	\$7.69
ETP-2	1.69E-08	9.13E-05	\$82,028	\$21,116	<\$0.01	\$7.49
AL	7.82E-09	7.82E-04	\$107,485	\$30,321	<\$0.01	\$84.10
ETB	6.24E-09	9.32E-05	\$82,028	\$17,707	<\$0.01	\$7.64
NTB	5.78E-09	2.06E-04	\$82,028	\$19,566	<\$0.01	\$16.93
ETP-1	1.65E-09	6.82E-05	\$82,028	\$19,800	<\$0.01	\$5.60
NST	3.22E-09	2.88E-04	\$25,456	\$27,922	<\$0.01	\$7.37
NTH-1	9.08E-10	1.02E-04	\$82,028	\$20,077	<\$0.01	\$8.38
EL	2.29E-10	2.29E-03	\$108,052	\$31,943	<\$0.01	\$247.28
ES	9.40E-10	9.40E-05	\$24,649	\$30,164	<\$0.01	\$2.32
NSW	3.19E-10	3.19E-05	\$24,683	\$30,206	<\$0.01	\$0.79
NTH-2	2.06E-11	2.85E-07	\$82,028	\$20,959	<\$0.01	\$0.02
ATR	2.02E-14	2.92E-06	\$82,028	\$17,775	<\$0.01	\$0.24
AS	1.53E-14	3.42E-07	\$24,676	\$30,196	<\$0.01	\$0.01

Pink: Aerosol; Brown: Solid Waste; Blue: Liquid waste; Green: Transference; Purple: Catastrophic

Figure 8.2-2 graphically presents the expected risk values from Table 8.2-1. In this figure, events are organized by event tree, and the height of each bar represents the total risk for each event tree. Whiskers extending above each bar represent the estimated risk plus the associated uncertainty (standard deviation). Bars are sub-divided to show the contribution of each individual event to the total risk for each tree; individual events within each tree are ordered from bottom to top in order of the smallest risk contributors to the largest risk contributors. Because the y-axis is logarithmic, the relative contribution of each event is not necessarily proportional to the relative area represented on the bar for that event.

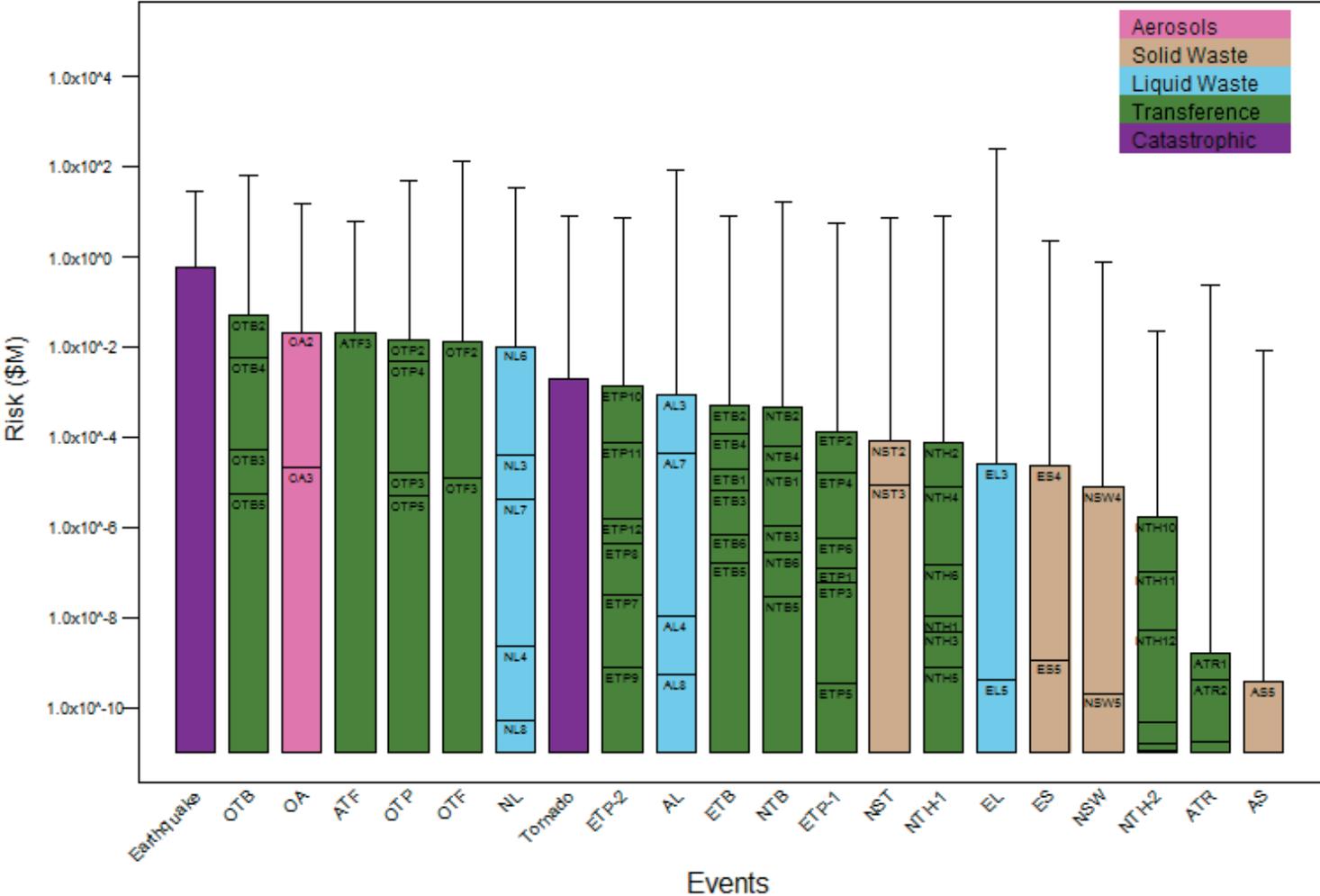


Figure 8.2-2: Aggregate Risk by Event Tree

A total of seventy-seven (77) individual FMDv events assessed resulted in a nonzero estimate of expected risk. Of these 77 events, two occurred along the aerosol pathway (with the loss originating outside containment), 11 occurred along the solid waste pathway, 11 occurred along the liquid waste pathway, 51 occurred along the transference pathway, and two were due to catastrophic events. In all cases, the estimated risk was found to be less than \$1M, with the catastrophic earthquake posing the highest risk (approximately \$0.6M). The transference events represent the greatest fraction of all events resulting in expected risk; however, in all cases, the transference event risks (aggregated across all events within a given tree) are less than \$0.05M. A more detailed discussion of the risks, organized by pathway, is presented below.

8.2.1 Aerosol Pathway

Virtually no risk was observed from the aerosol pathway when the event originated within containment. A total of 32 aerosol release events originating from NBAF BSL-3Ag containment (AHRs, necropsy suites or BSL-3E/BSL-3E SP rooms) were evaluated; none resulted in credible risk. Specifically, the probability of an aerosol loss occurring from any one of the BSL-3Ag rooms and resulting in an infection approaches zero ($\leq 4.70 \times 10^{-36}$). As a point of reference, this is less than the probability of the decay of a single proton in a vacuum (10^{-32}), an asteroid impacting the earth (10^{-6}), or suffering a fatal air travel accident (10^{-5})². This finding is also consistent with the ABSL-4 Assessment, which indicated no credible risk from the aerosol pathway when the release originated within ABSL-4 containment. ***This suggests that the 65% NBAF Design, which has been upgraded to include fully redundant in-series HEPA filtration, sufficiently mitigates the risk of release of infectious material via the aerosol pathway.***

The only aerosol events that resulted in observable risk (events OA2 and OA3 within event tree OA) were those that originated outside of containment, for which building engineering controls such as HEPA filtration are not involved. In these events, a release could occur due to a failure of the primary and secondary containers of a package containing viable FMDv being received by the NBAF. If both the primary and secondary containers failed, a fraction of the sample would be aerosolized. Because this type of release was modeled as occurring outside of the NBAF building (between the Transshipping Facility and the Laboratory Building), it had a significant impact relative to some of the other modeled events. ***Although the overall expected risk of the transshipping error events is relatively low (less than \$0.02M), the consequence of one of these events (conditional on their occurrence) are among the highest consequence events (\$108B).***

8.2.2 Liquid Pathway

All of the liquid waste event trees (EL) resulted in estimated risk of \$0.01M or less. Within each area, the specific events that correspond to nonzero (but low) risk are events associated with cook tank failures. No risk was observed in any location when the cook tank was functional, regardless of whether there

² Sources of probability statistics info; National Center for Health Statistics, CDC; American Cancer Society; National Safety Council; International Federation of Red Cross and Red Crescent Societies; World Health Organization; USGS; Clark Chapman, SwRI

were failures in any other node of the effluent decontamination system (drain priming or waste pre-treatment). Multiple process alarms are in place to provide indication to the control system and operators if any anomaly in the cook tank performance is detected. The NBAF engineering control practice of including an independent and redundant verification indicator of cook tank performance prior to releasing liquid waste from the NBAF significantly reduced the risk along this release pathway. As a result, a cook tank failure and the subsequent failure to recognize a cook tank failure (and thus release FMDv material) is expected to be a very rare event. ***However, if a cook tank failure were to occur, the consequence of the failure would be significant (approximately \$108B). Although the overall risk is low based on the low expected frequency of a loss, the estimated economic consequence values underscore the criticality of the function of the cook tanks in all areas to preventing the release of contaminated liquid waste.***

8.2.3 Solid Waste Pathway

Risks associated with solid waste pathways are very low in all cases, with solid waste aggregate risk values (summed across all events within a given solid waste tree) falling between 3.8×10^{-10} and 8.2×10^{-5} . These low risk values, as compared to other event trees considered in the Updated SSRA, reflect low probabilities of releases leading to infections. These low probabilities are the result of the efficacy of redundant and independent solid waste decontamination systems planned for the NBAF. In addition, the estimated economic consequences associated with solid waste infections (if one were to occur), were found to be low relative to the consequences observed for other events. Specifically, the estimated economic consequence if an infection were to occur due to a solid waste release were found to be generally between \$24B and \$28B (compared to consequences over \$100B for other pathways). ***The addition of redundant and independent solid waste decontamination systems in the 65% Design, including the addition of on-site incineration, has mitigated the risks of release of infectious material via the solid waste pathway from the NBAF.***

8.2.4 Catastrophic Events

The event with the highest risk value was the catastrophic earthquake event, for which a risk of \$0.56M was observed, which is driven by the return period of an earthquake event that may cause sufficient damage to the NBAF that would result in a loss of containment. The observed risk associated with a catastrophic tornado event was less than \$0.01M (approximately \$0.002M), since the return period of a tornado with winds in excess of 228 mph is so long. Thus, it can be concluded that the tornado hardening improvements implemented since the 2010 SSRA was released have greatly reduced the risk associated with a tornado event at the NBAF. If either of the catastrophic events (earthquakes or tornados) were to occur, the estimated economic impact is approximately \$28B to \$30B, which is somewhat lower than the estimated consequences associated with other events (transference, liquid waste, and aerosol events in particular).

8.2.5 Transference Events

Interestingly, none of the individual transference events resulted in an expected risk greater than \$0.04M but they were among the most numerous events resulting in nonzero risks (representing 51 of the 77 or 66% of the risk-generating events). The most significant transference events are those that occurred with the greatest event frequency –as all the transference events, if they lead to any probability of infection, resulted in the same overall expected economic impact of approximately \$82B. Even though the economic impact was significant (and greater than the solid waste events described previously), the frequency of an infection due to a transference event was estimated to be less than once in 2 million years ($F_{Event} = 5.33 \times 10^{-7}$) for each of the transference event trees considered, resulting in overall risk values of less than \$0.05M.

The events that occurred most frequently and thus occupied the greatest transference risk space either occurred outside of containment (OT event trees) or were due to a full disregard of procedures and a resultant fomite transfer (a single event ATF3). If an initiating event were to occur outside of containment (event trees OTB, OTP, OTF), engineering/operation controls in place within the containment block would not be available to reduce the amount of virus that is released to the environment. In these outside containment events, workers in-processing/handling containers of viable FMDv that have been shipped with failed primary and secondary containers or those cleaning up a spill associated with the failed containers would be exposed to FMDv on the hand, footwear or other parts of the body. The only mitigation nodes that are assumed to reduce the source term are gloves, Tyvek® (or equivalent) suit, removal/containment of contaminated footwear, and/or a body shower (event dependent). If a failure of the primary and secondary packages were to occur, even if the exposure were recognized, the mitigations modeled for non-containment were not assumed to always be sufficient to eliminate all of the associated risk – as evident in risks observed with OTB2, OTF2, OTP2, OTB4 and OTP4.

As in the non-containment events, the fomite transference event ATF3, occurred at a relatively high frequency compared to the other transference events (roughly an order of magnitude or more) and therefore carried slightly greater risk. This event was due to failure to follow established practices and procedures (similar to nearly all of the transference events that occurred within containment that resulted in observable risk). The vast majority of the risk observed with the transference events therefore can be attributed to human error. ***As concluded in the 2010 SSRA, training and a safety-oriented culture are key to reducing accidents from transference events.***

8.3 Cumulative Risk Calculations

The discussion in Section 8.2 focuses on the comparison of risks across the various FMDv loss-of-containment events considered in this Updated SSRA. This type of events-based evaluation and comparison of risks allows decision-makers to quantitatively evaluate the NBAF facility design, procedures, and policies to make informed decisions and prioritize investments as the NBAF implementation effort progresses. In addition to the comparative risk analysis shown above, feedback

from the NAS SSRA Committee (and subsequently in public law) stated that the Updated SSRA should also present cumulative probability and risk values across events and over the 50-year anticipated operating lifetime of the NBAF. Accordingly, this section presents cumulative risk estimates for the NBAF.

Several caveats are critical to consider in the interpretation of the cumulative risk values. First, the uncertainty associated with the estimates comprising the cumulative risk values is, in many cases, large relative to the estimated risks. One implication of this uncertainty is that the cumulative calculations shown in this section are also highly uncertain. In addition, due to the lack of information about the potential changes in accident frequencies, research priorities, and economic consequences over time, cumulative risk calculations are based on an assumption of static risk over the anticipated 50-year operating lifetime of the NBAF. This assumption is almost certainly not valid, but any assumed changes over time would be equally fraught with uncertainty and therefore were not incorporated into this evaluation. Additionally, the economic consequences are presented in present-day dollar amounts and do not account for interest or inflation. As a result, while the risk calculations provide useful information for ranking risks, identifying vulnerabilities, prioritizing investments, and planning response, care should be taken to avoid over-interpreting the cumulative risk estimate as an absolute number.

Cumulative risks summed over all events (for a single year) are presented in Section 8.3.1, and cumulative risks, summed over the 50-year operating lifetime of the NBAF, are presented in Section 8.3.2.

8.3.1 Cumulative Risks Across Events

The probability, across all event trees, of one or more events in a given year that results in an infection is denoted as P_{1Y} and is computed as follows:

$$P_{1Y} = 1 - \prod_{k=1}^{26} \{(1 - P_{tree})^{R_o}\}_k$$

The cumulative risk, summed across all fault trees, is denoted as $Risk_{1Y}$ and is computed as follows:

$$Risk_{1Y} = \sum_{k=1}^{26} (Risk_{tree})_k$$

Calculations were performed with all events, and using only non-catastrophic events (i.e., tornadoes and earthquakes excluded). Table 8.3.1-1 summarizes the results of these calculations.

Table 8.3.1-1: Cumulative Risks Across Events (for One Year)		
	P_{1Y} Probability of one or more loss-of-containment outcomes that results in an infection	$Risk_{1Y}$ Cumulative risk over all event, for one year
All Events	2.16×10^{-5}	\$0.7M
Non-Catastrophic Events Only	1.52×10^{-6}	\$0.13M

Uncertainty in the probability calculations was estimated as follows:

1. A low-end estimate for P_{1Y} was computed by first setting P_i for each event equal to P_{iL} for that event (recall that P_{iL} is the probability of infection associated with the 5th percentile of possible Q values associated with a given loss-of-containment outcome). Subsequent P_{event} and P_{tree} calculations were performed using these low-end estimates of P_i . The low-end estimate P_{tree} for each tree was then used in the P_{1Y} calculations shown above.
2. A high-end estimate for P_{1Y} was computed by first setting P_i for each event equal to P_{iH} for that event (recall that P_{iH} is the probability of infection associated with the 5th percentile of possible Q values associated with a given loss-of-containment outcome). Subsequent P_{event} and P_{tree} calculations were then performed using these high-end estimates of P_i . The high-end estimate P_{tree} for each tree was then used in the P_{1Y} calculations shown above.

These calculations resulted in probability estimates ranging from 3.07×10^{-11} to 4.23×10^{-4} when all events are included, and from 3.07×10^{-11} to 2.33×10^{-5} when catastrophic events are excluded. In other words, when all events are considered, the probability of at least one release resulting in an infection in a given year is estimated to range between approximately 3.1×10^{-9} % and 0.04%. When catastrophic events are excluded, the probability of at least one release resulting in an infection in a given year is estimated to range between 3.1×10^{-9} % and 0.002%.

The uncertainty (standard deviation) in the one-year risk was computed as the square root of the sum of the tree-specific estimated variances. The resulting standard deviation in the risk value is approximately \$306M when catastrophic events are included and \$304M when catastrophic events are excluded.

8.3.2 Cumulative Risks Across Time

In addition to computing the cumulative risk across all events for a single year, the cumulative risks over the 50-year operating lifetime of the NBAF were considered.

The equation for computing the probability of at least one event that results in an infection over the 50-year operating lifetime of the NBAF is:

$$P_{50Y} = 1 - \prod_{y=1}^{50} (1 - P_{1Y})_y$$

The cumulative risk, summed across the 50-year operating lifetime is denoted as $Risk_{50Y}$ and is computed as follows:

$$Risk_{50Y} = \sum_{k=1}^{50} (Risk_{1Y})_k$$

The results are summarized in Table 8.3.2-1.

Table 8.3.2-1: Cumulative Risks Across Events for the 50-Year Operating Lifetime of the NBAF		
	P_{50Y} Probability of one or more loss-of-containment outcomes that results in an infection	$Risk_{50Y}$ Cumulative risk over events, over 50-year operating lifetime of the NBAF
All Events	1.08×10^{-3}	\$35M
Non-Catastrophic Events Only	7.61×10^{-5}	\$7M

Figures 8.3.2-1 and 8.3.2-2 present the cumulative calculations graphically. Figure 8.3.2-1 shows the cumulative probabilities over time, and Figure 8.3.2-2 shows the cumulative risks over time.

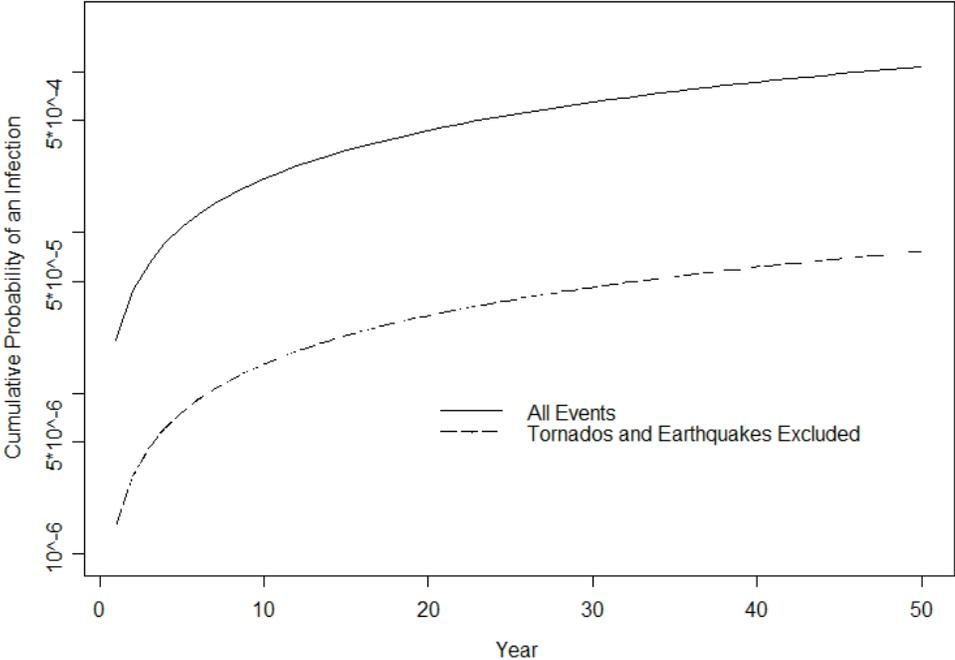


Figure 8.3.2-1: Cumulative Probability of an Infection Over the 50-Year NBAF Operating Lifetime

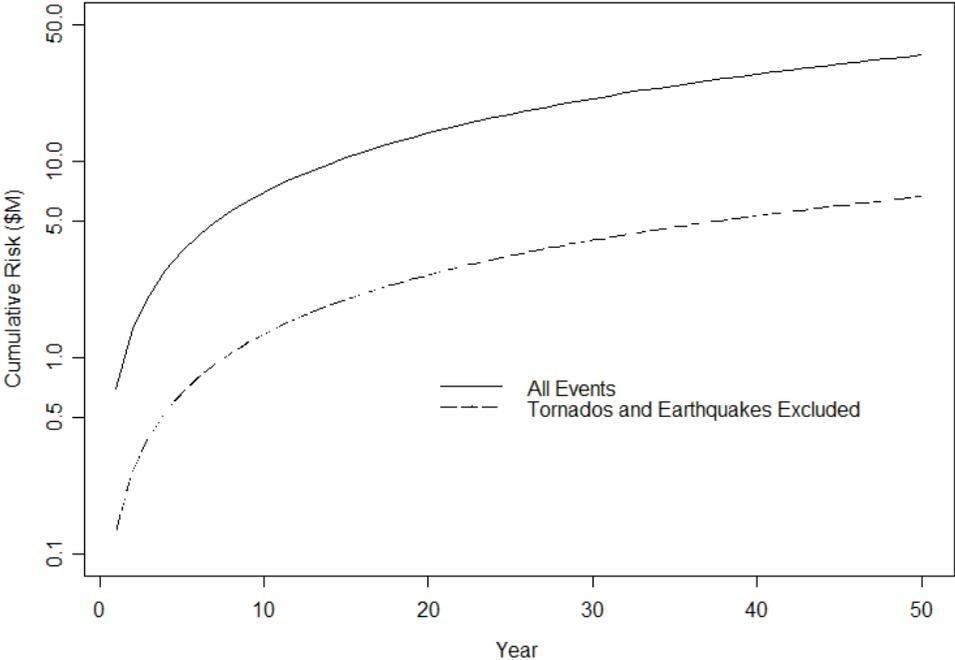


Figure 8.3.2-2: Cumulative Risk (\$) Over 50-Year NBAF Operating Lifetime

Uncertainty in the 50-year probability and risk calculations was estimated using the same procedures as described above for the one-year probability and risk values. The calculations resulted in 50-year cumulative probability estimates ranging from 1.54×10^{-9} to 2.09×10^{-2} when all events are included, and from 1.54×10^{-9} to 1.17×10^{-3} when catastrophic events are excluded. In other words, when all events are considered, the probability of at least one release resulting in an infection over the 50-year NBAF operating lifetime is estimated to range between approximately 1.5×10^{-7} % and 2.1%. When catastrophic events are excluded, the probability of at least one release resulting in an infection over the 50-year NBAF operating lifetime is estimated to range between 1.5×10^{-7} % and 0.1%.

The uncertainty (standard deviation) in the 50-year cumulative risk was found to be approximately \$15B, regardless of whether catastrophic events are included.

In summary, with the caveat that care should be taken to avoid interpreting the cumulative calculations as absolute values, the estimated probability that an accidental release of FMDv from the NBAF will occur and cause a subsequent outbreak during the NBAF's nominal 50-year operating life is 0.11%, which reflects updated design, operations, and accident response strategies that have been implemented since the 2010 SSRA.

9. Large Animal BSL-4 Assessment

Abstract: *This Large Animal BSL-4 (ABSL-4) Assessment relied on a panel of international containment subject matter experts (SMEs), members of the NBAF Design Partnership (NDP), and risk assessment professionals to develop and analyze a set of events that represent the state-of-the-practice risks associated with handling (infected) large animals within BSL-4 containment. A total of 109 events that span potential loss of containment across four release pathways – aerosol, liquid waste, solid waste, and transference – are described. For each of the events, a quantitative fault tree analysis was performed from which the associated event frequency and event impact (based on historical Nipah and Hendra case studies) were calculated and used to determine an estimated risk for each event. In this assessment, the greatest risk was identified along the transference pathway, which relies less on design elements and more on trained, compliant staff adhering to well defined plans, practices, and standard operating procedures (SOPs). Through this assessment, with the exception of a few of improbable solid waste and aerosol pathway events (that occur with frequencies of less than once every 10 million years), it appears that the NBAF 65% Design elements mitigate the risk of Nipah virus (NiV) or Hendra virus (HeV) release along the aerosol, solid waste, and liquid waste pathways from ABSL-4 containment. Furthermore, the vast majority of the risk observed in this ABSL-4 assessment could be attributed in some way to human error. This observation highlights the importance for the NBAF (as it nears operation over the next eight years) to develop SOPs, plans, and practices with continued periodic training of staff to assess their continued compliance. The observable risk also indicates that proper training of staff (e.g., biosafety, biosecurity, biocontainment, security, etc.) through continuing education and refresher training to ensure the understanding and compliance with SOPs, plans, and practices, will reduce the potential for the human errors attributed to the transference events.*

9.1 Introduction

The use of best practices and experience-based knowledge compiled from the design, construction, and operation of animal pathogen and human pathogen facilities greatly reduces the NBAF-related risk to U.S. citizens and agricultural infrastructure. However, it is impossible to eliminate all of the risk associated with high-consequence pathogen research. It is also impossible to identify and model every possible accident condition, but it is feasible to use accident event modeling to assist decision-makers and designers. The primary overall objective of the Updated SSRA is to assess the risks associated with the current NBAF design (65% Design) that incorporate changes made since the 15% Design was used in the 2010 SSRA. The assessment of these risks will be used to inform DHS so additional changes can be made, if necessary, to the facility design, operational strategy plans, or response mitigation planning processes while there is still time to address these issues. This updated assessment is intended to help prioritize resource allocations to develop policies and procedures that will allow DHS to build and operate a model containment laboratory facility.

The primary objective of the ABSL-4 Assessment within the Updated SSRA is to identify and categorize the unique risks associated with working with large animals exposed to pathogens studied in BSL-4 containment. With these unique risks identified, this effort served to reveal potential gaps in the current NBAF plans relevant to research in BSL-4 containment with large animals and identify and suggest alternate design, operations, and or response strategies that have proven effective at other laboratories and that could be leveraged for use at the NBAF to reduce the risk of BSL-4 pathogen exposures within or from the NBAF. A sub-objective of this effort was to update pathogen characteristic information that was presented in the 2010 QRA for NiV and HeV related to the pathogen etiology, host range, epidemiology, immune response, laboratory requirements, and anticipated research needs. NiV and HeV pathogen updates were included in this quantitative modeling effort and may continue to support future assessments and/or development and validation of models relevant to BSL-4 pathogens.

Furthermore, the ABSL-4 element of this 2012 Updated SSRA directly addresses NAS SSRA Committee finding 11 which states:

“The SSRA’s qualitative risk assessment of work with BSL-4 pathogens in large animals was inadequate. The committee does not concur with the SSRA’s finding that its quantitative risk assessment regarding FMDv and Rift Valley fever virus (RVFv) sufficiently represents the range of risk regarding the other pathogens that will be studied at the NBAF, that is, the pathogens that are included in the qualitative risk assessment. The committee does not agree that the BSL-3 quantitative risk assessment adequately frames the risks associated with operating a BSL-4 large animal facility, because it is insufficient to use BSL-3 pathogens to predict risks associated with BSL-4 pathogens that are zoonotic and for which no treatment is available.”

Finally, this effort will fulfill the goals and objectives of the FY2011 continuing resolution language (SEC. 1647. (a) Section 560 of Public Law 111–83), which states that *“the revised site-specific biosafety and biosecurity mitigation risk assessment required by subsection (b) shall.....include overall risks of the most dangerous pathogens the Department of Homeland Security expects to hold in the National Bio- and Agro-defense Facility’s biosafety level 4 facility, and effectiveness of mitigation strategies to reduce those risks.”*

This effort represents a significant change from the previous 2010 SSRA, which performed a purely qualitative assessment of the eight primary research pathogens to be studied at the NBAF. In this iteration, a complete event-driven evaluation of ABSL-4 (NiV and HeV) risk was completed. This effort was informed and supported by the enhanced fidelity of BSL-4 design data from the 65% Design; additional detail on proposed NBAF BSL-4 containment practices; BSL-4 systems performance, including failure nodes and probabilities across all four release pathway associated systems; published data regarding the amount of NiV and HeV typically observed during ABSL-4 activities; prevalence and proximity of susceptible species/reservoir hosts surrounding the NBAF; and a historical review of NiV and HeV case studies to inform impact metrics integral to the estimation of the associated ABSL-4 risk.

It is important to stress that the risks resulting from this ABSL-4 assessment represent estimated risk and should not be mistaken for absolute risk. At this stage in the NBAF development, and with the maturity of available data for NiV and HeV disease research, a risk ranking is appropriate and offers a means by which to identify areas of focus for DHS in regards to additional operational, design, or mitigation strategies that should be considered before going operational in 2020. The event fault analyses alone, which estimate the frequency of accidental releases for each event but are not highly dependent on any particular pathogen, provide valuable information. Understanding the failures that can lead to a release are as critical, if not more so, than estimating the impact in regards to the identification of relevant strategies to prevent their occurrence. The impact analyses, although based on historical data, come with a level of uncertainty given the outbreaks reported have occurred in nations with grossly different farming and medical practices than what exists at and around the NBAF. Furthermore, there are noted uncertainties in several components evaluated in the impact and risk determinations—namely the probability of infection of NiV and HeV given an exposure, the infectious dose in human or large animal models, and the amount and transmissibility of virus shed by infected animals. However, even with these uncertainties, the impact analyses performed do provide a means of ranking the estimated risk of the ABSL-4 events such that DHS can begin prioritizing efforts on the events that exhibit the most significant risk and/or occur with the greatest frequency, understanding that this body of work is limited to the current state of available information. Clearly, as more data become available for NiV, HeV, or emerging pathogens, the values presented in this body of work and the resulting conclusions and recommendations should be re-evaluated for relevance.

9.2 ABSL-4 Assessment Approach

The ABSL-4 assessment was performed following the same general process as previously described for the quantitative FMDv risk assessment. The ABSL-4 assessment included event development, event (fault tree) analysis, including development of associated error probabilities and event frequencies, event impact estimation and determination of risk. The ABSL-4 assessment made use of conceptual models of the ABSL-4 originating locations, the previously described transport pathways (Section 4), published and available virus and disease characteristics, forecasted research activity, the NBAF laboratory plans (65% Design), presumptive NBAF procedures (based on plans and SOPs from Australian Animal Health Laboratory currently working with HeV infected horses), and other response plans based on best practices and existing DHS directives similar to those described for FMDv. In contrast to the FMDv assessment, however, aerosol fate and transport modeling, epidemiological modeling and economic impact modeling were not performed for the ABSL-4 assessment as the lack of available published/peer-reviewed data and lack of necessary validated models at this stage of NiV and HeV research preclude these types of analyses for these or emerging pathogens. Conversely, the potential impact of a release of NiV or HeV from the NBAF along any one of the four transport pathways was estimated through review and extrapolation from documented NiV and HeV case studies. Following review and evaluation of NiV and HeV outbreaks across the globe; an outbreak impact score was derived for each of the two pathogens and applied to each ABSL-4 event according to defined criteria. The impact score was subsequently factored into the calculation of risk for each event.

The cornerstone to any successful scenario-driven risk assessment is the development of a thorough and representative set of events that encompass the envisioned risks. An event is an accident (loss of containment) that may or may not result in an infection outside of containment (the undesirable outcome). Performance of this critical component of the assessment was done through collaboration and solicitation of world-renowned biocontainment specialists, including representatives from the only facilities in the world currently handling large animals within ABSL-4 containment. The following international panel of BSL-4 containment experts provided invaluable support to the development of the ABSL-4 NBAF assessment—specifically in regard to the development of the unique set of events that encompass risks associated with handling large animals within ABSL-4 containment. Those subject matter experts (SMEs) and their affiliations include:

- Thomas Ksiazek, DVM, Ph.D., Professor , University of Texas Medical Branch, Pathology
- Michael Johnson, Ph.D., Institute for Animal Health, Head of Pirbright Laboratory
- Greg Smith, Ph.D., Microbiological Security Manager, Commonwealth Scientific and Industrial Research Organization (CSIRO)
- Martyn Jeggo, Ph.D., B. Vet. Med., Director, Australian Animal Health Laboratory
- Paul Langevin, P.Eng., Senior Vice President, Merrick Canada ULC (Director of Laboratory Design)
- Tammy Beckham, DVM, Ph.D., Director, National Center for Foreign Animal Disease and Zoonotic Disease Defense
- Luis Rodriguez, DVM, Ph.D., Research Leader, Animal Virology, Plum Island Animal Disease Center
- Terrance M. Wilson, DVM, Ph.D., ACVP– Private Consultant
- Les Wittmeier, Manager, Technical Services, Public Health Agency of Canada
- Robert P. Ellis, Ph.D., DACVM, CBSP, Professor, Department of Microbiology, Immunology and Pathology, and University Director of Biosafety, Environmental Health Service, Colorado State University
- William R. White, BVSc, MPH, Supervisory V.M.O., Lead Veterinarian, Plum Island Animal Disease Center, S&T, DHS
- Steve Bolin, DVM, Ph.D., Professor, Michigan State University
- Fernando Torres-Velez, DVM, Head, Diagnostics Services Section, NVSL Foreign Animal Disease Diagnostic Laboratory
- Christopher Broder, Ph.D., Professor and Director, Uniformed Services University of the Health Sciences
- Michelle Colby, Ph.D., Branch Chief, Chem-Bio Division, S&T
- Mr. Michael Robertson, AAAS S&T Policy Fellow, Chem-Bio Division, S&T
- Steven Kappes, Ph.D., Deputy Administrator, Animal Production and Protection, USDA Agriculture Research Service
- Steve Bennett , Ph.D., Assistant Director for Risk Analytics, Department of Homeland Security
- Ms. Natasha Hawkins, Senior Risk Analyst, Department of Homeland Security
- Mr. Joseph Kozlovac, Agency Biosafety Officer, USDA Agricultural Research Service
- Thomas Mettenleiter, Friedrich-Loeffler Institute, Federal Research Institute for Animal Health

Input from these experts, as well as the engineering collaborators from the NBAF Design Partnership, was integral to development of a comprehensive and relevant set of events and overall evaluation of ABSL-4 risk. Additional detail regarding the process used and assumptions applied during the ABSL-4 assessment are included throughout the following detailed sections.

9.3 BSL-4 Large Animal Research at the NBAF

9.3.1 Types of Research Proposed

Of the current pathogens proposed for study at the NBAF, Nipah virus (NiV) and Hendra virus (HeV) are the only agents that require BSL-4 and ABSL-4 practices and facilities. The general research areas anticipated at the NBAF (as identified by the QRA SME Panel in conjunction with Scientific End-Users in the 2010 SSRA) for NiV and HeV include experimentation regarding vaccine development and efficacy countermeasures; pathogenesis; route of entry and infectious dose; improved diagnostics; development of rapid pen side tests; modes of transmission; identification of natural reservoir(s); susceptibility of North American bats; and drug therapy discovery. Recent progress in vaccine development, post-exposure therapeutics and characterization of NiV and HeV are described below.

9.3.2 Updated Nipah and Hendra Pathogen Characteristics

A literature review was performed to present the current state of knowledge regarding NiV and HeV. Although the vast majority of the content presented in the 2010 SSRA remains relevant, several recent vaccine development advances have been made.

There are currently no antiviral therapies or vaccines available for treating or preventing NiV or HeV infection [Pallister et al., 2011a; Bossart et al., 2007]. It is unlikely that a live-attenuated virus will be approved due to the BSL-4 containment requirements for NiV and HeV; however vaccine development for the Henipavirus has significantly progressed in the past few years and these advances have recently been reviewed by Pallister et al. [2011a].

In the first successful Henipavirus vaccine experiment, recombinant vaccinia viruses that encode NiV F or G glycoprotein protected against NiV challenge in Syrian (golden) hamsters and provided protection up to five months post-challenge [Guillaume et al., 2004a]. These results suggest that such vaccines can protect against late-onset symptoms. Unfortunately, these vaccines are not viable for human candidates because of risks of vaccinia virus vaccination [Guillaume et al., 2004a]. Another recent study demonstrated that recombinant canarypox virus-based vaccines encoding NiV F or G protected pigs against NiV challenge [Weingartl et al., 2006]. While this vaccine is also not suitable for human study, significant progress has been made towards a veterinary vaccine for NiV [Bossart et al., 2007].

Mungall et al. developed a subunit vaccine comprised of soluble G glycoprotein (sG) from HeV and NiV and evaluated its efficacy in a feline model [2006]. Immunized cats challenged with NiV and HeV did not develop any signs of disease [Mungall et al., 2006]. A similar vaccine formulation was designed by McEachern et al. that contained recombinant, soluble G glycoprotein from HeV and CpG adjuvant was also tested in the feline model [2008]. Vaccinated cats challenged with lethal NiV were protected from disease with the virus detected 21 days post-challenge in a single animal [McEachern et al., 2008]. Recombinant subunit immunogens are a viable and efficient option for vaccines for Henipaviruses as they can be quickly implemented, are simple, and can be administered with no risk of infection [Pallister

et al., 2011a]. Recently, Pallister et al. evaluated a similar vaccine of HeVsG adjuvanted with CpG, which protected ferrets against lethal doses of HeV [Pallister et al., 2011b].

In the last few years, several groups have tested neutralized antibodies for protection against NiV and HeV infection [Bossart et al., 2009, 2011; Defang et al., 2010; Guillaume et al., 2006; Zhu et al., 2008]. Guillaume et al. utilized monoclonal antibodies to both glycoproteins to protect against NiV in hamsters in which high levels of anti-G MAb and anti-F MAb (112 and 180 µg, respectively) gave a sterilizing immunity with protection observed at lower levels (1.12 and 1.8 µg, respectively) [2006]. Work by Defang and colleagues suggested that a vaccine could be developed against HeV and NiV based on HeV immunogens as the F or G glycoprotein of either HeV or NiV can induce cross-reactive neutralizing antibodies [2010]. Similar results were obtained by Zhu et al. using a human monoclonal antibody [2008]. Recently, a neutralizing human monoclonal antibody, m102.4 has been shown to protect against NiV viral doses of 500 TCID₅₀ applied to ferrets [Bossart et al., 2009]. In this study, m102.4 was administered intravenously to mimic human drug delivery and all animals treated post-NiV-challenge were protected, and one out of three ferrets treated before the NiV challenge survived. Bossart and colleagues have also evaluated m102.4 against HeV challenge in African green monkeys in an attempt to mimic human conditions in regards to the pathogenic process as closely as possible [Bossart et al., 2011]. Fourteen subjects were inoculated via the intra-tracheal route with a lethal dose of HeV. All twelve monkeys that received two 100 mg doses of m102.4 survived infection, whereas all of the untreated control animals succumbed within eight days. Further research is ongoing to develop the safest, most effective vaccination against NiV and HeV.

A Henipavirus vaccine must adhere to certain standards in order to be considered for human use. It must be successful in two animal models, a natural route of infection should be used in protection studies, the mechanism and limits of protection should be elicited, and the highest standards should be used for reagent production to assure safety and success in human trials [Bossart et al., 2007].

In addition to vaccine development, post-exposure therapeutics are also being investigated in response to Henipavirus exposure. Several studies have been performed examining the effects of passive therapy on NiV challenge experiments on hamsters [Pallister et al., 2011a; Bossart et al., 2007]. While these trials have been successful, further research is needed before testing these therapeutic measures on humans. In addition to passive therapy, research involving attachment glycoprotein [G], fusion glycoprotein, fusion inhibitors, soluble ephrin-B2 ligand, EphB3 ephrin receptors, and polyclonal and human monoclonal envelope-specific antibodies has also advanced in the past few years in relation to prevention and post-exposure Henipavirus therapeutics.

These advancements in NiV and HeV vaccine and post-exposure therapeutics are significant and appear to be advancing at a fairly rapid pace in recent years. Careful attention should be paid to monitor the progress of these therapeutics over the next several years as the NBAF response and operation plans are developed as they may significantly impact (presumably reduce) the risks of working with NiV and HeV at the NBAF (or other containment facilities).

An update to the available pathogen etiology is provided in Table 9.3.2-1. Areas with substantial updates include: *Transmission/Route, Incubation Period, Morbidity/Mortality, Treatment, Outbreak Control Measures, Current Zoonoses, and Biosafety Level.*

Table 9.3.2-1: Updated BSL-4 Pathogen Summary Matrix

Virus	Family	Type	Zoonotic	Insect-Borne	Size (diameter)	Stability			Inactivation		
						UV	Temperature	Humidity	Heat	Disinfectant	pH
Hendra Virus (HeV)	Paramyxoviridae Henipavirus	RNA	Yes; HeV and NiV are only the zoonotic paramyxoviruses [Eaton et al., 2006]	No	38-600nm (polymorphic)	No data found (NCD: stable up to 45 min)	No data found	No data found	60 °C / 60 min [OIE, 2009] (Paramyxovirus)	hypochlorite, iodophors biguanidines	< 4.0 > 11.0
Nipah Virus (NiV)	Paramyxoviridae Henipavirus	RNA	Yes; HeV and NiV are the only zoonotic paramyxoviruses [Eaton et al., 2006]	No	40-600nm (polymorphic)	No data found (NCD: stable up to 45 min)	No data found	May be transmitted on fomites. Unpublished experiments suggest it can survive for days in fruit juice or fruit bat urine [Roth and Spickler, 2008].	60 °C / 60 min [OIE, 2009] (Paramyxovirus)	lipid solvents [OIE, 2009] sodium hypochlorite	< 4.0 > 10.0

Table 9.3.2-1: Updated BSL-4 Pathogen Summary Matrix (cont.)

Virus	Host range			Epidemiology			
	Domestic Animals	Wild Animals	Humans	Transmission Routes	Survival	Carrier State	Incubation Period
Hendra Virus (HeV)	Horses, Dogs	Pteropid Bats (Flying Foxes)	Yes	Nasopharynx inoculation. Virus shed by flying fox placental fluids, urine [FAD, 2008]. Direct exposure to body fluids and secretions from infected horses [CDC, 2007]. No HeV disease has been identified in wildlife handlers who came in contact with sick bats [Bossart et al., 2007].	Survives more than 4 days in flying fox urine at 22 °C. Can remain viable for a few hours to a few days in fruit juice. Does not survive well at higher temps and is inactivated in less than a day in either urine or fruit juice at 37 °C [OIE, 2009].	Pteropid Bats [Calisher,2006, Halpin 2011]	5-10 days (horses) 4-18 days (humans)
Nipah Virus (NiV)	Pigs (amplifying), Dogs, Cats, Horses, Goats	Pteropid Bats (Flying Foxes)	Yes	Respiratory secretions, saliva, and urine. Aerosolized from pigs to pigs and pigs to humans. Route of infection from bats to pigs unknown. Highly contagious in swine [WHO, 2010, CFSPH, 2007]; in Malaysia, where strong epidemiological association existed between human NiV infection and close direct contact with pigs, there was no direct association with flying foxes [Bossart et al., 2007]. Half of reported cases in Bangladesh 2001-2008 were due to human-to-human transmission. In 2004 in Bangladesh, the common epidemiological link among cases was drinking fresh date palm sap that is believed to be regularly contaminated by flying foxes and their excretions [Bossart et al., 2007].	NiV virus may be transmitted on fomites. How long this virus can survive in the environment is unknown; however, unpublished experiments suggest that it can survive for days in fruit juice or fruit bat urine [CFSPH, 2007].	Pteropid Bats [Calisher,2006, Halpin 2011]	7-14 days (pigs) 7-10 days (humans) [Bossart et al., 2007]

Table 9.3.2-1: Updated BSL-4 Pathogen Summary Matrix (cont.)

Virus	Epidemiology					Outbreak Control Measures
	Morbidity	Mortality	Treatment	Burden/Impact on Health Care System	Burden/Impact on Agricultural/Animal Industry	
Hendra Virus (HeV)	Low [FAD, 2008]; High rates in horses and people [Eaton et al., 2006]	High [FAD, 2008]; High rates in horses and people [Eaton et al., 2006]	HeV infections in humans are very rare, and proven drug therapies have not been developed; however, treatment with antiviral drugs combined with supportive care, has been tried in recent cases. A recent study evaluating the effects of ribavirin and chloroquine against HeV and NiV hamsters demonstrated that ribavirin was effective in reducing viral spread, as well as delayed death by 3 days, but did not cure [Freidberg et al., 2009]. Other than supportive therapy, there is no treatment for HeV in animals. In some cases, surviving horses have been euthanized due to uncertainties about virus persistence [CFSPH, 2009].	Concern to those with close contact with infected horses. In a 2008 outbreak in a veterinary clinic in Australia, 1 out of 2 infected humans died after contact with infected horses [Field et al., 2010]. The clinic had to be quarantined immediately upon suspected Hendra outbreak [Playford et al., 2008].	In 2008, an HeV outbreak occurred in a veterinary clinic in Australia that resulted in 5 infected horses with 4 out of 5 fatalities, and the fifth horse humanely euthanized [Field et al., 2010 & Playford et al., 2008]. Equine outbreaks, including this one, have been occurring in Australia since 1994, and infection is attributed to spillover events from flying foxes [Bossart et al., 2007 & Field et al., 2010]. Clinic had to be quarantined immediately upon suspected HeV outbreak and time and resources used to investigate the outbreak and evaluate all staff as well as possible infected animals [Playford et al., 2008].	Horses that develop signs consistent with HeV infections should be isolated and stringent infection control measures should be taken. People should limit interaction with the horse, using PPE to protect the skin, mucous membranes and eyes. Use caution to avoid generating aerosols or splashing material, both when examining the horse and during disinfection. Other horses, as well as domesticated animals (particularly cats) should be kept away from the suspect case. Exposed horses should be examined daily for signs of disease. Quarantines and rigorous hygiene have been effective in containing past outbreaks. The low rate of horse-to-horse transmission also aids control [CFSPH, 2009].
Nipah Virus (NiV)	100% (pigs); High rates in people [Eaton et al., 2006]	40% (piglets); 5% (pigs); 40-76% (humans); High rates in people and lower rates in pigs [Eaton et al., 2006]	Treatment is supportive, and may include mechanical ventilation. Ribavirin has been promising in some outbreaks but remains to be investigated fully. [CFSPH,2007]; a recent study evaluating the effects of ribavirin and chloroquine against HeV and NiV in hamsters demonstrated that ribavirin was effective in reducing viral spread, as well as delayed death by 3 days, but did not cure [Freidberg et al., 2009].	Serious clinical disease; no antiviral treatment	Between 1998 and 1999 there was a NiV outbreak in Malaysia that resulted in over 200 infected patients in hospitals and a significant disruption in the pig farming industry due to the culling of so many pigs [Goh et al., 2000]. A study referenced by Daszak et al. (2006) reported one million pigs slaughtered, 36,000 jobs lost, and US\$120 million in exports lost due to outbreak control measures.	The Malaysian outbreaks were controlled in both domesticated animals and humans by culling more than one million pigs. In addition, pig farming was permanently banned in some high-risk areas. [CFSPH, 2007]. To prevent outbreaks in endemic areas: minimize exposure to roosts of flying foxes; hospital-based surveillance of acute encephalitis; and surveillance of respiratory syndrome among pigs [Reynes et al., 2005].

Table 9.3.2-1: Updated BSL-4 Pathogen Summary Matrix (cont.)

Virus	Epidemiology	Immune response		Laboratory	
	Current Zoonoses	Natural Infection	Immunization	Staff/PPE Requirement	Biosafety Level
Hendra Virus (HeV)	Endemic to Australia [CFSPH,2009]	Antibodies post-infection are detectable, but because of the reportable and zoonotic nature of the disease, no information is available on whether these antibodies are protective against challenge [FAD, 2008].	No current vaccination; see Section 9.3.1	BSL-4 PPE	BSL-4: High throughput screening (HTS) assay has been developed for inhibitors that target several stages of the Henipavirus viral cycle that can be carried out under BSL-2 conditions [Porotto et al., 2009]. "The multicycle pseudotyped virus HTS assay was highly reproducible and served as a suitable surrogate for HTS assays using live virus, which normally require high-level biocontainment."
Nipah Virus (NiV)	NiV has been reported from Malaysia, Bangladesh and India. Areas of Southeast Asia where fruit bats (<i>Pteropus</i>) are present should be considered endemic. [OIE, 2009]; Singapore [CDC, 2007; Freidberg et al., 2010]	Humoral response in animals and humans [FAD, 2008]	No current vaccination; see Section 9.3.1	BSL-4 PPE	BSL-4: High throughput screening (HTS) assay has been developed for inhibitors that target several stages of the Henipavirus viral cycle that can be carried out under BSL-2 conditions [Porotto et al., 2009]. "The multicycle pseudotyped virus HTS assay was highly reproducible and served as a suitable surrogate for HTS assays using live virus, which normally require high-level biocontainment."

9.4 BSL-4 Facilities

There are no Large Animal BSL-4 (ABSL-4) facilities at the existing PIADC facility. Thus, the current DHS and USDA missions do not include research, diagnostic test development and validation, or discovery and development of effective countermeasures for zoonotic diseases of livestock.

The NBAF is designed to provide a safe and modern BSL-4 capability that will enable the DHS and USDA programs to perform these necessary research functions. The BSL-4 area will be located in the middle of the containment zone, as indicated in Figure 9.4-1 and described in Section 2.2.1.

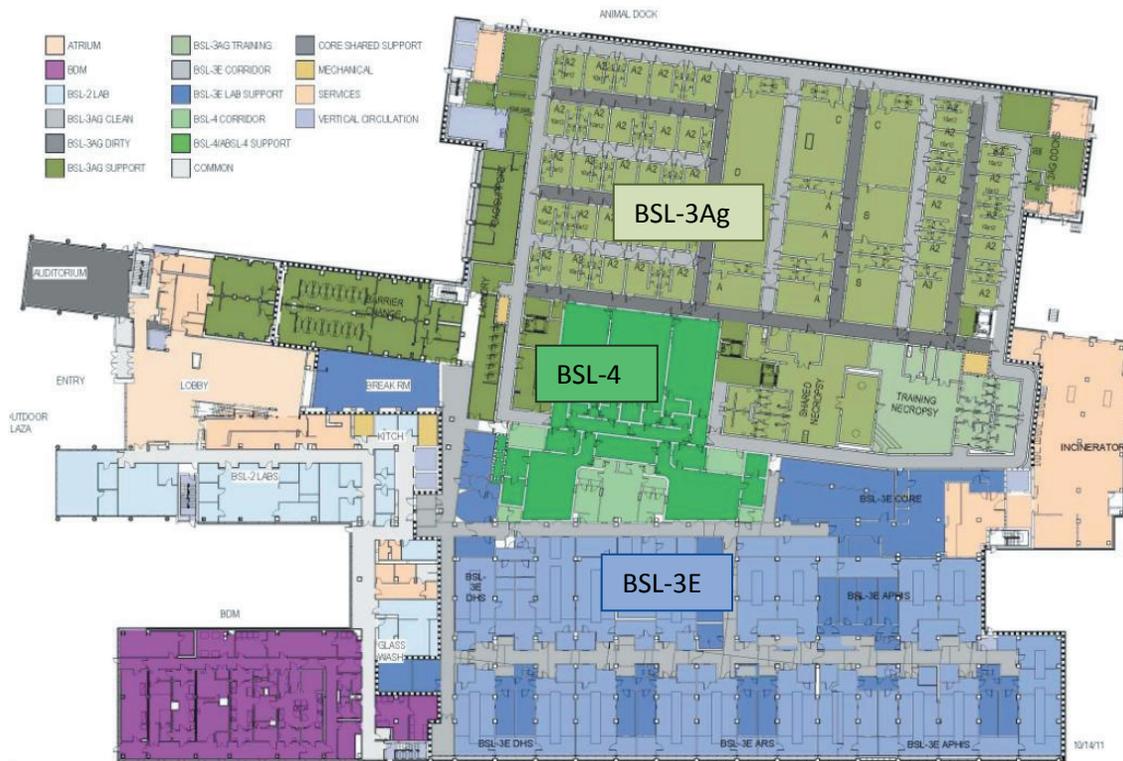


Figure 9.4-1: NBAF Main Building First Floor Plan [NDP, 2011]

The NBAF BSL-4 containment block employs the “box within a box” concept in order to maximize the use of containment areas to provide a pressure-controlled buffer. This facility is relatively unique compared to other recent BSL-4 facilities employing this concept in that due to the sheer size of the NBAF, the buffer surrounding the BSL-4 is not a corridor, but the adjacent BSL-3E and BSL-3Ag program space. Delineation of the containment zone begins in the barrier change area. “Clean” and “Dirty” clothes changing areas are provided (for both genders) and separated by shower facilities. Inside of the containment zone, the BSL-3E and BSL-3Ag are separated and buffered from each other by “Clean” corridors. The program space dedicated to each level of containment is listed in Table 9.4-1.

Table 9.4-1: Gross containment space [NDP 65% Design, 2011]	
Area	Base Gross Square Footage
BSL-3E/BSL-3E SP	37,578
BSL-3Ag	43,596
BSL-3E/BSL-3Ag Support	10,233
BSL-4	13,376

The BSL-4 facilities will be shared between DHS, USDA ARS, and USDA APHIS. The major functional components of the BSL-4 area include large animal holding rooms, small animal holding rooms, necropsy rooms procedure rooms, laboratory spaces, virus collection, cold room storage, autoclave staging areas, decontaminating showers, and body shower/change areas, as depicted in Figure 9.4-2.



Figure 9.4-2: BSL-4 Facilities

The NBAF Design Partnership developed a process flow illustration for BSL-4 containment that is presented in Figure 9.4-3. This illustration shows the designed movements for personnel, materials, wastes, and large animals. The decontaminating (chemical) showers (locations indicated on Figure 9.4-3) serve as an airlock on personnel entry and a decontaminating shower on personnel exit. Furthermore, the decontaminating shower system is controlled by interlocks which allow only one door at a time to be opened, and upon exit; opening of each door into the subsequent areas requires a complete disinfection cycle to be run.

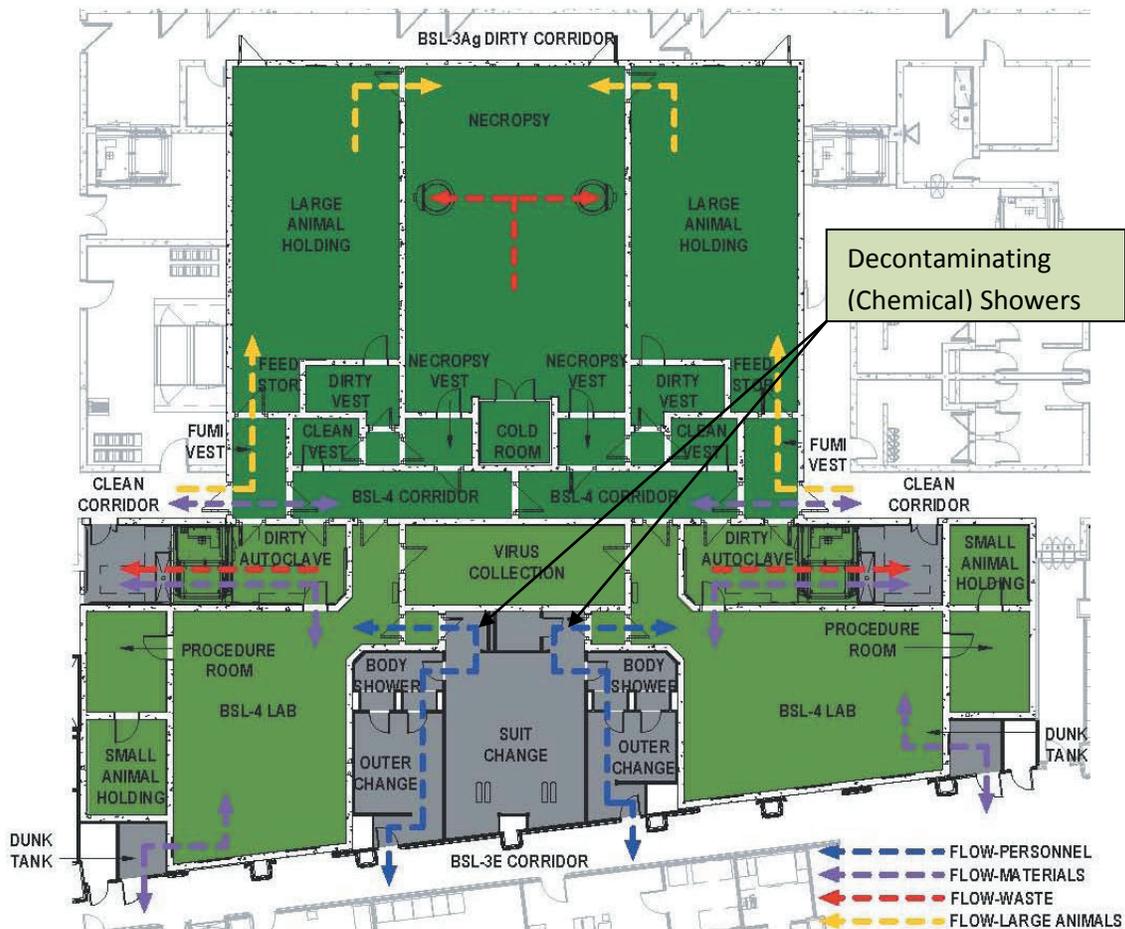


Figure 9.4-3: BSL-4 Facilities Flow

The containment systems used in BSL-4 are similar to those described in Section 2 for BSL-3Ag.

9.4.1 ABSL-4 Animal Holding Rooms

The ABSL-4 animal holding rooms (AHRs) abut and share the single necropsy room. (Note that for the ABSL-4 assessment, the focus is limited to activities and rooms involving large livestock – and therefore all AHRs discussed herein refer to large animal holding.) Surrounding the AHRs are decontaminating showers as described above, and passing out of these rooms into the laboratory area proper requires a decontaminating shower to reduce gross contamination of the suit. Feed storage is also located within the animal area as well as adjacent to the fumigation vestibules.

9.4.2 ABSL-4 Necropsy

As depicted in Figure 9.4.2-1, ABSL-4 necropsy is surrounded by the ABSL-4 AHRs. Necropsy is connected to the BSL-4 corridor via a necropsy vestibule and connects to the ABSL-4 AHR via a decontaminating shower, which as for AHRs, all researchers must pass through and complete on entry and exit. Additionally, fumigation vestibules provide for the introduction and removal of equipment and/or animals to the ABSL-4 areas. The necropsy room contains large double door, pass-through autoclaves for removal of solid (red-bagged) waste, as well as two large tissue autoclaves for the removal of animal carcasses and carcass components, as discussed in detail in Section 9.5. Cold storage and two large necropsy tables are also contained within the room to facilitate large animal manipulations.

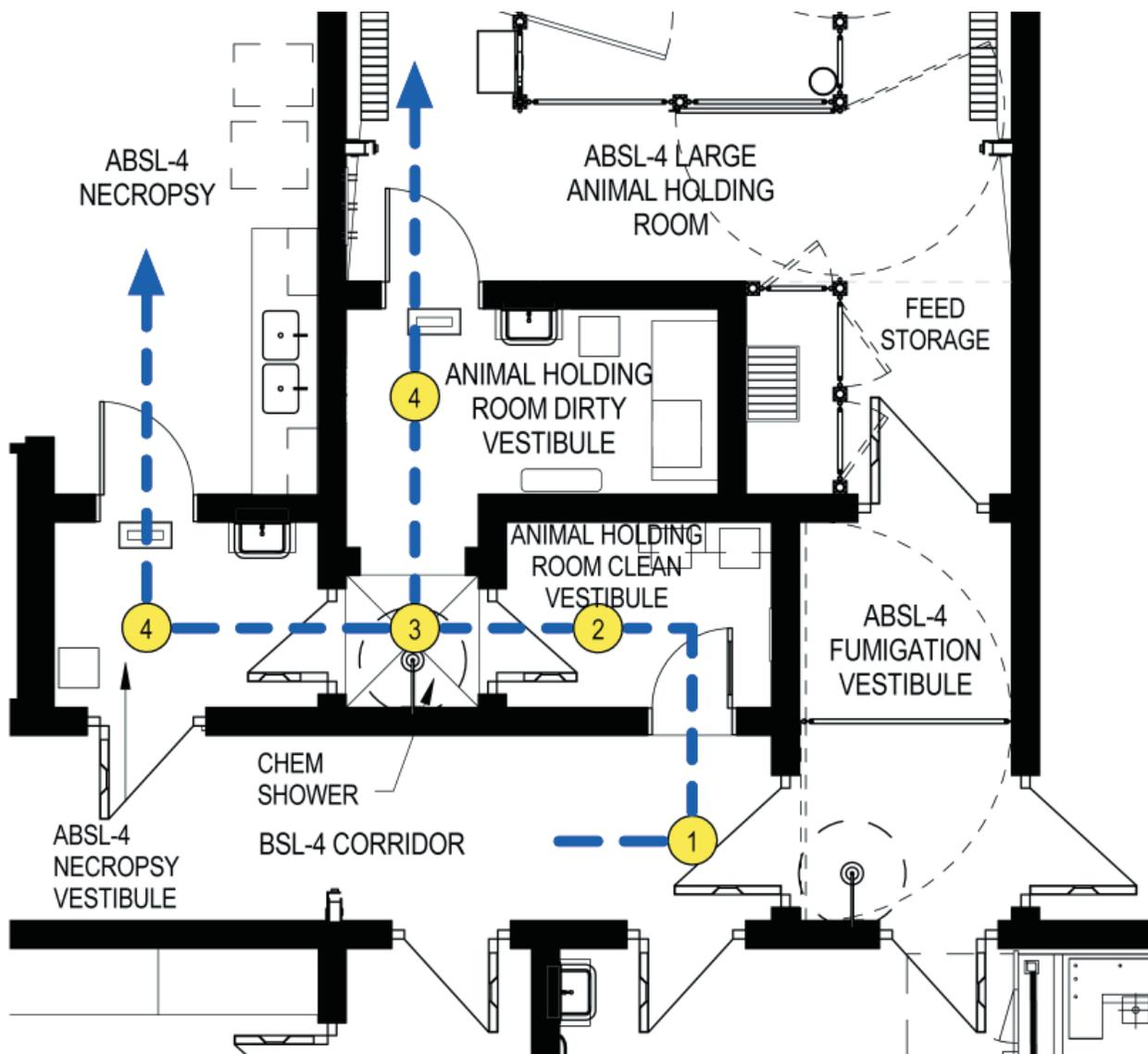


Figure 9.4.2-1: ABSL-4 Large Animal Holding Room and Necropsy Showing Entry Protocol and Relationship of the Two Areas

A mirror AHR (not shown) is located on the left side of the necropsy room.

9.4.3 BSL-4 Laboratory

The BSL-4 laboratory is designed to provide researchers space to maintain live virus collections, microbiological equipment, and conduct small animal experiments depending on the defined needs by the scientific research user group. The BSL-4 laboratory is an open plan design that can be reconfigured with casework and scientific equipment based on the specific needs of the research to be conducted within. The dunk tank, autoclave, and fumigation vestibules serving the BSL-4 laboratory are located immediately adjacent to the lab to allow stand-alone functionality as needed. Each BSL-4 suite contains one small animal holding room for studies that utilize small animal models such as rabbits or rodents. An adjacent procedure room may be used for the surgical manipulations or necropsies of these small animals as well. The BSL-4 laboratory is adjacent to the suit change room, and all personnel must pass out of the laboratory into the main suit change room for doffing of the fully encapsulated BSL-4 suit, then into the body shower and into the outer change room to remove and discard the inner laboratory garments, and don the BSL-3E laboratory clothing to pass into the surrounding BSL-3E corridor. (Note that the focus of this assessment remains on the NBAF BSL-4 containment areas where work on large animals will be performed; however, it is important to present the relationship of the large animal BSL-4 spaces (AHRs and necropsy) to the BSL-4 laboratory as they are adjacent and interconnected, and their personnel share common shower out and change areas within the BSL-4 laboratory.)

9.5 ABSL-4 Release Pathways and Associated Mitigations

Pathogen containment is maintained by providing redundant systems and processes that decontaminate and/or sterilize biological materials that leave the containment block. There are four pathways, or transport mechanisms, by which infectious materials might escape the ABSL-4 containment areas:

1. In certain accident events, pathogens such as NiV and HeV in a viable condition may escape containment as an **aerosol**. **Aerosols**, including procedure-generated aerosols, animal respiration, and other sources are generally controlled by the use of biosafety cabinets (BSC), special air flow control devices, and high-volume HEPA filtration systems.
2. It is also theoretically possible that NiV and HeV could escape containment in **solid waste**. **Solid wastes** and durable equipment (i.e., all materials exiting containment by autoclave, dunk tank, wipe down, or vapor decontamination) are sequentially decontaminated when leaving containment. Generally, all such materials are subjected to at least two or three sterilization or decontamination processes.
3. Other accident sequences can be developed where it is possible that these viruses could escape containment as a **liquid waste**. **Liquids** (i.e., all materials discharged into the NBAF liquid effluent treatment system) in containment areas are disinfected by protocol prior to being collected and processed by a liquid Effluent Decontamination System (EDS).
4. The potentially most-elusive mode of containment loss is the **transference** pathway. **Transference** includes fomites, contact events, and laboratory-acquired infections from injection (such as a needle stick, scalpel injury, animal bite, or exposure of existing break to the skin barrier), inhalation (suit failure) or ingestion (e.g., drinking or eating improperly sterilized solid

or liquid waste). **Fomites** are controlled by access restrictions and procedural requirements for the decontamination and sterilization of all materials prior to removal from a containment area and by personal protective equipment changes and shower out requirements. **Laboratory-acquired infections** are controlled by procedures and personal protective equipment (PPE) and monitored by medical response protocols and reporting requirements if an exposure (contact, inhalation, injection) is suspected or known.

The conceptual pathways of potential pathogen release are illustrated in Figure 9.5-1.

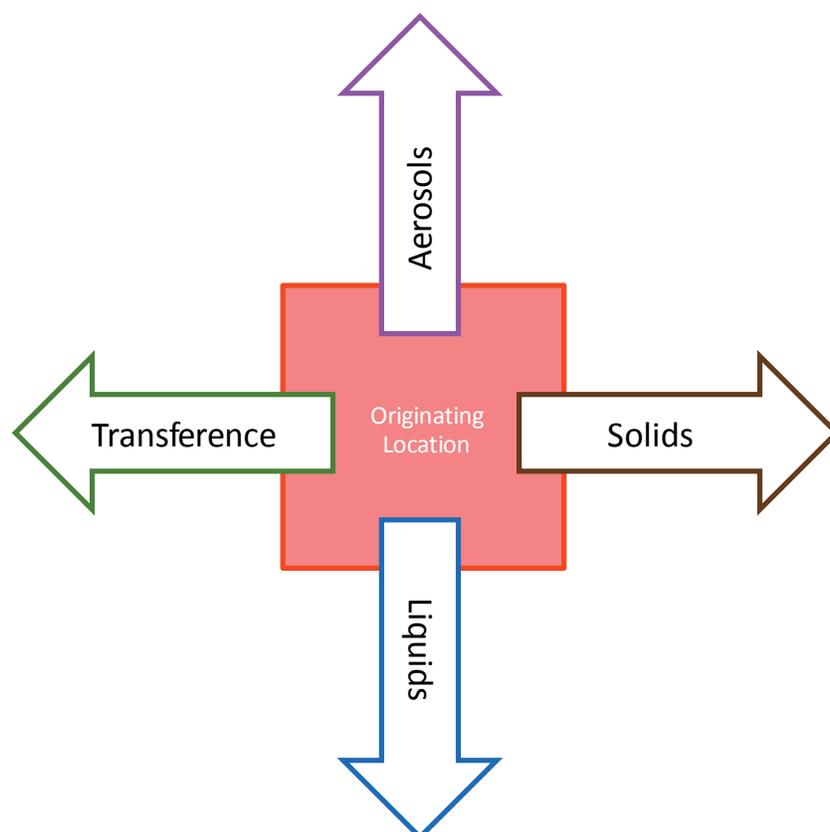


Figure 9.5-1: Pathways for Loss of Containment from ABSL-4 to the Environment

In the following subsections, the modeled engineering and procedural mitigations for the loss of pathogenic material by each of the four pathways is discussed for the ABSL-4 originating locations. These discussions include an illustration of the modeled mitigation techniques derived from the 65% Design and presumptive NBAF procedures.

9.5.1 Aerosols

Like all high-containment facilities, NBAF design and operational strategies depend on sound laboratory practices and layered engineering solutions. Specifically with regard to air handling filtration systems, good laboratory practices are used to minimize the creation of aerosols. Layered engineering solutions include the use of BSCs, negative pressure and directional airflow, in-laboratory airflow patterns by design including placement of room supply and room exhaust, air exchange rates, HEPA filtration, single-

pass circulation, well-maintained equipment-level aerosol mitigation systems (e.g., autoclaves, pipette systems, necropsy tables, etc.), biocontainment dampers, and other manual and automated safety systems. As in the BSL-3Ag described in Section 4, the ABSL-4 AHRs become the primary containment barrier and effective building air handling and filtration systems are critical to successful biocontainment.

9.5.1.1 ABSL-4 Animal Holding Rooms

Like the BSL-3Ag rooms, ABSL-4 AHRs will use HEPA-filtered supply air and double-HEPA exhaust filtration to protect against and reduce the probability of an agent release. There are two BSL-4 large AHRs (25' × 44'), each with four room exhaust penetrations. In accordance with recommendations from the CDC and NIH publication on Biosafety in Microbiological and Biomedical Laboratories (BMBL-5th Edition) [USDHHS/CDCP 2007], the BSL-4 AHR exhaust air is filtered by two HEPA filters in series. The NBAF design, as depicted in the conceptual model provided in Figure 9.5.1-1, incorporates two filtration caissons (each with two HEPA filters in series). In Figure 9.5.1-1 and subsequent conceptual model figures, the controls and fault/event tree nodes are illustrated (at the left of the figure) in the same arrangement that was used to calculate associated failure rates described in detail later within the Fault Analyses and Event description section.

Under nominal conditions, the AHR exhaust air is first filtered by a “rough filter” (accessible from the AHR) to remove larger airborne particulate (e.g., detritus, dust, hair, etc.) that could potentially accelerate HEPA performance degradation or damage a filter surface. The room air is divided in a plenum to flow through both caissons to achieve the HEPA series filtration. Flow balance is accomplished with a control valve at the exhaust plenum. Each of the caissons also has an independent set of bubble-tight bio-seal dampers than can be used to isolate both flow paths and the AHR. Each caisson also includes a pre-filter section (in addition to the rough filter) that is intended to remove large airborne particulates and aerosols. However, like the rough filters, no removal of virus is attributed to this filter. Test and scan areas are incorporated before and after each HEPA filter. The entire room exhaust flow can be diverted to either one of the parallel caissons in the event that service is needed on one caisson or an anomalous pressure indication is reported by the control system. This configuration provides a 2N redundancy.

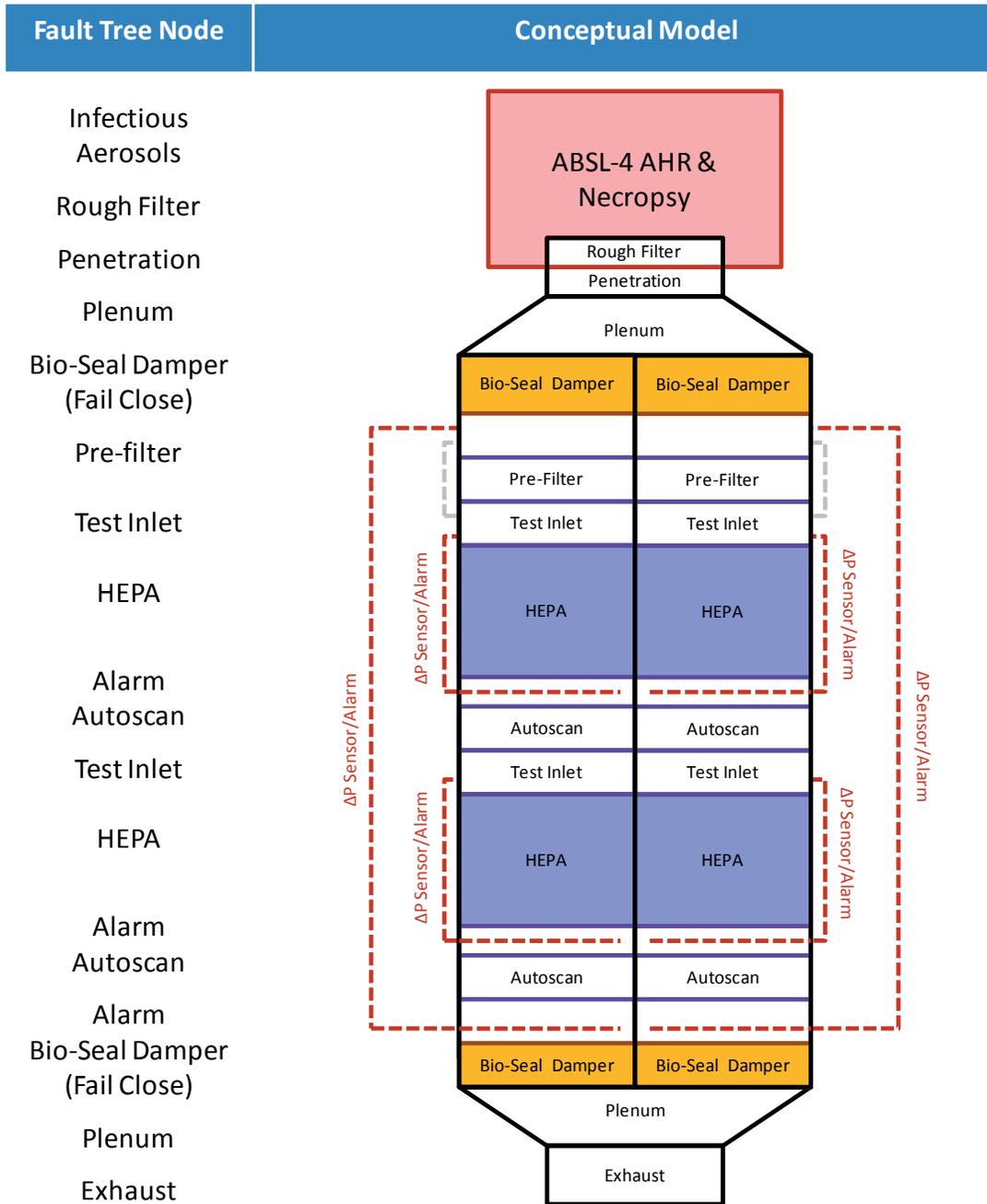


Figure 9.5.1-1: Conceptual Model of ABSL-4 Animal Holding Room & Necropsy Exhaust System

9.5.1.2 ABSL-4 Necropsy

The ABSL-4 necropsy rooms are primarily designed for large animals. Infected animals will be moved from the ABSL-4 AHR to the directly connected shared necropsy space through a pen and gate system if the animal is moving under its own power. Within necropsy there is a small squeeze chute that may be configured to hold the animal during euthanasia and then the overhead-rail hoist system will be used to

move the carcass within the necropsy suite, as needed. Downdraft workstations are used in the necropsy area to assist with the removal of procedurally-generated aerosols. The primary room exhaust air handling system are identical to those described for the ABSL-4 AHRs. Every HEPA filtration in an exhaust process was modeled as having the same efficiency and as detailed below.

HEPA Efficiency

The HEPA specifications used within this assessment are based on the filtration efficiency of the Most Penetrating Particle Size (MPPS), which is specified as 0.3 μm (300 nm). HEPA filters must arrest 99.99% of the MPPS particles, inferring that the filtration efficiency for smaller and larger particulates and aerosols will be greater than 99.99% (per Specifications 23 41 15 -3). Refer to Section 4.0 for studies on efficacy of HEPA filtration in the containment of airborne microorganisms. For modeling purposes, consideration was given to the selection of a nominal pass-through factor derived from specifications (3×10^{-4} and 1×10^{-4}) and the published references described in Section 4.0. A summary of the specifications and findings is provided in Table 4.2.1-1 and again in Table 9.5.1-1. The pass-through factors quoted in the studies by Kowalski, Wang, and Arunkumar are based on empirical data and provide the basis for selection of the modeled pass-through factor of 1×10^{-5} per HEPA filter applied in this assessment.

Source	Pass-Through Factor
HEPA Definition	3.0×10^{-4}
DHS Specification	1.0×10^{-4}
Kowalski	3.0×10^{-5}
Wang	3.0×10^{-5}
Arunkumar (new filter)	1.5×10^{-5}
Arunkumar (loaded)	2.0×10^{-6}

In HEPA filtration installations, there is some potential for small leaks at the filter frame or housing seals (either resulting from manufacturing defects or human errors) that could reduce the efficiency of the filter. The NBAF 65% Design incorporates systems to monitor the pressure differential across each HEPA filter and across the entire HEPA caisson (Autoscan or equivalent feature), and performs installation particulate challenges designed to detect small leaks should they be present so that failed installations are never allowed to go operational. No other virus removal (other than the sequential HEPA filters) is modeled in the room exhaust removal process.

Once installed, at any given time each individual HEPA filter may be in a non-degraded (fault-less), degraded condition, shut-off (if alarm is functional), or open without providing filtration (alarms fail). Each of these HEPA filter operational conditions is modeled in Section 9.8 where the specific reduction factors and probability of such conditions existing are provided.

9.5.2 Solid Waste and Equipment/Property

During the performance of an experiment, solid waste will be generated and articles will become contaminated. At the NBAF, the safe removal of waste from the containment areas is accomplished by a combination of different engineered systems and practices that have been validated and successful in many BSL-3E and BSL-4 facilities for years. Pass-through autoclaves are used to sterilize (autoclave-tolerant) materials before removal from containment areas at the NBAF. Solid waste exiting the BSL-4 spaces will be autoclaved via the double door, pass-through autoclave to the BSL-3E spaces, where it will be autoclaved a second time out of the BSL-3E space and then incinerated. Reusable potentially contaminated laundry (garments worn in BSL-4 containment within the fully encapsulated suit) is doffed in the outer change room and is autoclaved out of the BSL-4 outer change room to the BSL-3E corridor, and is laundered in the laundry processing facility within the BSL-3E containment space. Non-waste materials, such as equipment and samples are disinfected by other mechanisms that include chemical disinfectant wipedown, disinfectant dunk tanks, and decontaminating showers. The solid waste and equipment removal pathway is discussed for each originating location in the following subsections. The modeled conceptual illustration of solid waste and contaminated materials handling for the ABSL-4 AHRs and necropsy room is presented in Figure 9.5.2-1.

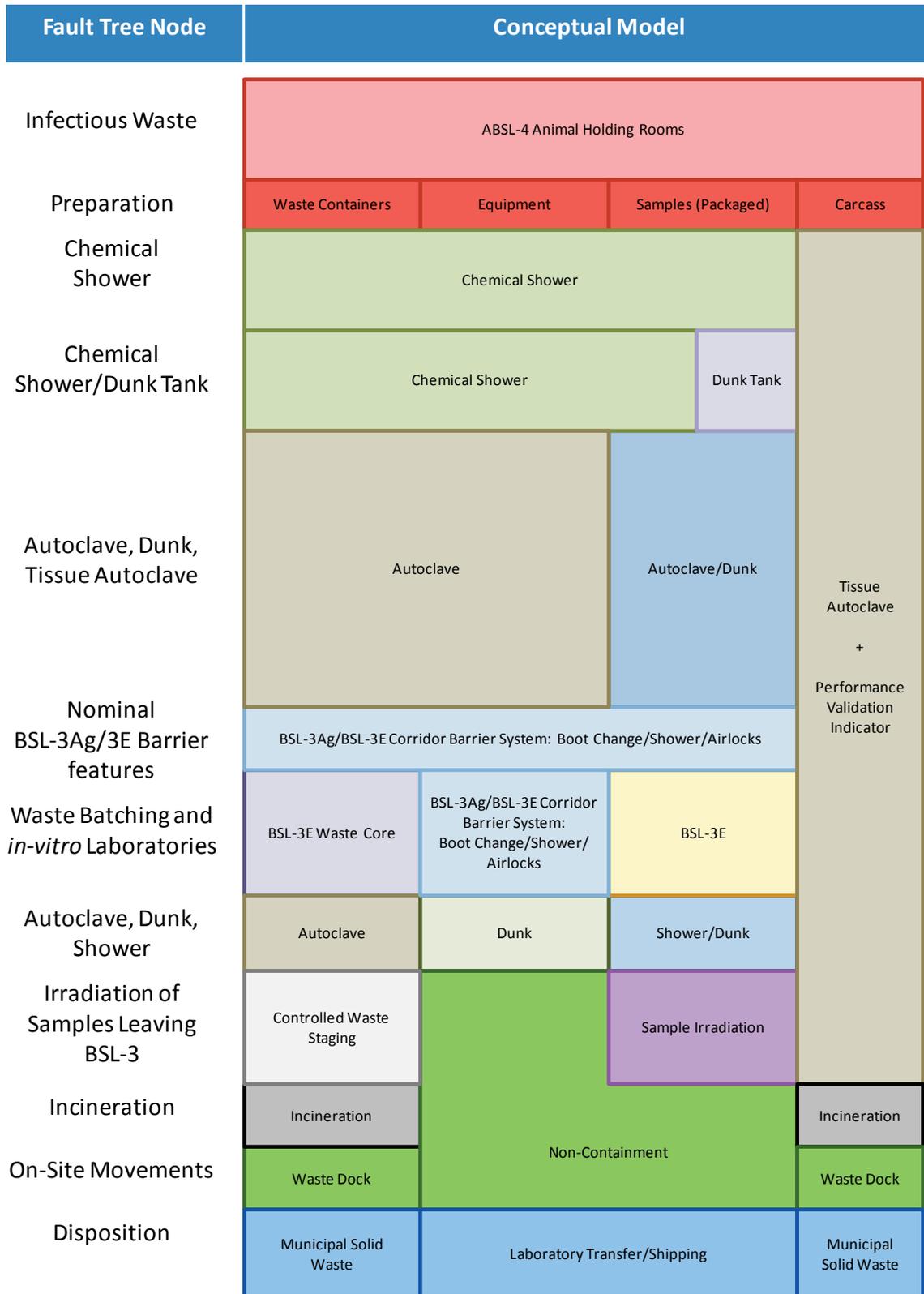


Figure 9.5.2-1: Conceptual Diagram for Solid Waste and Removal of Other Items from ABSL-4 AHRs and ABSL-4 Necropsy Room

9.5.2.1 ABSL-4 Animal Holding Rooms

The solid waste generated in the ABSL-4 AHRs is collected and containerized in the AHR, similar to the BSL-3Ag protocols. The waste containers along with any equipment and packaged samples to be moved out of the ABSL-4 AHR will be moved first through a chemical shower. Small items may also be moved through a dunk tank into the BSL-3E corridor. Larger solid waste items will then be autoclaved for movement into the BSL-3E corridor. Once in the BSL-3E dirty corridor, the waste container is transported to the end of the corridor to a second pass-through autoclave. Equipment and other materials are decontaminated as appropriate. If the equipment or material can be processed by an autoclave, it will also be transported via the dirty corridor to the pass-through autoclaves. If autoclaving is not an option, the equipment or material will be wiped down with a disinfectant (as specified by the NBAF Biosafety Officer) and processed in a pass-through gaseous decontamination chamber. The gaseous decontamination chamber also terminates in the BSL-3E area. According to current plans, samples and other personal effects are retained by the personnel exiting the AHR through the dirty anteroom. Surface disinfection of these items is accomplished by immersion in a disinfection solution (i.e., a dunk tank) and the efficacy of these procedures is described in Section 9.5.4. (The specific disinfectant, concentration, and immersion time are yet to be determined by the NBAF Biosafety Officer; however efficiencies of standard practices have been determined and applied for the purposes of this assessment.)

It is important to note that current NBAF protocols do not require the removal of the solid fraction of animal waste by this method. The solid fraction (feces) and liquid fraction (primarily urine) of animal waste generated in the AHRs are disposed of by the liquid EDS as described in subsequent sections.

Efficiency of Autoclaves

Modern autoclaves are capable of accommodating many different sizes and shapes of material while providing effective sterilization when used correctly. With appropriate pressure, temperature, steam, and exposure time, practically any virus material can be neutralized in an autoclave. The NBAF 65% Design provides preliminary procurement specifications for the autoclaves that will be used at the NBAF [GMP-3, 2011]. NBAF autoclaves will incorporate biological seals, door interlocks, and other safety features to ensure effective sterilization. Periodic testing of the system helps to ensure that the instrument is calibrated and operating in accordance with specifications. Bulk double-door, pass-through autoclaves (sterilizers) are used in the NBAF BSL-4 to satisfy many of the sterilization needs. Autoclaves will be used for waste and equipment in both the ABSL-4 AHRs and necropsy for removal into the BSL-3E dirty corridor for further decontamination and removal from the facility. Specific protocol development and methods validation must be performed to determine the efficiency of the installed NBAF autoclaves based on the types of materials used and sterility objectives. Lewis developed logarithmic reduction constants (D-values) to model the neutralization of microbial activity at fixed temperature and pressure conditions [Lewis, 2002]. Lewis' work implies the reduction constants can be used to reduce the initial titer to a sterility assurance level (SAL) of 10^{-6} even with a very high initial titer. Other references provide similar results and limitations on the efficacy of the autoclave but there is limited data on the efficiency with high initial titers. The Updated SSRA uses the most representative value of autoclave efficiency of 99.9999%, which results in a pass-through factor of 10^{-6} . For the

autoclaves, the systems failure rate of 1×10^{-5} was used, and if the autoclave were to fail, no reduction factor was applied (i.e., reduction factor = 1).

9.5.2.2 ABSL-4 Necropsy

The solid waste generated in the ABSL-4 necropsy room is collected and containerized within the necropsy room. The modeled conceptual illustration of containerized (red-bagged) solid waste and contaminated materials handling for the ABSL-4 necropsy room is identical to that presented in Figure 9.5.2-1. All of the mitigation design and practices for the solid waste and equipment pathway are similar to those discussed for the AHRs with an additional tissue autoclave feature for the removal of animal carcasses that follows the general scheme depicted in Figure 9.5.2-1 and as described below.

Tissue Autoclave

The ABSL-4 necropsy room has an additional solid waste removal mechanism – two carcass renderers (referred to herein as tissue autoclaves) located on the floor. As in the BSL-3Ag necropsy room, the tissue autoclave comprises a processing vessel that can accommodate up to six 500-pound carcasses (3,000 pounds total) per cycle. Alternatively, a vessel can receive and process a single 1,200 pound whole animal carcass. (Larger carcasses, if any, will have to be sectioned.) The systems are capable of heating the contents to 302 °F (150 °C) and macerating the contents during the decontamination cycle. After the decontamination cycle, excess liquids will be boiled off, vapors cooled to 140 °F (60 °C), collected, and discharged to the EDS and vented via a double HEPA filtration system, leaving behind a semi-solid that is containerized and finally incinerated onsite. The principals of pathogen neutralization used in the tissue autoclave are the same as those of more traditional autoclaves. High temperature, high pressure, liquid content, and long exposure times combined with mechanical agitation of the contents. Thus, the modeled reduction factor of pathogen destruction for the tissue autoclave is also 10^{-6} .

In addition to the dual pressure and dual temperature transmitters built-into the NBAF tissue autoclave system, the performance of each tissue autoclave run will be verified using a redundant, orthogonal indicator, such as a biological indicator or independent temperature/pressure indicator (the specific indicator type is to be determined) prior to release of the contents to the incinerator or the EDS. The tissue autoclave system outlined in the 65% Design includes a biotest drywell with removable rod and adjustable basket assembly that will accommodate a biological test or other performance indicator. If the performance of the tissue autoclave is not verified, the contents will be subject to another round of tissue autoclave decontamination and verification. This redundant tissue autoclave system verification provides an additional layer of fault protection with a systems failure rate of 1×10^{-5} .

Efficiency of Incineration

NBAF waste management incorporates the use of redundant self-contained medical waste incineration systems that are capable of processing up to 400 pounds/hour. Each incinerator will have at least two combustion chambers: the primary chamber shall be capable of maintaining a set point of 1600°F and the secondary chamber must be capable of maintaining 1800 °F. The ash removal system is automated and facilitates continuous operations, if needed. The Environmental Protection Agency (EPA) tested the reduction of endospore counts (*B. anthracis*) and reported a five log reduction in viable spore counts

after incineration [Wood et al., 2004]. However, this research included some experimental limitations that were noted in the report. Biological testing of a laboratory pathological waste incinerator at the Australian Animal Health Laboratory in Australia produced extraordinary results [Le Blanc Smith, et al., 2002]. Using another biological indicator (*Escherichia coli* K12), a reduction of $10^{8.39}$ PFU of bacteriophage was measured from the processes in the primary and secondary chamber and an additional $10^{7.65}$ reduction was determined to occur in the stack. The total reduction factor was $10^{16.04}$ PFU. The reduction factors calculated by Le Blanc Smith are very useful, but may not be representative of the lethality/removal factor for incineration of NiV or HeV specifically. In Le Blanc Smith's research, the indicator was sprayed in the primary chamber—a form of pathogen introduction most conducive to high kills rates. Given the large range of incineration efficiencies gleaned from the literature, and a lack of published incineration efficiency on the pathogens of specific interest, a median reduction value of 10^{-9} was used in the Updated SSRA and this ABSL-4 assessment.

9.5.3 Liquid Waste

The NBAF's operational practice will require that liquids going down drains within containment laboratories be decontaminated by a validated method before being discharged. The Effluent Decontamination System (EDS) at the NBAF provides gravity-based drainage from each of the originating locations—the drainage piping is sized appropriately for the anticipated waste streams and components. The mode of initial disinfection depends on the originating location—it is different for the AHRs, the necropsy room, and the BSL-4 laboratories. The EDS comprises eleven cook tanks: eight cook tanks for the BSL-3Ag/3E areas and three for the BSL-4 areas (N+1). The redundant tank for the BSL-4 area can be used to provide redundant capacity for the BSL-3Ag/E areas if an anomalous condition requires its use. However, BSL-3E/Ag and BSL-4 liquid effluents will not be combined in a cook tank. Each cook tank has a minimum capacity of 7,500 gallons and is capable of heating (under pressure) the liquid effluent up to 270 °F (~132 °C). The contents of the cook tanks are continuously agitated as long as the tank is greater than 50% full during the treatment period. Multiple process alarms provide indications to the control system and operators if any system failure or anomaly is detected in the system during the decontamination process. A recently-added engineering control that adds an independent and redundant verification indicator of cook tank performance prior to releasing liquid waste from the NBAF has mitigated the risk along this release pathway.

The conceptualized and modeled liquid (less the redundant temperature monitor) waste flow for the BSL-4 containment areas is provided in Figure 9.5.3-1. All liquid effluent from the containment areas is processed through the EDS. The barrier change room (showers and restrooms), laundry, and other restrooms in the containment area are all serviced by the decontamination system.

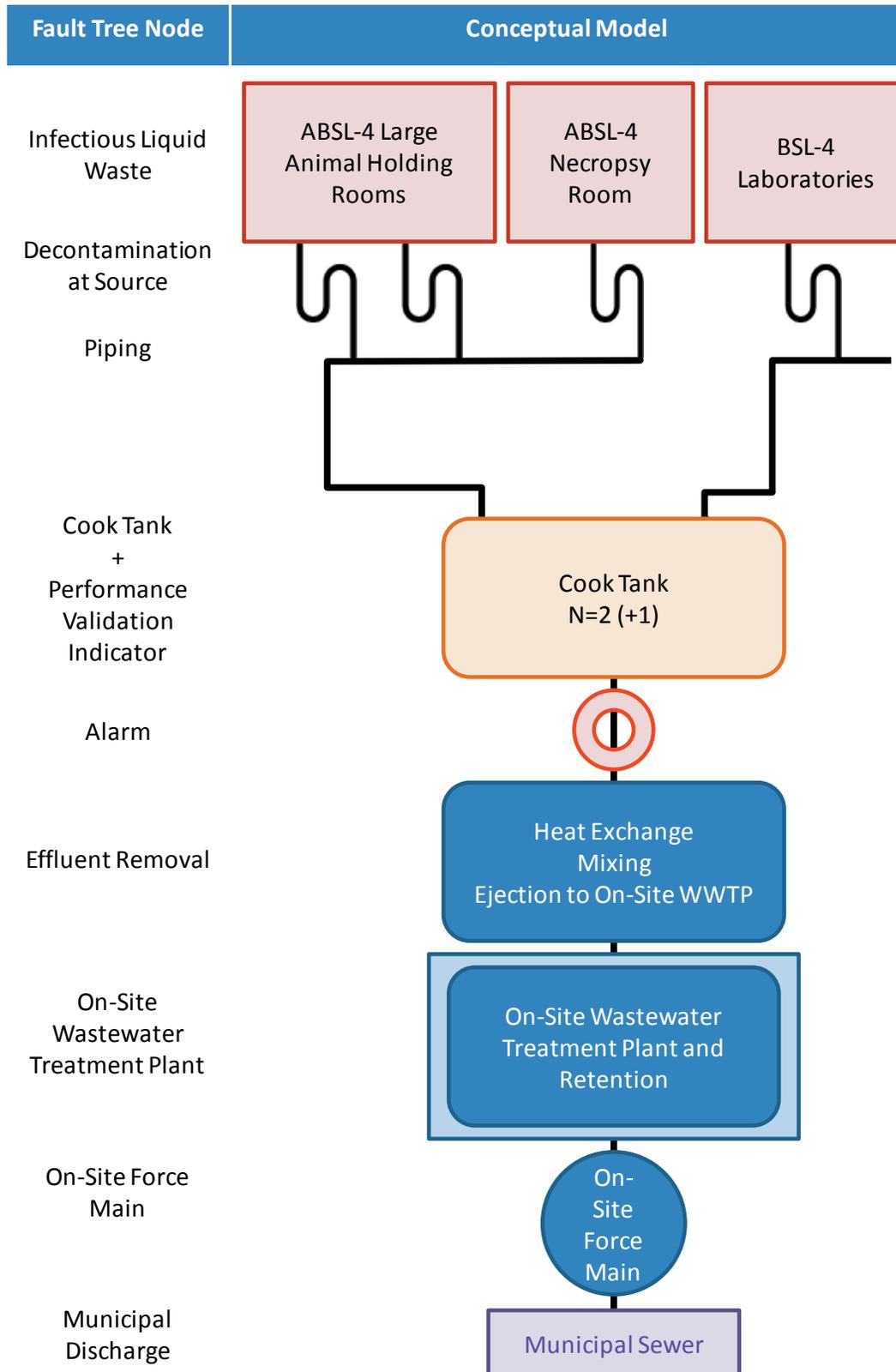


Figure 9.5.3-1: Conceptual Diagram for Liquid Effluent Collection and Treatment for All Originating Locations in BSL-4 Containment

9.5.3.1 ABSL-4 Animal Holding Rooms

The AHRs floors are equipped with grated drains for animal waste and other liquid wastes. Traps on the grated drains will be primed with a suitable disinfectant according to standard animal containment practices. The disinfectant mixes with existing liquid waste in the drain trap and as the trap drains, some fraction of the disinfectant is discharged (along with the liquid effluent) to a designated cook tank where it is mixed with liquid effluent from other AHRs, the necropsy room, and the BSL-3E laboratories and Special Procedure rooms prior to heat treatment.

The NBAF Biosafety Officer will determine the protocols and frequencies of AHR wash downs. The purpose of the wash down is to remove animal waste products from the walls, floors, and animals to provide a hygienic environment for the research animals, researchers, and to satisfy research objectives. Nominally, AHR wash downs will occur twice per day (~every 12 hours); however, the frequency will be largely dependent on the study and personnel requirements and constraints. The wash down will be preceded by priming the floor drains with suitable disinfectant. All other drains (including showers) in the ABSL-4 AHR areas drain into the cook tanks. The material available for release estimated for the AHRs accounts for re-aerosolization of material due to activities in the room, such as wash-downs, animal movement or staff movement.

The upper end of the range of disinfectant efficiency is bounded by the maximum efficiency (99.9999%) or the modeled nominal value of 99.999%. If it is assumed that each deep seal P trap (estimated volume 1-2 L) is primed with a high concentration of disinfectant, the liquid fraction of animal manure (depending on species, number of animals, and room type) will likely dilute the trap volume—no data is available on the decontamination efficiency for diluted disinfectant volumes and its ability to work on mixed waste in the trap. In addition, residual disinfection of aggregated AHR effluent in the cook tank should be considered. Empirical data will eventually need to be collected to more precisely characterize the efficiency of the specific disinfectants used for NBAF-specific conditions. For the purpose of modeling, it is assumed that the low end of disinfectant efficiency is 50% and the high end is 99%, with the most representative value being 90%. In terms of the disinfectant pass-through factor, these modeling assumptions equate to a reduction factor of 1×10^{-1} for each drain pipe in the animal holding rooms. In the ABSL-4 AHRs, there are a total of 12 drain pipes, six in each AHR.

9.5.3.2 ABSL-4 Necropsy

The ABSL-4 necropsy areas only produce a fraction of the animal waste products that are generated in the AHRs at all containment levels. Animals are euthanized on entry to the necropsy area and relatively small amounts of liquid animal waste (feces/urine) products are generated during this process. However, the two floor drains in the necropsy areas will drain infected blood, blood products, and other contaminated animal fluids and potentially small tissue fragments. The necropsy tables are equipped with sinks and drain pans that collect most of the liquids and excised tissue that is not collected for disposal in the tissue digesters. Based on activity levels and research objectives, washdowns will also be performed in the necropsy area with all liquid waste being discharged to the EDS. In general, the liquid waste effluent in the necropsy area is scheduled or at least more predictable than effluent generated in the AHRs. Thus, the practice of priming the drain traps is assumed to be more effective. While it will still be necessary to characterize the effectiveness of disinfection practices with the collection of empirical

data, it can be assumed that the source disinfection rates in the necropsy area are between 1 and 2 orders of magnitude more efficient. Thus, the modeled reduction factor of the disinfection at each individual drain pipe in the necropsy room is 1×10^{-3} . In the ABSL-4 necropsy room, there are 11 drain pipes.

EDS Cook Tank Efficiency

Specifications from the NBAF 65% Design indicate a kill efficiency of 99.9999% (reduction factor = 1×10^{-6}) for the cook tank. This is consistent with the kill efficiencies determined for autoclaves that operate by similar mode of treatment and action. The Updated SSRA and specifically this ABSL-4 Assessment therefore applied a reduction factor of 10^{-6} for a successful effluent decontamination cook tank batch.

Within the cook tank system designed for the NBAF, temperature and pressure are continually monitored while the cook tank is in heat mode. As a redundant check of the cook tank system, an orthogonal temperature and pressure or biological indicator (the specific type is to be determined) will be included in each cook tank batch. The temperature/pressure or biological indicator performance will be verified after each batch prior to release of the contents to the onsite wastewater pretreatment plant. If the performance is not verified, the contents will be subject to another round of cook tank decontamination and verification. This redundant cook tank system verification provides an additional layer of fault protection with a systems failure rate of 1×10^{-5} .

On-Site Wastewater Treatment Efficiency and Dilution

On-site treatment of wastewater from the NBAF will be performed prior to discharge in an effort to reduce the BOD (biological oxygen demand) on the Manhattan, Kansas sewer system. In addition to reducing the BOD, if there were a release from the EDS at the NBAF, the on-site wastewater treatment will likely result in some reduction of total viable pathogen (e.g., NiV/HeV) as well as serve as another dilution point for the laboratory-generated waste effluent.

No specific data regarding NiV and HeV degradation during wastewater treatment were available, although SMEs agreed that some level of degradation is likely to occur. To address this issue, the Updated SSRA turned to the published works of Irving and Smith who recorded enterovirus reductions of 93% during wastewater treatment [Irving, Smith, 1981]. Based on this information, a modest 1 order of magnitude reduction during wastewater treatment was assumed (wastewater reduction factor = 10^{-1}) for the ABSL-4 assessment.

At the NBAF, the sterilized effluent (EDS discharge) from the containment areas is mixed with other effluent waste from the laboratory building before the wastewater from the laboratory is discharged. From the laboratory building, the average total daily flow and average maximum daily flow are 40,248 gpd and 58,411 gpd, respectively [NDP, Re-Baseline On-Site Wastewater Analysis, 2010]. It is estimated that 10% of this volume is from non-containment contributions. Effluent from the Central Utility Plant, the Transshipping Facility, and the Water Treatment office space contribute an estimated additional 10% to the treatment system influent. Thus, it is approximated that 85% of the discharge into the Manhattan sanitary sewer system originated from containment sources.

9.5.4 Transference

The transference events are intended to model the transfer of viable NiV or HeV from the NBAF to a susceptible person/animal by mechanisms other than those modeled for the aerosol, solid waste, and liquid waste pathways. The faults recognized in the transference events are primarily driven by human error. As concluded in the 2010 SSRA and confirmed in Finding 9 of the NAS SSRA Committee, human error is the most likely cause of an accidental pathogen release. The failure probabilities and estimates used in modeling the events from non-transference pathways include contributions from both human error and mechanical/material failures. The faults recognized in the transference events are primarily driven by human error.

There are a virtually unlimited number of accident event sequences that could be theorized and modeled to represent the risk of containment loss by these pathways. A panel of containment facility SMEs was solicited to provide an as-complete-as-possible list of the unique concerns associated with ABSL-4 research; these events are summarized later in Section 9.6 and described in detail within Section 9.7. Included in these SME derived events; are all associated routes of potential exposure which have been reflected in the conceptual models designed for each transference event, either through injection, inhalation, or fomite contact.

9.5.4.1 BSL-4 Animal Holding Rooms and Necropsy Room Transference

During periods of animal infection, the ABSL-4 AHRs are essentially a primary containment vessel—people and objects are potentially exposed to NiV or HeV in aerosols, solid waste, and liquid waste. The AHRs and necropsy room are used as the representative originating locations for transference events involving human respiratory exposure, contact exposure and fomites. The mitigation measures that will be used to reduce the respiratory and contact contamination include complete BSL-4 suit encapsulation with respiratory support, room-specific outer footwear/boots, clothing changes, decontaminating shower and subsequent body shower from the ABSL-4 AHR to BSL-3E, and the shower/clothing and boot change upon exit from the BSL-3E. In instances where skin is knowingly exposed with pathogenic material, chemical disinfection (spot treatment) of an exposed area, such as the hand, provides an additional mitigation layer. Mitigation measures for fomites include disinfection procedures (dunk, wipedown, autoclave, or gaseous decontamination) between the BSL-4 areas and BSL-3E and a second disinfection procedure upon exit from BSL-3E. A conceptual diagram of exposure mitigations and corresponding fault tree nodes associated with the ABSL-4 transference events are provided in Figure 9.5.4-1.

All animals utilized at the facility are euthanized, regardless of infected status. The euthanasia typically occurs as an animal is brought into the necropsy area, either under the animal's own power or through a system of hoists designed to assist in the movement of a downed or deceased large animal. Following euthanasia, the carcass is stored, a necropsy performed, or prepared for the carcass disposal system. During these activities, the researcher or animal handling staff has the potential to become exposed to blood, body fluids and other fine pieces of animal tissues if there are breaches in PPE.

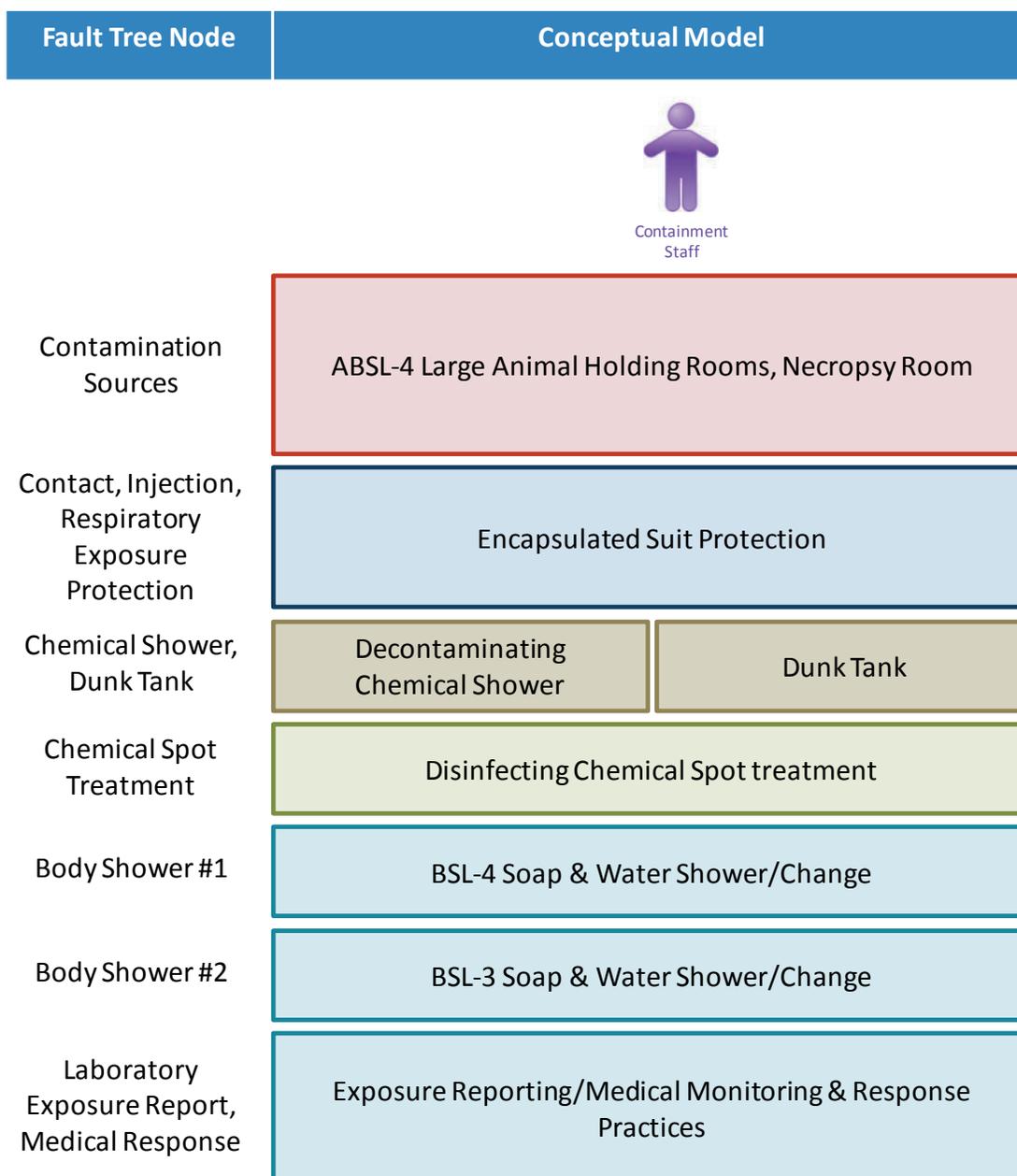


Figure 9.5.4-1: Conceptual Diagram for Transference Events

Laboratory Exposure Transference - Injection

A critical pathway considered for transference of NiV or HeV (applicable to any agent in study within the BSL-4 containment area) is the possibility of injection, through needle stick injury, contaminated scalpel injury, animal bite, or contamination of an existing wound or break in the skin of the laboratory worker. In particular the inoculation of large animals (primarily equines and bovine species) with concentrated virus during study initiation presents a risk of a needle stick. The risk is confounded when large animals are the study model due to the added potential loss of control of the animal during the inoculation event. Per the panel of containment facility SMEs, uncontrolled animal movement (e.g., agitated animals, improper use of pen and gate systems, etc.,) increases the potential for worker injury (through

kicking, biting, worker displacement etc.) and/or a suit breach (tear, hose entanglement, cut or puncture) that may lead to subsequent exposure to laboratory workers. If the primary level of personal protection (BSL-4 suit) is breached (i.e., the needle surpasses the suit) and the skin barrier of the laboratory worker is punctured or broken, it is assumed that approximately 5% transfer from a one-milliliter inoculum syringe occurs (one drop of approximately 50 μ L, corresponding to 5% of the 1 mL). While data is not available to directly substantiate this transfer value for NiV and HeV, studies on the rates of exposure of other viruses and bacterial pathogens suggest that this load represents a reasonable amount capable of a subcutaneous dose and infection event. The needle stick injury event will be treated as a laboratory-acquired infection that requires the requisite incident reporting and medical response as dictated by standard practice and NBAF protocols.

Laboratory Exposure Transference – Inhalation (Respiratory)

An exposure to NiV or HeV via the inhalational pathway implies that a number of events must occur in the ABSL-4 area to make that material available for respiration. With the release of aerosolized agent through a spill, conducting necropsy procedures, or other aerosol generating activities, a corresponding breach in the BSL-4 suit and a loss of positive pressure must occur such that sufficient viable virus material is available for a respiratory exposure capability of initiating an infection. As studies are not available on the amount of NiV or HeV a person may inhale during ABSL-4 research activities or harbor in their nasal passage after performing ABSL-4 research activities the Updated SSRA will leverage information on available FMDv data presented previously in Table 4.2.4-1 and based on the works of Sellers and Parker. For ABSL-4 Transference respiratory exposure events, it is assumed that 5.7% of the aerosolized levels of NiV or HeV available in the AHR or necropsy room will be transferred to (via respiration) and harbored in the researcher's respiratory tract.

Laboratory Exposure Transference - Contact

Upon physical contact between a surface, spill, or material contaminated with viable virus, a certain percentage will be transferred to the recipient surface or material. The contaminated fomite or individual can then act as a vehicle to transfer viable viral particles to susceptible animals or humans outside of the NBAF if not appropriately decontaminated. Two primary modes of contact transference were examined for the ABSL-4 spaces: 1) a laboratory worker cuts the BSL-4 suit through sharps use (e.g., scalpel during necropsy) that does not cause a subsequent break in the skin, but does result in skin contact with infectious material (such as the palm of the hand); and 2) an infectious sample that is being packaged and transferred out of necropsy room containment is placed in a container that is contaminated (on the outside) with NiV or HeV resulting in a potentially infectious fomite being transferred out of containment. Using the same approach to calculating transfer efficiency as the BSL-3 assessments, the transfer efficiency in a contact event varies greatly depending on the conditions and parameters of the contact, including the physical state of the donor material (wet or dry), contact duration, contact pressure, friction applied during contact, and the time between deposition and contact. Ansari et al. measured transfer efficiencies of approximately 16% for human rotavirus for a dry, 10-second contact between a stainless steel disc and fingerpad [Ansari et al., 1988]. Mbithi et al. calculated similar transfer efficiencies for hepatitis A virus (22%) between a steel disc and a fingerpad under dry conditions [Mbithi et al., 1992]. In a more recent study, Knobben et al. evaluated transfer

efficiencies of bacteria under dry and moist conditions between fomites and a glove and obtained an average efficiency of 42% for moist conditions without friction applied [Knobben et al., 2007]. Similarly, Julian et al. studied virus transfers for MS2 and bacteriophages for a dry, 10-second contact, and determined 21 to 39% of the deposited material was transferred [Julian et al., 2010]. Cohen et al. characterized residue transfer using a fluorescent tracer under a variety of contact conditions and determined that higher transfer efficiencies were obtained with greater pressure and upon moist conditions, with efficiencies ranging from 0.6 to 49% under all conditions [Cohen Hubal et al., 2007]. In earlier work, Reed also determined that transfer efficiencies of rhinovirus were greater with damp material, ranging from 0.6% to 49% (average of 22%) [Reed, 1975]. Based on these data, for the transference events that will typically involve contact with liquid spills or moist, contaminated material, a transfer efficiency of 40% is used in the Updated SSRA.

Transference – Contact Person to Person

Contact from person to person through an unmitigated and unreported laboratory-acquired infection provides a potential for exposure and resultant disease in the population at large. Standard human error is the only attributable probability, as an appropriate response to suspected or known exposure through medical monitoring (including contact precautions) and reporting is likely to reduce the potential for subsequent person-to-person spread.

In the event that a laboratory-acquired infection goes unreported, unmonitored and escapes containment via a human vector, the resultant infection rate of close contacts is high for NiV. Initial reporting for HeV translates to approximately 10% efficiency rate for transfer in person to person close contact infections, significantly lower in comparison to NiV. See Section 9.9 for a discussion of the transmission factors and probability of infection rates applied across all the events analyzed.

Efficiency of Fully Encapsulated Positive Pressure BSL-4 Suits

In the BSL-4 facilities, all workers will don fully-encapsulated suits and rely on air supplied directly to the individual suit. The efficacy of the positive pressure BSL-4 suits will be used for modeling the respiratory protections. Anecdotal information provided by BSL-4 suit users at a recent (October 2011) National Institutes of Health Research Festival points to defects in the feet or zippers as common areas of manufacturer defects leading to suit leaks. Defects in the suits are an important consideration for the laboratory worker, and thus a thorough and comprehensive evaluation of the suit is a vital step in preparation for entrance into the BSL-4 facilities.

ILC Dover, a manufacture of BSL-4 positive pressure suits, tested the protection of their Model 3525 Chemturiion Chemical suits in accordance with the NFPA (National Fire Protection Association) 1991 Standard on Vapor-Protective Ensembles for Hazardous Materials Emergencies by releasing SF₆ and measuring the chemical concentration levels inside and outside of the suits [ILC Dover, 2002]. All suits were tested with air supplied to the suit at 9 cfm and six different suits were evaluated. The penetration efficiencies (equivalent to the reduction factor) at three different regions of the suits and the average penetration efficiencies are shown in Table 9.5.4-1.

Table 9.5.4-1: Chemical Penetration Efficiency of ILC Dover Chemtursion Model 3525 BSL-4 Suits			
Suit	Breathing Zone ^a	Suit Closure ^a	Exhaust Valve ^a
1	6.186×10^{-5}	6.742×10^{-5}	7.317×10^{-5}
2	5.556×10^{-5}	5.825×10^{-5}	5.882×10^{-5}
3	5.357×10^{-5}	5.714×10^{-5}	5.941×10^{-5}
4	6.667×10^{-5}	5.556×10^{-5}	6.452×10^{-5}
5	6.383×10^{-5}	7.895×10^{-5}	9.231×10^{-5}
6	6.742×10^{-5}	8.451×10^{-5}	8.696×10^{-5}
Average	6.148×10^{-5}	6.697×10^{-5}	7.253×10^{-5}
Overall Average = 6.699×10^{-5} ($\pm 1.038 \times 10^{-5}$)			

As all measured values were below the detection limit, a reduction factor of one order of magnitude better than the average presented in Table 9.5.4-1, 6.7×10^{-6} , was used to represent the respiratory protection of the BSL-4 positive pressure suits. If there was a small tear or leak in the suit it was assumed (with SME input) that positive pressure would be maintained but that some reduction in respiratory protection would result; thus the reduction factor was set to 1×10^{-3} to represent this degraded respiratory performance condition. If positive pressure was lost (due to large breach in the suit, or small breach coupled with loss of air supply), the suit was modeled as not providing any protection.

Although manufacturer failures of BSL-4 suits are possible and documented as stated above; suit mechanical failure to the point at which the positive pressure air supply fails is a very low probability event. More probable however, is the failure of the person donning the BSL-4 suit to follow movement restriction protocols within the ABSL-4 environment (that prevent suit snags and tears on pens or coming into contact with animals that may scratch/bite/kick or otherwise breach the suit) or to perform complete testing and verification of suit performance prior to donning in the BSL-4 Change Room. Accordingly, BSL-4 suit failures are assigned the probabilities associated with human error as opposed to mechanical failure of the suit.

Efficiency of Disinfectants for Wipedown and Dunk Tanks

The effective use of disinfectants is critical to the safe operation of any biocontainment laboratory. Specific disinfectant(s) should be identified by the NBAF Biosafety Officer who will give consideration to many factors in the selection process. These factors include suitability for the pathogen, concentration,

application method, contact time, stability, and special procedures or safety precautions [Dvorak, 2008]. Reduction factors are reported in the 10^{-4} to 10^{-5} range for commercially-available decontamination solutions such as glutaraldehyde and chlorine dioxide commonly used in BSL-4 decontamination for NiV, HeV, and other high-risk pathogens. However, some disinfectants were noted to completely inactivate viruses like SARS. A list of the efficacies and reduction factors for chlorine dioxide against a variety of biological agents is shown in Table 9.5.4-2 [Taylor and Butler, 1982; Chen and Vaughn, 1990; Zoni et al., 2007].

Table 9.5.4-2: Efficacy of Chlorine Dioxide Disinfectant

Conc.	Organism	Time (min)	pH	Efficacy (%)	Reduction Factor	Reference
6 μ M	coliphage f2	2.0	9	0.999998	2.00×10^{-6}	Taylor and Butler, 1982
0.5 mg/L	SA-11	2.0	6	0.999990	1.00×10^{-5}	Chen and Vaughn, 1990
0.3 mg/L	SA-11	5.0	6	0.999990	1.00×10^{-5}	Chen and Vaughn, 1990
0.2 mg/L	HRV	2.0	6	0.999990	1.00×10^{-5}	Chen and Vaughn, 1990
0.6 mg/L	SA-11	0.5	7	0.999980	2.00×10^{-5}	Chen and Vaughn, 1990
0.2 mg/L	HRV	3.0	7	0.999990	1.00×10^{-5}	Chen and Vaughn, 1990
0.05 mg/L	SA-11	0.3	8	0.999990	1.00×10^{-5}	Chen and Vaughn, 1990
0.05 mg/L	HRV	0.3	8	0.999990	1.00×10^{-5}	Chen and Vaughn, 1990
1.0 mg/L	Staphylococcus aureus	1.0	7	0.999990	1.00×10^{-5}	Zoni et al., 2007
0.25 mg/L	Escherichia coli	1.0	7	0.999995	5.00×10^{-6}	Zoni et al., 2007
1.0 mg/L	Streptococcus	0.3	7	0.999995	5.00×10^{-6}	Zoni et al., 2007
1.0 mg/L	Lactobacillus brevis	5.0	7	0.999995	5.00×10^{-6}	Zoni et al., 2007
1.0 mg/L	Pseudomonas aeruginosa	1.0	7	0.999995	5.00×10^{-6}	Zoni et al., 2007
0.6 mg/L	Coxsackie Virus B5	4.5	7	0.999990	1.00×10^{-5}	Zoni et al., 2007

Table 9.5.4-2: Efficacy of Chlorine Dioxide Disinfectant

Conc.	Organism	Time (min)	pH	Efficacy (%)	Reduction Factor	Reference
0.6 mg/L	HAV	2.5	7	0.999990	1.00×10^{-5}	Zoni et al., 2007
Average				0.999991	8.80×10^{-6}	
Std. Dev.				0.000004	4.02×10^{-6}	

Based on the reported efficiencies, and given that the precise disinfectants are not yet identified for the NBAF, for the purposes of modeling in the Updated SSRA, the conservative representative reduction value by any disinfectant is considered to be 10^{-5} . NBAF protocols on use of dunk tanks, when followed properly, should then result in a 99.999% efficiency of decontamination of materials introduced, with a reduction factor of 10^{-5} .

Efficiency of Decontaminating (Chemical) Showers

Chemical decontaminating showers from the BSL-4 suites at the exit from the AHRs, necropsy rooms and the BSL-4 laboratory may utilize a variety of chemical disinfectants to provide maximum efficiency in decontaminating the exterior of the fully encapsulated suits worn in the BSL-4 spaces. The precise disinfectants have not been established for the NBAF; however, due to efficacy, health and safety, and common practices in BSL-4 containment, it is probable that quaternary ammonia based disinfectants will be used. According to a document published by the Division of the Institute of Agriculture and Natural Resources at the University of Nebraska–Lincoln, quaternary ammonia compounds are effective against enveloped viruses [Kennedy et al., 2000]. A literature review did not reveal any studies/papers reporting the specific effect of quaternary ammonia compounds on NiV/HeV; however, others [Kennedy et al., 2000, Suarez et al., 2003, Best et al., 1994] reported the effectiveness of this disinfectant on other enveloped viruses. A quaternary ammonia compound used in other BSL-4 laboratories, Micro-Chem Plus, has reported virucidal activity against enveloped viruses between 3.0-6.0 log [National Chemical Laboratories, Inc., Micro-Chem Plus Datasheet]. As no exact data were available regarding the efficacy of quaternary ammonia (or any other suitable disinfectant) against NiV and HeV, based on the data reported for other enveloped viruses, a representative reduction value of 10^{-5} was applied.

Efficiency of Spot Decontamination of Skin Exposure

Once an infectious agent has come into contact with the skin (suspected or known contact), spot decontamination should provide complete decontamination of the surface up to the probability of human error to follow effective decontamination procedures. The combination of hand-washing procedures, spot decontamination and chemical shower out of BSL-4 facilities contribute to an efficiency of 99.999% (reduction factor of 10^{-5}), identical to the efficiency attributed to chemical shower and dunk tank disinfections modeled individually.

Efficiency of Water Body Showers

Studies on the efficacy of water showering for removing contamination upon exit from animal pathogen laboratories have not been found. However, the results of numerous studies that have quantified the effectiveness of hand washing at removing viral contamination were identified. A 2004 review by Kampf and Kramer reports data from Bellamy [Bellamy et al., 1993] on the removal of rotavirus from hands when washing with plain soap and water or water alone [Kampf and Kramer, 2004]. A range of 1.17-1.19 \log_{10} TCID₅₀ of virus (6.8%-7.6%) remained. Other studies by Ansari and Mbithi performed similar experiments with rotavirus, HAV, and poliovirus, and found a removal rate of 81.44-98.39%, 6.11%-18.56% remained [Ansari et al, 1989] [Mbithi et al., 1993]. Without data specific to water showers and NiVHeV, or emerging infectious agent removal, these data were used to model the rate of virus removal by decontamination showers as a beta distribution with a mean of 89.9% removal (10.1% remain) and a standard deviation of 6.6%.

The use of personal protective equipment and the complete removal of apparel exposed to a viral-contaminated environment provide a valuable barrier layer to the contamination of skin. However, microorganisms on the skin surface can be effectively removed when water and a cleansing agent such as a soap or detergent are used simultaneously [Ayliffe et al, 1990]. Any procedure involving showering of an individual will result in significant removal of contamination from the skin surface [Amlôt et al., 2010]. Amlôt also showed, with a fluorescent tracer contaminant, that the use of a washcloth can enhance the removal of a skin contamination by approximately 20%. Unfortunately, this study did not quantify the overall removal efficiency of the contamination. However, data on the efficiency of removal of bacteria by shower indicate that 84% to 98% of contamination is removed by a single washing with unmedicated liquid soap [Ojajärvi, 1981]. For hand washing, it has been demonstrated that the mean percentages of virus removal with liquid soap and water alone are 86.9% and 83.6%, respectively [Ansari, 1989]. In consideration of the data reviewed, the removal efficiency for the body showering process is modeled as 90%—meaning that 10%, or 1×10^{-1} , of the skin contamination survives the showering process.

9.6 Event Summary

9.6.1 Event Circumstances

Based on the activities and experiments to be performed in the ABSL-4 AHR and necropsy laboratories in the NBAF, a total of sixteen circumstances (resulting in 109 events) were modeled that can result in a release of infectious material via the four pathways under consideration. These sixteen circumstances were solely developed around activities that are unique to handling and working with large animals (e.g., cattle, horses, sheep, pigs) in the BSL-4 environment. Further, critical feedback from subject matter experts was used to develop and refine these situations based on containment community collective concerns regarding working with large animals infected with zoonotic pathogens within BSL-4 containment [November ABSL-4 Assessment SME Solicitation meeting]. The sixteen circumstances are detailed in Table 9.6.1-1 and include eight originating from the ABSL-4 AHRs and eight originating from activities in the ABSL-4 necropsy room.

Table 9.6.1-1: ABSL-4 Event Circumstance Summary

Label	Originating Location	Pathway	Situation Leading to a Release of Infectious Material
L4AAi	AHR	Aerosol (Inoculation)	Animal sedation failure and squeeze chute failure results in inoculum being dropped, container failing, and the release of the aerosolized fraction of the inoculum
L4AA	AHR	Aerosol	Respiring infected animals secreted infectious material into the AHRs as an aerosol
L4AL	AHR	Liquid Waste	Disposal of infectious liquid waste generated in AHRs
L4AS	AHR	Solid Waste	Disposal of infectious solid (red bag) waste generated in AHRs
L4ATli	AHR	Transference (Injection, Inoculation)	Failure to sedate and restrain animal results in a failed inoculation event in which the researcher accidentally punctures the suit and skin barrier with the syringe resulting in self-inoculation
L4ATR	AHR	Transference (Respiratory)	Failure to restrain and pen animals results in an uncontrolled animal that causes a severe cut in the researcher suit and loss of positive pressure (either through the large cut or hose entanglement) resulting in an exposure to infectious aerosols
L4ATI	AHR	Transference (Injection)	Failure to restrain and pen animals results in an uncontrolled animal that bites the researcher through PPE gear, breaks the skin barrier and results in direct exposure to infectious material from the oral/nasal region of the animal
L4ATRs	AHR	Transference (Respiratory, Suit Failure)	Researcher fails to test suit and enters ABSL-4 AHR with a suit with leaks, or the researcher fails to pay attention to their movements in the ABSL-4 AHR and tears a small hole in the suit, resulting in degraded respiratory protection and potential exposure to infectious aerosols
L4NA	Necropsy	Aerosol	Aerosolized infectious material from necropsy procedures is released into the necropsy room
L4NL	Necropsy	Liquid Waste	Disposal of liquid waste generated in necropsy room
L4NSW	Necropsy	Solid Waste (Red Bag)	Disposal of solid (red bag) waste generated in necropsy room
L4NST	Necropsy	Solid Waste (Tissue/Carcasses)	Disposal of animal tissue and carcasses generated in necropsy room

Table 9.6.1-1: ABSL-4 Event Circumstance Summary

Label	Originating Location	Pathway	Situation Leading to a Release of Infectious Material
L4NTRs	Necropsy	Transference (Respiratory, Suit Failure)	Researcher fails to test suit and enters ABSL-4 AHR with a suit with leaks exposing them to infectious aerosols
L4NTI	Necropsy	Transference (Injection)	Researcher cuts through PPE with a necropsy tool (e.g., scalpel) , PPE does not protect the skin barrier, resulting in a direct transfer of infectious material from the contaminated tool to the researcher via injection
L4NTCp	Necropsy	Transference (Contact, Palm)	Researcher cuts through PPE, skin barrier is not compromised, but infectious material comes in direct contact with their skin (e.g., palm)
L4NTCf	Necropsy	Transference (Contact, Fomite)	Infectious sample is being packaged for shipment out of the necropsy room and the surface of container is contaminated

9.7 Pathogen Source Terms

To determine the risk of working with BSL-4 zoonotic foreign animal diseases, the typical amounts of these agents involved in BSL-4 activities were determined. These amounts of material, specifically concentration or infectious quantity distributions, used in experiments and procedures involving large animals in BSL-4 were used in accident event models. Research conducted in the ABSL-4 is expected to involve foreign animal and zoonotic diseases such as NiV, HeV, Rift Valley Fever virus (RVFv) or emerging biological agents. It is important to note that NiV and HeV were used as the representative pathogens by which to estimate the risk of working with infected livestock in ABSL-4 containment. Rift Valley Fever virus (RVFv) may also be studied within ABSL-4 containment at the NBAF but because the 2010 SSRA previously characterized the impact of RVFv through a quantitative risk assessment and there is no current requirement to study RVFv at the BSL-4 level; the focus of this assessment remained on estimating the never previously characterized risks of NiV, HeV and/or emerging pathogen work on livestock within ABSL-4 containment.

In order to estimate the amount of material available for release (MAR), the pathogen concentration distribution (i.e., source term) was determined by searching open source literature for experiments involving animal studies using NiV or HeV. The literature search was not limited to experiments conducted on large animals (e.g., cattle, horses, pigs, sheep), but rather all animal experiments including both vaccine and pathogenesis studies. Source term distributions were obtained for the concentration of infectious NiV and HeV in all tissues and biological matrices in which these viruses could be transmitted including: blood; urine; feces; brain; nasal/oral swabs; rectal swabs; naso/oro passages; lung; bronchial nodes; heart; spleen; kidney; uterus; bladder; and intestine. The source terms were also determined for the amount of material used for inoculation experiments conducted.

No data were obtained on the respiratory shedding of NiV or HeV in any animal. Nor was any data obtained on NiV and HeV tissue concentrations in cattle or sheep. Due to the limited number of animal studies on these viruses, the tissue concentrations and biological matrix concentrations were averaged across all species and animals. To calculate a more accurate distribution of the viral source terms, individual measurements of specific animals, including those animals which did not become diseased, were included in the statistical analysis; (e.g., measurements of 0 PFU in tissue of an individual animal in an experiment were included to account for animals which may have been inoculated but did become diseased or infected.) In addition, only studies which had measurements of infectious virus were included in the source term distributions; no attempts were made to convert relative viral RNA levels to infectious concentrations (i.e., TCID₅₀ or PFU).

The use and frequency of each Originating Location (e.g., AHR and necropsy room) and Pathway (e.g., aerosol, liquid waste, solid waste, transference) were estimated based on the 65% Design, expected activities in the ABSL-4 at the NBAF [Rodriguez, L., personal communication, 13 Nov 2011], and known activities at similar laboratories [Jeggo M., personal communication, 13 Nov 2011]. The use and frequency values were used in conjunction with the source terms to calculate the MAR for each set of circumstances as defined in Section 9.6. For each set of circumstances, there are mitigating nodes (see

Section 9.5) that reduce the MAR to its *Q* value (or quantity of infectious material released at that stage of the accident sequence), and these *Q* values are presented in Section 9.8.

Presented herein are the methodologies for determining the use and frequency of each Originating Location and Pathway, as well as for calculating the MAR for each set of circumstances.

9.7.1 Animal Holding Rooms

9.7.1.1 Use and Frequency – AHRs

The ABSL-4 Animal Holding Rooms (AHRs) will be used by NBAF researchers to conduct large animal experiments on BSL-4 zoonotic and foreign animal disease agents such as NiV and HeV. The NBAF ABSL-4 facility consists of two large AHRs that can each accommodate up to 2 horses (< 1440 lbs), 4 cattle (< 770 lbs), 8 pigs (< 110 lbs), or 8 sheep (< 110 lbs) [NDP, October 2011]. The AHRs are a shared resource of the NBAF tenants including the USDA ARS, USDA APHIS, and DHS.

Over the course of a year, it is expected that between 8 and 10 experiments would be conducted per AHR [Rodriguez L., personal communication, 13 Nov 2011; Jeggo, M., personal communication, 13 Nov 2011]. There are two types of experiments which will likely be conducted in the ABSL-4: 1) vaccine studies which will last up to 14 weeks; and 2) pathogenesis studies lasting approximately 3 weeks. The studies are divided amongst “large” animals (i.e., cattle, horses), and “small” animals (i.e., pigs, sheep). Vaccine studies will either have ~6 large animals or ~12 smaller animals; pathogenesis studies will have either ~4 large animals or ~10 small animals. For the purposes of modeling, it was estimated that 50% of the studies will be performed on smaller animals and 50% on larger animals. Based on the expected length of the vaccine and pathogenesis studies and a total number of 20 studies per year (between the two AHRs), four vaccine studies and 16 pathogenesis studies were modeled for a total usage of 104 weeks (100% occupancy assuming all studies take the full 3 or 14 weeks between the two AHRs). For both the pathogenesis and vaccine experiments, there will be a 1 week acclimation period for the animals prior to inoculation. Upon inoculation, the animals are considered infectious. Assuming four vaccine and 16 pathogenesis studies are conducted per year, 80.8% of the time, the AHRs will be considered infectious, for a total of 588 AHR days (84 infectious weeks). A summary of the modeled use and frequency of the ABSL-4 AHRs on a per year basis is shown in Table 9.7.1-1.

Table 9.7.1-1: Summary of Use and Frequency of ABSL-4 AHRs Per Year

	Vaccine		Pathogenesis		Total per Year (2 AHRs)
	Range	Modeled	Range	Modeled	
Experiments/yr	3 – 5	4	10 – 20	16	20 exp.
Length of Experiment (weeks)	14		3		104 weeks
Infectious Weeks/Experiment	13		2		84 weeks
Infectious Days/Experiment	91		14		588 days
Animals/yr	36		112		148 animals
Large Animal Experiments	2		8		10 exp.
Large Animals/Experiment (Cattle, Horses)	2 – 6	6	2 – 6	4	44 animals
Small Animal Experiments	2		8		10 exp.
Small Animals/Experiment (Pigs, Sheep)	8 – 16	12	8 – 12	10	104 animals

Based on the modeled values in Table 9.7.1-1, on a per day basis, there will be an average of 16 animals present in the AHRs (8 per AHR). Of these 16 animals, 11 on average will be pigs and sheep, while 5 will be cattle and horses. Using the same percent of time the animals are infectious of 80.8%, the average number of infectious animals per day were calculated. For modeling estimates, it was also presumed that on average, 50% of the large animal studies would be conducted on horses and 50% on cattle. Similarly, on average 50% of the smaller animal studies would be conducted on pigs and 50% on sheep. Additional animal characteristics such as their daily urine and fecal excretion, blood volume, and mass are included with the average number of animals present in the AHRs per day in Table 9.7.1-2.

Table 9.7.1-2: Animals per ABSL-4 AHR per Day and Animal Characteristics

Animal	# Per Day	# Infected / Day	Mass (lbs)	Average Mass (lbs)	Mass (kg)	Urine (L) per Day	Feces (kg) Per Day	Blood (L) per Animal
Total	16.00	12.93	---	51800	23496	34.04	105.04	177.76
Large	5.00	4.04	275 - 1430	1000	454	---	---	---
Cattle	2.50	2.02	275 - 1430	1000	454	4.95	11.00	30.0
Horse	2.50	2.02	275 - 1430	1000	454	7.26	35.24	49.2
Small	11.00	8.89	40 - 110	75	34	---	---	---
Sheep	5.50	4.44	40 - 110	75	34	0.35	0.58	1.5
Pigs	5.50	4.44	50 - 110	75	34	1.76	2.03	2.5

In the ABSL-4 AHRs it is expected that similar animal handling activities will be conducted as that in the BSL-3Ag. For the purposes of modeling, each morning two animal handlers will perform routine animal care and each evening two animal handlers will perform additional routine care. During the day, one researchers and one animal handler (or a second researcher) are expected to perform laboratory activities involving the animals (e.g., inoculation, sample collection, health monitoring); work in the ABSL-4 will involve researchers working in tandem at all times.

9.7.1.2 Aerosol Contributions – AHRs

Two aerosol events were modeled for the ABSL-4 AHRs: 1) aerosol release from the dropping of a syringe of inoculum; and 2) respiring of aerosols (i.e., respiratory shedding) of infectious material by infected animals present in the AHRs.

Aerosol Release through Dropped Inoculum (L4AAi)

The distribution of concentrations and total amount of infectious NiV and HeV used for inoculation experiments was determined through a literature search of BSL-4 experiments conducted on animals with these viruses. Twenty-four literature sources were identified that detailed the amount of material used for inoculation, totaling 83 specific inoculation experiments on hamsters, horses, pigs, guinea pigs, cats, ferrets, monkeys, and fruit bats [Berhane et al., 2008; Bossart et al., 2009, 2011; Geisbert et al., 2010; Georges-Courbot et al., 2006; Guillaume et al., 2004a, 2006, 2009; Li et al., 2010; Marsh et al., 2011; Mathieu et al., 2011; McEachern et al., 2008; Middleton et al., 2002, 2007; Pallister et al., 2011b; Rockx et al., 2010, 2011; Torres-Velez et al., 2008; Weingartl et al., 2005, 2006; Williamson et al., 1998, 2000]. A summary of the NiV and HeV inoculum distribution is shown in Table 9.7.1-3.

Statistic	PFU/Inoculum	log PFU/Inoculum
5 th -Percentile	6.93×10^0	0.84
50 th -Percentile	6.00×10^4	4.78
95 th Percentile	1.26×10^7	7.10
Mean	2.84×10^6	4.42
Std. Dev.	6.51×10^6	2.06

Based on the distribution of inoculum quantities, the log scale mean value and standard deviation were used to determine the MAR for this event (Table 9.7.1-4). The low and high MAR values represent ± 2 standard deviations away from the mean, and the mean is the middle MAR value. The quantity released upon dropping the syringe inoculum is the aerosolized release fraction (ARF) of a spill (1×10^{-4} of the quantity in solution).

	Inoculum (PFU)	Aerosolized MAR/Inoculum (PFU)
Low	1.99×10^0	1.99×10^{-4}
Medium	2.62×10^4	2.62×10^0
High	3.46×10^8	3.46×10^4

Aerosol Release Respiratory Shedding (L4AA)

The respiratory shedding of infected animals produced infectious aerosols that must be filtered to prevent and protect against releases. No data was found in the literature search on the respiration levels of Nipah and Hendra for infected animals, however, positive viral isolation has been measured in oral and nasal swabs of both animals and humans [Chua et al., 2001; Berhane et al., 2008; Li et al., 2010; Williamson et al., 1998] suggesting respiratory shedding. Furthermore, evidence suggests respiratory transmission, particularly for NiV [Luby et al., 2009a; b; Mounts et al., 2001; Ksiazek et al., 2011]. As no such specific data exists for NiV and HeV, for modeling an aerosol release event in the ABSL-4 AHRs, the low, medium, and high aerosol FMDv contributions from animal respiration were used (see Section 4.3 for details –due to the method of FMD animal respiration data it is expected that the amounts represented in this study encompass aerosolized virus contributions from not only the respiration, but also secondary aerosols generated through other activities in the room such as person and animal movement, splashing and washdown of urine and feces, etc.). The mean respiration levels for cattle were also used for horses. A summary of the mean respiratory levels and the MAR for the aerosol release through respiratory shedding is shown in Table 9.7.1-5. It is recognized that these Low, Medium and High values may not be truly representative of the amount of virus shed by NiV and HeV infected animals, however given that the range considered spans four orders of magnitude, it is presumed that the true value is likely to fall somewhere within this range and even if it does not this body of work at

least provides a starting point estimate by which an estimated risk ranking may be achieved. Clearly as more data become available these values (and resulting conclusions) should be re-evaluated.

Table 9.7.1-5: Aerosol Respiration Concentrations in ABSL-4 AHR

Species	Mean PFU / 24 h	# Infected Animals per Day per AHR	Aerosolized Material (PFU per day)
Cattle	1.37×10^4	1.01	1.38×10^4
Horse	1.37×10^4	1.01	1.38×10^4
Sheep	1.19×10^4	2.22	2.65×10^4
Swine	4.84×10^3	2.22	1.08×10^4
	Low	Medium	High
MAR (PFU/Day)	3.84×10^4	6.48×10^4	1.01×10^8

9.7.1.3 Liquid Waste – AHRs

Liquid Waste (L4AL)

The primary contribution to the liquid waste pathway in the ABSL-4 AHRs is expected to be from the urine and feces of the infected animals. The distribution of the Niv and HeV concentrations in urine and feces of infected animals was calculated. Few data points for urine and feces were found in the literature and were only found for HeV in horses and pigs [Li et al., 2010; Williamson et al., 1998]. A summary of the viral concentrations urine and feces is listed in Table 9.7.1-6.

Table 9.7.1-6: Viral Concentration Distribution in Urine and Feces (log PFU/g)

	Percentile			Mean	Std. Dev.	Notes
	5 th	50 th	95 th			
Urine	0.00	0.00	2.68×10^2	6.18×10^1	1.20×10^2	HeV, horses and pigs (n = 8)
Feces	6.93×10^0	6.93×10^1	1.32×10^2	6.93×10^1	9.18×10^1	HeV, pigs (n=2)

Based on the average number of animals present in the AHRs (see Section 9.7.1.1) and their average daily urine and fecal excretions, the MAR for the liquid waste pathway was calculated (Table 9.7.1-7).

Table 9.7.1-7: Liquid Waste MAR for ABSL-4 AHRs

Species	Median Urine Conc. (PFU/g)	Median Feces Conc. (PFU/g)	# Infected Animals/Day	Urine Excretion (kg/day)	Fecal Excretion (kg/day)	PFU/Day
Cattle	1.00×10^{-2}	6.93×10^1	2.02	4.95	11.00	1.54×10^6
Horse			2.02	7.26	35.24	4.93×10^6
Sheep			4.44	0.35	0.58	1.79×10^5
Swine			4.44	1.76	2.03	6.25×10^5
	Low		Medium		High	
MAR (PFU/Day)	7.28×10^5		7.28×10^6		1.61×10^7	

9.7.1.4 Solid Waste – AHRs

Solid Waste (L4AS)

The primary contribution to the solid waste pathway in the AHRs is the transfer of liquid waste to solid, disposable materials such as towels or other animal handling materials that come into contact with the urine, feces, and other infectious material in the AHRs. The NiV and HeV viral material present in the urine and feces represents a contact potential for items entering the solid waste stream. As discussed in Section 4.3, for modeling purposes, 20% of the infectious quantity in the liquid waste is estimated to be transferred to materials that will be disposed of in biohazard red bag waste and sterilized via autoclaves and incineration. In the ABSL-4 AHR, autoclave runs will be performed daily regardless of whether a complete batch of waste is generated. Thus, the MAR for the solid waste pathway is the amount of infectious material in the solid waste produced per day. Based on the values presented in Section 9.7.1.3, the MAR for the solid waste pathway in the ABSL-4 AHRs is listed in Table 9.7.1-8.

Table 9.7.1-8: Solid Waste MAR from AHRs

	Liquid Waste MAR (PFU/day)	Transfer Percentage to Solid Materials	Solid Waste MAR (PFU/Autoclave Run)
Low	7.28×10^5	20%	1.46×10^5
Medium	7.28×10^6		1.46×10^6
High	1.61×10^7		3.22×10^6

9.7.1.5 Transference – AHRs

Transference (Injection from Inoculum) (L4ATli)

One of the modeled transference events is the accidental injection of inoculum into a researcher. In this set of circumstances, while preparing to inoculate the animals, the animals are not appropriately restrained, the researcher is physically displaced by the animals, and the researcher accidentally injects a fraction of the inoculum into themselves. The source of pathogen involved in such a sequence of events would be the amount of material in a single syringe of inoculum. In such an event, it is expected that approximately 1 droplet would be injected (~50 µL), or approximately 5% of a 1 mL syringe. The MARs for this set of circumstances are detailed in Table 9.7.1-9.

	Inoculum (PFU)	Injected Fraction	Injected Inoculum (PFU)
Low	1.99×10^0	5%	9.95×10^{-2}
Medium	2.62×10^4		1.31×10^3
High	3.46×10^8		1.73×10^7

Transference (Respiratory from Cut Suit by Uncontrolled Animal) (L4ATR)

While working in a BSL-4 positive pressure suit in an AHR with large animals, there is a risk that the suit gets torn, in this set of circumstances by an animal which has become aggressive or that has not been properly restrained. If the suit is severely torn and the hose becomes entangled or disconnected from the suit, there will be a loss of positive pressure and a potential respiratory exposure to infectious aerosols present in the AHR. The exposure event was modeled to last for no longer than 30 minutes before the exposed individual would be able to exit the ABSL-4 AHR to the dirty vestibule. The MARs for this set of circumstances are the infectious aerosols produced in a 30 minute timeframe (as compared to the 24 h levels described in Section 9.7.1.2) and are detailed in Table 9.7.1-10. As described in Section 9.7.1.2, the pathogen aerosol source terms were derived from FMDv concentrations as no published data for NiV or HeV was found.

	Aerosol Levels (PFU / 24 h)	Respiratory MARs (PFU / 30 min)
Low	3.84×10^4	8.00×10^2
Medium	6.48×10^4	1.35×10^3
High	1.01×10^8	2.10×10^6

Transference (Injection from Animal Bite) (L4ATI)

A similar situation may occur in the AHR in which an animal which has become aggressive or that has not been properly restrained bites, kicks, or scratches a researcher resulting in an injection transference event. The MARs for this set of circumstances are based on NiV and HeV concentrations reported in the oral and nasal regions of the animals (i.e., if the injection was due to an infected animal bite these sources represent the amount of NiV or HeV available in the saliva or other bodily fluids). The distribution for virus concentrations in these biological matrices were derived from oral swabs, nasal swabs, nasal mucosa, and other oro/pharynx viral measurements in literature papers [Berhane et al., 2008; Li et al., 2010; Maisner et al., 2009; Rockx et al., 2010, 2011; Weingartl et al., 2005, 2006; Williamson et al., 1998]. A summary is presented in Table 9.7.1-11. The 5th, 50th, and 95th percentiles presented in Table 9.7.1-11 were used to derive the MARs by assuming that 10% of 1 g of infectious material was directly transferred (i.e., injected) into the researcher (Table 9.7.1-12).

Table 9.7.1-11: Viral Concentration Distribution in Oral/Nasal Region (PFU)

	Percentile			Mean	Std. Dev.	Notes
	5 th	50 th	95 th			
Oral/Nasal Region	0.00	1.00×10^2	1.07×10^4	2.84×10^1	2.84×10^3	Nasal swabs, oral swabs, nasal mucosa, tracheal swabs, oro/pharynx; <i>Pigs, monkeys, hamsters, guinea pigs, horses</i>

Table 9.7.1-12: MARs from Animal Bite Injection

	Oro/Naso Region (PFU/g)	Injected MAR (PFU)
Low	1.00×10^{-2}	1.00×10^{-3}
Medium	1.00×10^2	1.00×10^1
High	1.07×10^4	1.07×10^3

Transference (Respiratory through Suit Tear) (L4ATRs)

Another potential transference event in the AHRs is a respiratory exposure due to a leak in the BSL-4 suit or a small tear caused by having the suit snagged on pens or gates within the AHR. The small leak or tear may not be noticed immediately and this respiratory exposure was estimated to occur over a 4 h time period. The MARs for this set of circumstances are the infectious aerosols produced in a 30 minute timeframe (as compared to the 24 h levels described in Section 9.7.1.2) and detailed in Table 9.7.1-13. As described in Section 9.7.1.2, the pathogen aerosol source terms were derived from FMDv concentrations as no published data for NiV or HeV was found. SMEs have reported that small leaks or tears in BSL-4 suits do not result in loss of position pressure. Although this is acknowledged, the

Updated SSRA took the conservative approach and assumed that if a leak or small tear in the suit is present, than some loss of efficiency of respiratory protection should be applied. For cases where there was reduced efficiency a reduction factor of 1×10^{-3} was applied versus a reduction factor of 1×10^{-6} for full functioning respirator (see Section 9.8.2.5 for detailed reductions applied per the event).

	Aerosol Levels (PFU / 24 h)	Respiratory MARs (PFU / 4 h)
Low	3.84×10^4	6.40×10^3
Medium	6.48×10^4	1.08×10^4
High	1.01×10^8	1.68×10^7

9.7.2 Necropsy

9.7.2.1 Use and Frequency – Necropsy

At the NBAF, every animal that enters containment will ultimately be euthanized and a necropsy performed. The ABSL-4 in the NBAF contains two necropsy tables each with a 2000 lb load capacity [NDP, October 2011]. The necropsy room is anticipated to be staffed with two researchers. On any given work day, a necropsy can be performed on approximately 1 – 2 large animals (e.g., cattle, horses) or 4 – 6 smaller animals (e.g., pigs, sheep). As necropsies will be performed at the end of experiments, an average of 1.5 large animals or 5 smaller animals per day was assumed in the modeling [Rodriguez, L., personal communication, 13 Nov 2011]. Based on the use and frequency of the AHRs as presented in Section 9.7.1.1, a total of 148 animals are expected to be euthanized in the ABSL-4 in a year. Of these 148 animals, 44 will be large animals and 104 will be smaller animals. If an average of 1.5 large animal or 5 small animal procedures can be performed per day, it will take approximately 50 days to perform necropsies of all 148 animals. A summary of the necropsy room use in the ABSL-4 is presented in Table 9.7.2-1 using the assumptions made above and in Section 9.7.1.

Species	# Animals per Year	# Animals per Necropsy Day	# Necropsy Days	Average # Animals per Necropsy Day
Cattle	22	1.5	14.7	0.44
Horse	22	1.5	14.7	0.44
Sheep	52	5.0	10.4	1.04
Swine	52	5.0	10.4	1.04
TOTAL	148	n/a	50.1	2.95

9.7.2.2 Aerosol Contributions – Necropsy

Aerosol Release (L4NA)

During necropsy procedures, unprotected workers may be exposed to aerosols generated from cutting of tissue, bone, and carcasses, as well as from aerosolized portions of infectious liquids such as blood. For the purposes of determining the material available for release as aerosols, it is estimated that 50% of the blood volume will drain from the animal into the liquid effluent decontamination system. However, a portion of the remaining 50% may become aerosolized. Furthermore, as described in Section 4.3, the cutting of bone with power tools produces a significant amount of aerosolized particulate which can be inhaled. For the purposes of modeling the aerosol MAR in the necropsy room, the aerosolized release fraction (ARF) (1×10^{-4}) of 50% of the blood volume of the animals was summed with ten times the ARF times 1% of the average NiV or HeV concentrations in the tissue. One percent of the tissue is estimated to be exposed to cutting and of that 1%, ten times the ARF ($10 \times 10^{-4} = 10^{-3}$) of this material is estimated to be aerosolized. The aerosol MAR for the necropsy room is summarized in the following equations:

$$\text{Aerosol MA} = A \times 50\% \text{ Blood Volume} + 10 \times A \times 1\% \text{ Tissue Mass} \quad \text{Equation 9.7.2-1}$$

$$\text{Aerosol MA} = 10^{-4} \times 50\% \text{ Blood Volume} + 10^{-3} \times 1\% \text{ Tissue Mass} \quad \text{Equation 9.7.2-2}$$

The infectious levels (i.e., concentrations of NiV and HeV) in the blood and in the tissue were determined by averaging measured values published in literature. For the concentrations of NiV and HeV in blood, the average values measured in whole blood, serum, and plasma was calculated [Berhane et al., 2006; Geisbert et al., 2010; Guillaume et al., 2004b; Li et al., 2010; Mathieu et al., 2011; Rockx et al., 2011; Williamson et al., 1998, 2000]. For the concentration of NiV and HeV in tissue, an overall average of the NiV and HeV concentrations in all tissues was calculated [Georges-Courbot et al., 2006; Guillaume et al., 2004b, 2009; Li et al., 2010; Maisner et al., 2009; Middleton et al., 2002; Rockx et al., 2010, 2011; Weingartl et al., 2005; Williamson et al., 1998, 2000]. No attempt was made to weight the average viral concentrations in tissue by the average mass of each organ. The NiV and HeV virus concentration distribution in blood and tissue for animals is presented in Table 9.7.2-2. (For the log PFU/g values, any measurement of 0 PFU or 0 TCID was set to a log value of -2, equivalent to 0.01 PFU.)

Table 9.7.2-2: Viral Concentration Distribution in Blood and Tissue

	Percentile			Mean	Std. Dev.	Notes
	5 th	50 th	95 th			
Blood (Log PFU/g)	-2.00	-2.00	2.00	-1.42	1.41	Blood, serum, plasma; <i>pigs, hamsters, horses, monkeys, guinea pigs</i>
Tissue (PFU/g)	-2.00	1.40	5.38	1.03	2.92	Bladder, brain, bronchial nodes, bronchus, bone marrow, heart, intestine, kidney, lung, lymph nodes, pancreas, spinal cord, spleen, trachea, uterus; <i>hamsters, pigs, cats, monkeys, minipigs, horses, guinea pigs</i>
	Low			Medium		High
Blood (PFU/g)	1.00×10^{-2}			1.00×10^{-2}		1.00×10^2
Tissue (PFU/g)	1.57×10^{-5}			1.08×10^1		7.46×10^6

The average mass and average number of each type of animal was used to determine the aerosol MAR contribution from cutting tissue. Similarly, the average blood volume and number of type of each animal was used to determine the aerosol MAR contribution from the aerosolized blood. The details behind each of these subsets of aerosol contributions for the ABSL-4 necropsy room are listed in Tables 9.7.2-3 and 9.7.2-4.

Table 9.7.2-3: Aerosolized Tissue in ABSL-4 Necropsy per Day				
Species	Mean Viral Conc. in Tissue (PFU/g)	Average Mass (kg)	Average #Animals per Necropsy Day	Aerosolized Tissue (PFU/Necropsy Day)
Cattle	1.08×10^1	454	0.44	2.15×10^1
Horse		454	0.44	2.15×10^1
Sheep		34	1.04	3.81×10^0
Swine		34	1.04	3.81×10^0
TOTAL			2.95	5.07×10^1

Table 9.7.2-4: Aerosolized Blood in ABSL-4 Necropsy per Day				
Species	Mean Viral Conc. in Blood (PFU/mL)	Blood Volume (L)	Average #Animals per Necropsy Day	Aerosolized Blood (PFU/Necropsy Day)
Cattle	1.00×10^{-2}	30.0	0.44	6.58×10^{-3}
Horse		49.2	0.44	1.08×10^{-2}
Sheep		1.5	1.04	7.78×10^{-4}
Swine		2.5	1.04	1.30×10^{-3}
TOTAL			2.95	1.95×10^2

The MARs per necropsy day for the aerosol pathway in the necropsy room are listed in Table 9.7.2-5. These values were calculated by using the distributions of the viral concentrations in tissue and blood presented in Table 9.7.2-2.

Table 9.7.2-5: Aerosol MARs for ABSL-4 Necropsy Room	
	Aerosol Levels (PFU / Necropsy Day)
Low	1.95×10^{-2}
Medium	5.07×10^1
High	3.50×10^7

9.7.2.3 Liquid Waste – Necropsy

Liquid Waste (L4NL)

The primary sources of infectious material that will enter the effluent decontamination system from the necropsy room are the fluids from the infected animals which are lost during post-mortem analysis. The pathogen source terms for the liquid waste pathway in the ABSL-4 necropsy room were set to 50% of the blood volume of the animals, as described in Section 4.3 for the FMDv assessment. The blood volumes, viral concentration distributions in the blood, and average number of animals that go through the necropsy room during a necropsy day were used to calculate the liquid waste MAR (Table 9.7.2-6).

Table 9.7.2-6: Liquid Waste MAR in ABSL-4 necropsy room

Species	Mean Viral Conc. in Blood (PFU/mL)	Blood Volume (L)	Average #Animals per Necropsy Day	Liquid Waste Viral Conc. (PFU/Necropsy Day)
Cattle	1.00×10^{-2}	30.0	0.44	6.58×10^{-2}
Horse		49.2	0.44	1.08×10^{-1}
Sheep		1.5	1.04	7.78×10^{-3}
Pig		2.5	1.04	1.30×10^{-2}
		Low	Medium	High
MAR (PFU/Necropsy Day)		1.95×10^{-1}	1.95×10^{-1}	1.95×10^3

9.7.2.4 Solid Waste – Necropsy

The primary source of infectious material that is sterilized via the solid waste pathway in the ABSL-4 necropsy room is the infected animals – their tissues and carcasses. The MAR for the solid waste pathway in the necropsy room were derived from the mean NiV and HeV viral concentrations in the tissue (see Section 9.7.2.2 for details on how this viral concentration distribution was determined). As necropsies are only performed at the end of a study, for the purposes of modeling, tissues and carcasses from all animals in a single study were assumed to be processed (i.e., sterilized) as a batch. In other words, each autoclave run would consist of all infectious material (i.e., infectious tissue in the carcasses

of the animals) produced in an average study. The ABSL-4 necropsy room is equipped with freezer space capable of storing animals prior to sterilization. In the BSL-3Ag necropsy room, it is assumed that tissues and carcasses are disposed of once per week; similarly, in the ABSL-4 necropsy room it is assumed that tissues and carcasses are disposed of after completion of the study. As it is estimated that there will be 20 large animal studies in the ABSL-4 per year, animal tissue and carcasses will be processed 20 times per year. Each animal study averages approximately 2590 lbs (1175 kg), which falls well within the maximum process capability of the tissue autoclave per week of ~10,500 lbs. The values used to determine the solid waste contributions of viral concentrations in the necropsy room are listed in Table 9.7.2-7.

Species	Mean Viral Conc. in Tissue (PFU/g)	Animal Mass (kg)	# Animals Per Year	Mass Per Year (kg)	Viral Qty. in Tissue per Year
Cattle	1.08 × 10 ¹	454	22	9979	1.08 × 10 ⁸
Horse		454	22	9979	1.08 × 10 ⁸
Sheep		34	52	1769	1.91 × 10 ⁷
Pig		34	52	1769	1.91 × 10 ⁷
Average Per Study		158.8	7.4	1175	1.27 × 10⁷

Solid (Red Bag) Waste (L4NSW)

Of the infectious material produced per study in the ABSL-4 necropsy room, it is estimated that 20% of the tissue and carcass waste will be transferred to disposable solid material such as towels, disposable tools, containers, etc., and this material will be sterilized through two autoclaves in biohazard red bags and then incinerated. The solid red bag waste is expected to be processed on each necropsy day as opposed to at the end of each study. The infectious solid waste generated per necropsy day is listed in Table 9.7.2-8. The MAR in this solid (red bag) waste pathway is listed in Table 9.7.2-9.

Species	Mean Viral Conc. in Tissue (PFU/g)	Animal Mass (kg)	# Animals Per Necropsy Day	Mass Per Necropsy Day (kg)	Viral Qty. in Tissue per Necropsy Day
Cattle	1.08 × 10 ¹	454	0.44	199.0	2.15 × 10 ⁶
Horse		454	0.44	199.0	2.15 × 10 ⁶
Sheep		34	1.04	35.3	3.81 × 10 ⁵
Pig		34	1.04	35.3	3.81 × 10 ⁵
Total		158.8	2.95	468.7	5.07 × 10⁶

	Viral Qty. in Tissue Per Necropsy Day	Viral Qty. in Red Bag Waste Per Necropsy Day
Low	7.34×10^0	1.47×10^0
Medium	5.07×10^6	1.01×10^6
High	3.50×10^{12}	6.99×10^{11}

Solid Waste (Tissue and Carcasses) (L4NST)

The remaining 80% of the infectious tissue and carcass waste is assumed to be sterilized in the tissue autoclave and then incinerated. The MAR in this solid waste (tissue and carcass) pathway is listed in Table 9.7.2-10. These values are the contributions from the average number of animals per study.

	Tissue/Carcass Infectious Solid Waste (PFU/Study)
Low	1.47×10^1
Medium	1.02×10^7
High	7.01×10^{12}

9.7.2.5 Transference – Necropsy

Transference (Respiratory through Suit Leak) (L4NTRs)

A potential transference event in the necropsy room is a respiratory exposure due to a leak in the BSL-4 suit. The small leak may not be noticed immediately and this respiratory exposure was estimated to occur over a full day in the necropsy room. The MARs for this set of circumstances is the infectious aerosols produced during a necropsy day and detailed in Table 9.7.2-5. The respiratory MARs for the necropsy room are shown in Table 9.7.2-11. [Note that as stated in 9.5.4.1, “Efficiency of Fully Encapsulated Positive Pressure BSL-4 Suits”, in the case of a small leak in the BSL-4 suit, some positive pressure, and thus protection, is maintained.]

Table 9.7.2-11: Respiratory MARs for ABSL-4 Necropsy Room

	Aerosol Levels (PFU / Necropsy Day)
Low	1.95×10^{-2}
Medium	5.07×10^1
High	3.50×10^7

Transference (Injection from Cut with Tool) (L4NTI)

Another potential transference event in the necropsy room is one in which the researcher accidentally cuts their PPE suit and the tool cuts through the skin barrier resulting in a laboratory injection. The source terms for such circumstances were assumed to be 1 g of infectious tissue, of which 40% is transferred to the tool, and then 100% of this transferred material is injected into the cut. The MAR for this transference injection pathway is shown in Table 9.7.2-12.

Table 9.7.2-12: Transference Injection MAR for ABSL-4 Necropsy Room

	Viral Conc. in Tissue (PFU/g)	Mass Available for Transfer (g)	% Transferred from Tissue to Tool	% Injected from Tool into Cut	Injected Fraction (PFU)
Low	1.57×10^{-5}	1.00	40%	100%	6.26×10^{-6}
Medium	1.08×10^1				4.32×10^0
High	7.46×10^6				2.98×10^6

Transference (Contact with Palm through Cut PPE) (L4NTCp)

In the event that the PPE suit is cut in the necropsy room, the tool may not cut through the exposed skin, but rather may come into contact with skin resulting in a transference contact event. In these modeled events, the source terms were also assumed to be 1 g of infectious tissue, of which 40% is transferred to the tool, and then another 40% is transferred onto the palm. The MAR for this transference contact pathway is shown in Table 9.7.2-13. (Without the final transfer to the palm, the MAR is the same as that for the transference injection pathway as shown in Table 9.7.2-12.)

Table 9.7.2-13: Transference Palm Contact MAR for ABSL-4 Necropsy Room

	Viral Conc. in Tissue (PFU/g)	Mass Available for Transfer (g)	% Transferred from Tissue to Tool	% Transferred from Tool to Palm	Injected Fraction (PFU)
Low	1.57×10^{-5}	1.00	40%	40%	2.51×10^{-6}
Medium	1.08×10^1				1.73×10^0
High	7.46×10^6				1.19×10^6

Transference (Contact with Fomite) (L4NTCf)

The last modeled set of circumstances in the ABSL-4 necropsy room is a fomite contact transference pathway. In these events, an infectious sample from the necropsy room (e.g., tissue sample) is being shipped to another BSL-4 laboratory for further analysis. In the packaging of the sample, infectious material contaminates the outer surface of the package (i.e., the fomite). The source terms were set 1 g of infectious tissue all over the surface of the package; the MAR for this set of events is listed in Table 9.7.2-14.

Table 9.7.2-14: Transference Fomite Contact MAR for ABSL-4 Necropsy Room

	Viral Conc. in Tissue (PFU/g)	Mass Transferred (g)	Injected Fraction (PFU)
Low	1.57×10^{-5}	1.00	1.57×10^{-5}
Medium	1.08×10^1		1.08×10^1
High	7.46×10^6		7.46×10^6

9.8 Event Analyses

Based on the activities and experiments to be performed in the ABSL-4 AHR and necropsy laboratories in the NBAF, a total of sixteen circumstances were modeled that can result in a release of infectious material via the four pathways. These sixteen circumstances were solely developed around activities that are unique to handling and working with large animals (e.g., cattle, horses, sheep, and pigs) in a BSL-4 environment. Further, critical feedback from subject matter experts was used to refine these situations based on their concerns on working with large animals and BSL-4 agents [November ABSL-4 Assessment SME Solicitation meeting]. The sixteen situations were detailed in Table 9.6.1-1.

A summary of all of the nodes, the probability of failure, the reduction factor when the mitigating system is functional, and the reduction factor upon failure is listed in Table 9.8-1. The probability of human error was set to 5×10^{-3} based on human reliability assessments for highly reliable and trained workers such as those to be employed at the NBAF [Spurgin, 2009]. This failure rate was used for any mitigating systems or event nodes that were dependent upon a worker performing the action. System failure rates were set to 1×10^{-5} [SSRA, 2010]. Additional assumptions to the failure rates and transfer percentages are noted in Table 9.8-1.

The detailed accident sequences that resulted in the release of infectious material for each of these circumstances are included in the following sections. For each circumstance, each event node or mitigating (i.e., protection) system is included, along with their modeled probability of failure, reduction factor of the viral quantity when the mitigating system or node is functional, and the reduction factor when the mitigating system or node fails. The opportunity rate (i.e., how often such circumstances could occur based on the use and frequency of the AHRs and necropsy room per year, R_o) is also presented for each circumstance. Each unique detailed accident sequence creates an event under the circumstances and the probability for these specific loss-of-containment events occurring (P_{Loss}), the overall reduction factor along with the Q value (quantity released at this point in the event), and frequency of loss-of-containment (F_{Loss}) are presented.

$$F_{Loss} = P_{Loss}R_o \quad \text{Equation 9.8-1}$$

The probability is the product of the probabilities of each node's state (i.e., success/functional or failure) and the overall reduction is similarly the product of the reduction factors for each node based on its state. The frequency of loss-of-containment (number of times per year) is the product of the opportunity rate and the probability of loss-of-containment. In addition to the table for each set of circumstances indicating which nodes or mitigating system is functional or had failed along with the relevant information for each event, an event tree is also presented.

Table 9.8-1: Summary of Mitigating Systems and Nodes Reduction Factors and Probabilities

Pathway(s)	Originating Location(s)	Node/Mitigation System	Probability of Failure	Reduction Factor (Success)	Reduction Factor (Failure)	Notes
Aerosol	AHR	Syringe is not dropped when researcher is physically displaced by unrestrained animals	5.00E-02	n/a	n/a	10 times human error rate due to animal not being restrained
Aerosol, Transference	AHR	Animal is properly sedated and inoculation occurs while sedated	1.00E-02	n/a	n/a	2 times human error rate (error in sedating animal + error in performing experiment when animal not sedated)
Aerosol, Transference	AHR	Squeeze chute (animal restraints)	5.00E-03	n/a	n/a	Human error rate (5×10^{-3}) to appropriately restrain animals
Aerosol, Transference	AHR	Syringe maintains containment when dropped	1.00E-01	0.00E+00	1.00E+00	Syringe is naturally open container, 10% of the time all the material will be released
Liquid	AHR	Source decontamination at (12) drain pipes (AHR)	5.84E-02	1.00E-01	1.77E-01	12 drains = 2 AHRs in use, 6 trench drains per AHR, 2 outlets per drain
Liquid	AHR, Necropsy	Cook tank	1.00E-05	1.00E-06	1.00E+00	Systems failure rate
Liquid	AHR, Necropsy	Cook tank performance indicator	1.00E-05	n/a	n/a	Systems failure rate
Liquid	AHR, Necropsy	On-site wastewater treatment	1.00E-05	1.00E-01	1.00E+00	Systems failure rate

Table 9.8-1: Summary of Mitigating Systems and Nodes Reduction Factors and Probabilities

Pathway(s)	Originating Location(s)	Node/Mitigation System	Probability of Failure	Reduction Factor (Success)	Reduction Factor (Failure)	Notes
Liquid	Necropsy	Source decontamination at (11) drain pipes	5.36E-02	1.00E-03	9.41E-02	11 sink drains
Solid	AHR, Necropsy	Autoclave	1.00E-05	1.00E-06	1.00E+00	Systems failure rate
Solid	Necropsy	Tissue autoclave	1.00E-05	1.00E-06	1.00E+00	Systems failure rate
Solid	Necropsy	Tissue autoclave performance indicator	1.00E-05	n/a	n/a	Systems failure rate
Solid	AHR, Necropsy	Incinerator	1.00E-10	1.00E-09	1.00E+00	Systems failure rate for incinerator multiplied by systems failure rate for built-in redundant and orthogonal performance indicator
Transference	AHR	Penning of animals	5.00E-03	n/a	n/a	Human error rate (5×10^{-3}) to fail to correctly latch pens
Transference	AHR	PPE protects skin barrier	5.00E-01	0.00E+00	1.00E-01	Assumes 10% of material from animal is injected; 50% of the time PPE is cut by animal, skin barrier is broken
Transference	AHR	PPE suit hose does not become entangled or disconnected due to rogue animal	5.00E-01	6.70E-06	5.70E-02	Assumes 5.7% of aerosol material is inhaled into respiratory system (same as FMDv)

Table 9.8-1: Summary of Mitigating Systems and Nodes Reduction Factors and Probabilities

Pathway(s)	Originating Location(s)	Node/Mitigation System	Probability of Failure	Reduction Factor (Success)	Reduction Factor (Failure)	Notes
Transference	AHR	PPE suit protect against skin barrier being broken when PPE suit has been stabbed with syringe	5.00E-01	n/a	5.00E-02	Assumes 5% of material is injected from inoculum; 50% of the time PPE is stabbed, skin barrier is broken
Transference	AHR	Researcher does not stab through PPE suit given physical displacement from unrestrained animal	5.00E-02	n/a	n/a	10 times human error rate (given animal has displaced researcher)
Transference	AHR	Suit is not cut by rogue animal	1.00E-02	n/a	n/a	2 times human error rate (twice as likely to cut suit than walking around normally)
Transference	AHR	Suit is not cut by rogue animal	1.00E-02	n/a	n/a	2 times human error rate (twice as likely to cut suit than walking around normally)
Transference	AHR	Suit is not torn while moving in AHR	5.00E-03	6.70E-06	1.00E-03	Human error rate (5×10^{-3})
Transference	AHR, Necropsy	Appropriate medical response to an exposure	5.00E-03	n/a	n/a	Human error rate (5×10^{-3})
Transference	AHR, Necropsy	BSL-4 suit does not have a leak	1.00E-03	6.70E-06	1.00E-03	
Transference	AHR, Necropsy	BSL-4 Suit is tested for leaks prior to entry	5.00E-03	n/a	n/a	Human error rate (5×10^{-3})

Table 9.8-1: Summary of Mitigating Systems and Nodes Reduction Factors and Probabilities

Pathway(s)	Originating Location(s)	Node/Mitigation System	Probability of Failure	Reduction Factor (Success)	Reduction Factor (Failure)	Notes
Transference	AHR, Necropsy	Laboratory exposure is reported	5.00E-03	n/a	n/a	Human error rate (5×10^{-3})
Transference	Necropsy	Body shower	5.00E-03	1.01E-01	1.00E+00	Human error rate (5×10^{-3})
Transference	Necropsy	Decontaminating (Chemical) showers	1.00E-05	1.00E-05	1.00E+00	Systems failure rate
Transference	Necropsy	Chemical spot treatment	5.00E-03	1.00E-05	1.00E+00	Human error rate (5×10^{-3})
Transference	Necropsy	Cut through PPE suit does not break the skin barrier	5.00E-01	0.00E+00	1.00E+00	Assumes 100% of material is injected from cutting self with tool; 50% of the time PPE is cut, skin barrier is broken
Transference	Necropsy	Cut through PPE suit does not result in contact exposure	1.00E+00	0.00E+00	4.00E-01	100% of the time, after cutting PPE gear, there will be a contact event; 40% transferred
Transference	Necropsy	Dunk tank	5.00E-03	1.00E-05	1.00E+00	Human error rate (5×10^{-3})
Transference	Necropsy	Researcher does not cut PPE suit during necropsy procedures	5.00E-03	n/a	n/a	Human error rate (5×10^{-3})

9.8.1 Animal Holding Room Events

9.8.1.1 AHR – Aerosol Release Through Dropped Inoculum (L4AAi)

In this situation, the researcher enters the ABSL-4 AHR preparing to inoculate the animals. Prior to inoculation, the animals should be sedated and restrained in the squeeze chute (per NBAF proposed protocol). However, the researcher may have failed to sedate the animal completely, or enters the AHR before the animals are sedated or after the sedation has worn off. In such a situation, if the researcher failed to appropriately restrain the animals, the animal may physically displace the researcher resulting in the inoculum syringe being dropped, breaking, and releasing an aerosolized portion of the inoculum into the room. In this set of circumstances, there are four nodes prior to the HEPA filters: 1) failure to sedate the animals; 2) failure to appropriately restrain the animals in the squeeze chute; 3) failure to hold the syringe upon being physically displaced; and 4) the syringe container failing. If all four of these nodes fail, then there will be an aerosolized release which will be mitigated by the operational state of the HEPA filters.

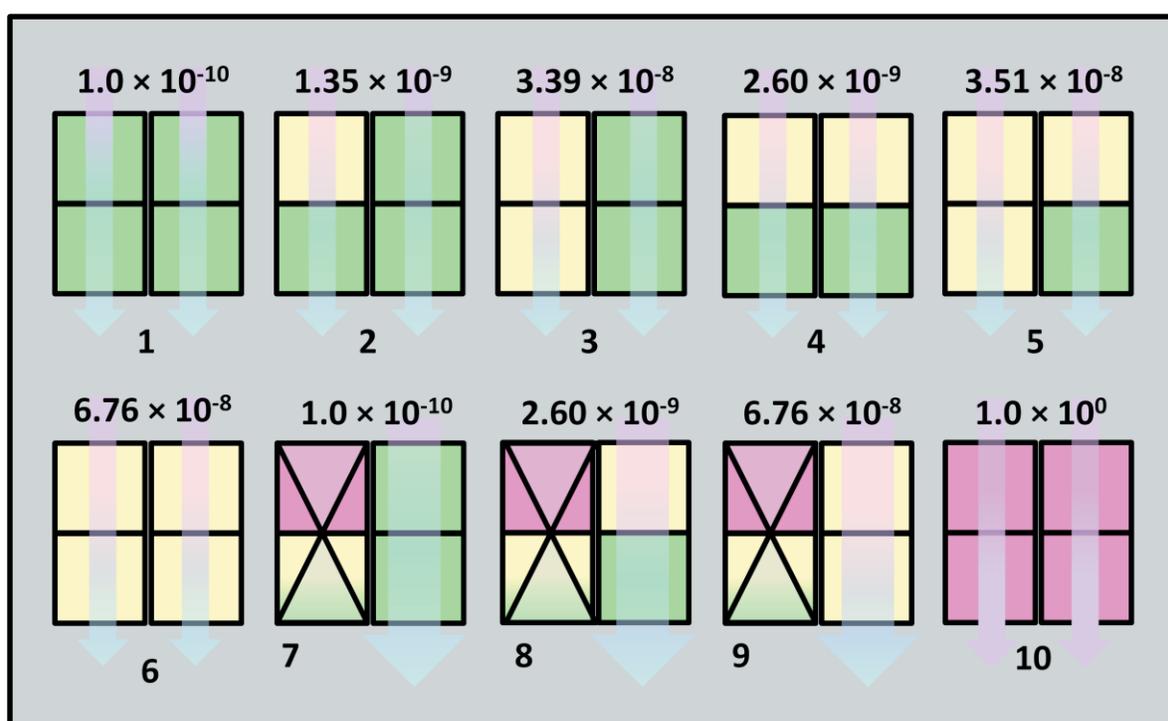


Figure 9.8.1-1: Conceptual Diagram of the HEPA Filtration Events for Aerosol Releases

The same ten events associated with HEPA filters are used as presented in Section 4 for the BSL-3 laboratories. The ten release events through the HEPA filters are shown in Figure 9.8.2-1 along with their reduction factors on top and probability of the event on the bottom. The HEPA filters reduce the quantity of viral material. For the parallel double-caisson arrangement, the HEPA filters can be fully functional (green), degraded (yellow), in a recognized fault state such that air flow is blocked (pink with an X), or in an unrecognized fault state in which unfiltered air is being let through (pink without an X). The original material available for release is the aerosolized release portion of the inoculum in a single syringe. The opportunity rate for this set of circumstances is 148 yr^{-1} , corresponding to the average

number of animals to be in the AHRs over the course of a year, as each animal presents a single opportunity for release upon its inoculation. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.1-1. The event tree is shown in Figure 9.8.1-2. (The event tree has four events which are not modeled, events in which one HEPA filter caisson fails with a shutdown failure releasing unfiltered air and the other HEPA filter caisson is operational. As discussed in more detail in Section 4.5, these events were considered but not modeled as the pressure transducers on the operational HEPA filter caisson would likely indicate a fault in the overall HEPA filter shutting down the system.)

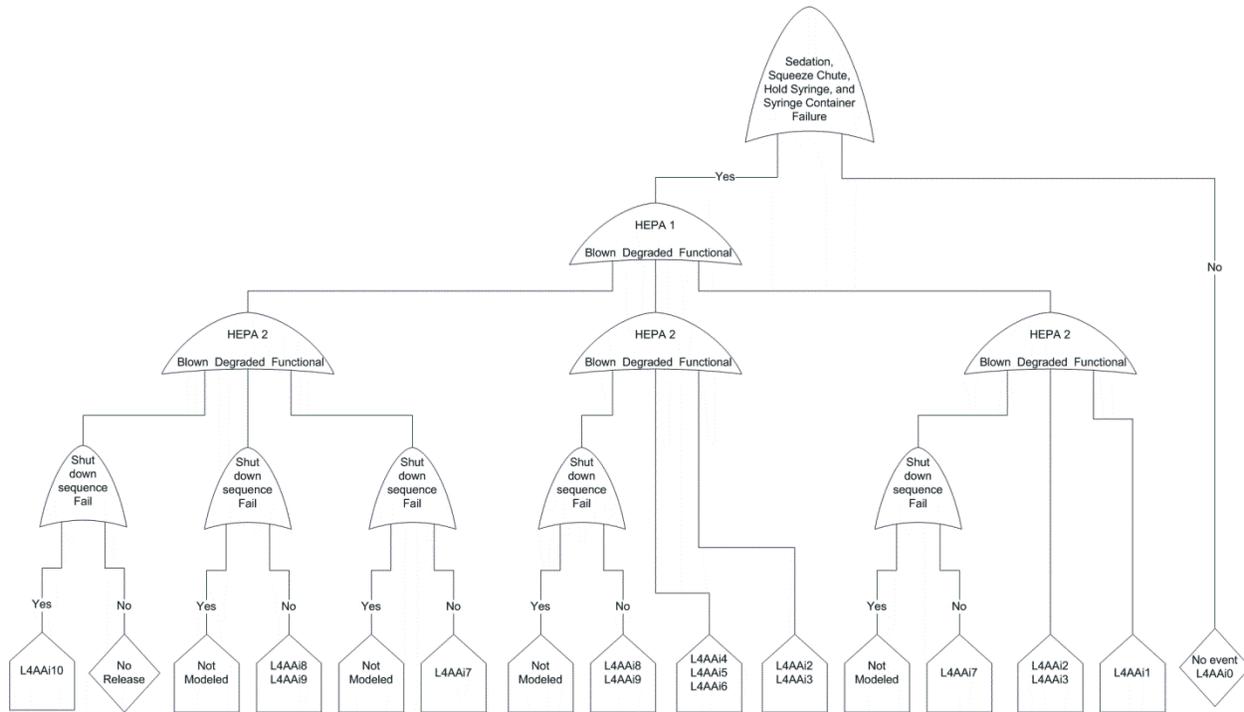


Figure 9.8.1-2: Event Tree for Aerosol Release via Dropped Inoculum in AHRs (L4AAi)

Table 9.8.1-1: ABSL-4 Animal Holding Room Aerosol Release Through Dropped Inoculum (L4AAi)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor	L4AAi0	L4AAi1	L4AAi2	L4AAi3	L4AAi4	L4AAi5	L4AAi6	L4AAi7	L4AAi8	L4AAi9	L4AAi10
Sedation Failure	1.00E-02	9.90E-01	1.00E+00	WORK or	FAIL									
Squeeze Chute Failure	5.00E-03	9.95E-01	1.00E+00	WORK or	FAIL									
Failure to Hold Syringe (when animals not restrained)	5.00E-02	9.50E-01	1.00E+00	WORK or	FAIL									
Syringe Container Failure	1.00E-01	9.00E-01	1.00E+00	WORK	FAIL									
HEPA Specific Failure Probabilities	n/a	n/a	n/a	n/a	9.81E-01	5.73E-02	4.37E-04	8.73E-04	1.33E-05	5.06E-08	3.88E-04	1.18E-05	9.00E-08	1.00E-34
HEPA Specific Reduction Factors	n/a	n/a	n/a	n/a	1.00E-10	1.35E-09	3.39E-08	2.60E-09	3.51E-08	6.76E-08	1.00E-10	2.60E-09	6.76E-08	1.00E+00
Overall Reduction Factor				0.000E+00	1.000E 10	1.350E 09	3.385E 08	2.598E 09	3.509E 08	6.761E 08	1.000E 10	2.598E 09	6.761E 08	1.000E+00
	Q_{Low} (PFU)			0.000E+00	1.991E-14	2.688E-13	6.740E-12	5.171E-13	6.986E-12	1.346E-11	1.991E-14	5.171E-13	1.346E-11	1.991E-04
	Q_{Medium} (PFU)			0.000E+00	2.623E-10	3.542E-09	8.881E-08	6.814E-09	9.206E-08	1.774E-07	2.623E-10	6.814E-09	1.774E-07	2.623E+00
	Q_{High} (PFU)			0.000E+00	3.457E-06	4.668E-05	1.170E-03	8.980E-05	1.213E-03	2.337E-03	3.457E-06	8.980E-05	2.337E-03	3.457E+04
	Probability (P_{Loss})			9.999998E 01	2.3524E 07	1.4331E 08	1.0913E 10	2.1826E 10	3.3240E 12	1.2656E 14	9.6998E 11	2.9545E 12	2.2499E 14	2.5000E 41
	Frequency (F_{Loss}) (yr⁻¹)			1.48E+02	3.48E 05	2.12E 06	1.62E 08	3.23E 08	4.92E 10	1.87E 12	1.44E 08	4.37E 10	3.33E 12	3.70E 39

MAR Low = 1.99 × 10⁻⁴ PFU
 MAR Medium = 2.62 × 10⁰ PFU
 MAR High = 3.46 × 10⁴ PFU
 Opportunity Rate = 148 yr⁻¹

9.8.1.2 AHR – Aerosol Release Respiratory Shedding (L4AA)

In this situation, the respiratory shedding of infectious aerosols from the animals is mitigated by the HEPA filters. The same ten events associated with HEPA filters are used as presented in Section 4 for the BSL-3 laboratories and as presented in Section 9.8.1.1. The HEPA filters reduce the quantity of viral material and the material available for release is the viral concentration shredded per day in each AHR. (As data for the respiratory shedding levels of NiV and HeV from animals could not be found, the levels of FMDv were used to calculate the MAR.) The opportunity rate for this set of circumstances is 588 yr⁻¹, corresponding to the number of infectious days in the AHRs (294 infectious days each of the two AHRs). The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.1-2. The event tree is shown in Figure 9.8.1-3.

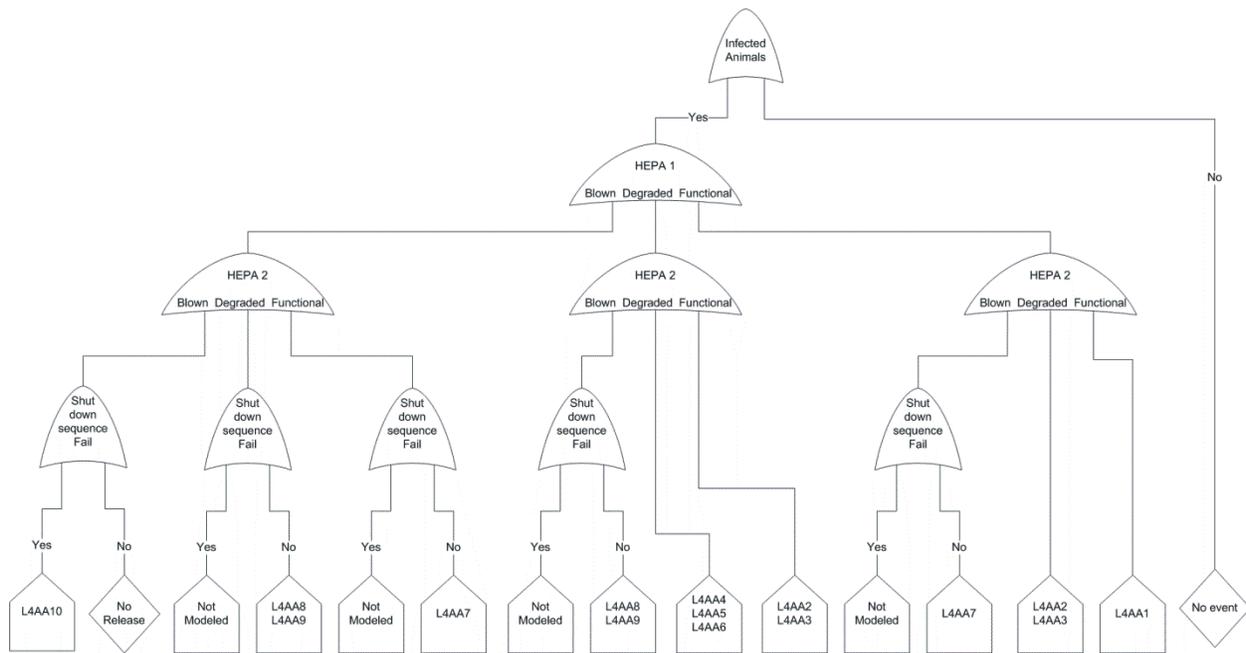


Figure 9.8.1-3: Event Tree for Aerosol Release via Respiratory Shedding of Infected Animals in AHRs (L4AA)

Table 9.8.1-2: ABSL-4 Animal Holding Room Aerosol Release Respiratory Shedding (L4AA)													
Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor	L4AA1	L4AA2	L4AA3	L4AA4	L4AA5	L4AA6	L4AA7	L4AA8	L4AA9	L4AA10
HEPA Specific Failure Probabilities	n/a	n/a	n/a	9.410E-01	5.732E-02	4.365E-04	8.730E-04	1.330E-05	5.063E-08	3.880E-04	1.182E-05	9.000E-08	1.000E-34
HEPA Specific Reduction Factors	n/a	n/a	n/a	1.000E-10	1.350E-09	3.385E-08	2.598E-09	3.509E-08	6.761E-08	1.000E-10	2.598E-09	6.761E-08	1.000E+00
Overall Reduction Factor				1.000E 10	1.350E 09	3.385E 08	2.598E 09	3.509E 08	6.761E 08	1.000E 10	2.598E 09	6.761E 08	1.000E+00
	Q_{Low} (PFU)			3.838E-06	5.183E-05	1.299E-03	9.970E-05	1.347E-03	2.595E-03	3.838E-06	9.970E-05	2.595E-03	3.838E+04
	Q_{Medium} (PFU)			6.483E-06	8.754E-05	2.195E-03	1.684E-04	2.275E-03	4.383E-03	6.483E-06	1.684E-04	4.383E-03	6.483E+04
	Q_{High} (PFU)			1.006E-02	1.359E-01	3.406E+00	2.613E-01	3.531E+00	6.802E+00	1.006E-02	2.613E-01	6.802E+00	1.006E+08
Probability (P_{Loss})				9.410E 01	5.732E 02	4.365E 04	8.730E 04	1.330E 05	5.063E 08	3.880E 04	1.182E 05	9.000E 08	1.000E 34
Frequency (F_{Loss}) (yr^{-1})				5.53E+02	3.37E+01	2.57E 01	5.13E 01	7.82E 03	2.98E 05	2.28E 01	6.95E 03	5.29E 05	5.88E 32

MAR Low = 3.84×10^4 PFU
 MAR Medium = 6.48×10^4 PFU
 MAR High = 1.01×10^8 PFU
 Opportunity Rate = $588 yr^{-1}$

9.8.1.3 AHR – Liquid Waste (L4AL)

The liquid waste generated in the animal holding rooms is decontaminated by the Effluent Decontamination System (EDS). The urine and feces excreted from the animals are drained through pipes which are primed with a chemical disinfectant. The liquid waste is then combined with other liquid waste streams, decontaminated in a cook tank and the cook tank performance verified prior to release to the on-site wastewater treatment plant. The mitigating nodes are the priming of the drain pipes, the cook tank, the redundant and orthogonal cook tank performance indicator, and the wastewater treatment plant.

As there are 12 total drains which need to be primed in the animal holding rooms each with an independent failure rate of 5×10^{-3} (human error rate), an overall probability of failing to prime the drains was calculated. Failure to prime the drains was defined as failing to prime any number (1 – 12) of drains (P_{PRIME}) by the following equations:

$$P_{PRIME} = \sum_{i=1}^{n_d} \left[\binom{n_d}{i} (P_{TRAP})^i (1 - P_{TRAP})^{n_d-i} \right] \quad \text{Equation 9.8.1-1}$$

where

$$P_{TRAP} = \text{Probability of failing to prime a single trap} = 5 \times 10^{-3} \quad \text{Equation 9.8.1-2}$$

$$n_d = \text{number of drains in A s with infected animals} = 12 \quad \text{Equation 9.8.1-3}$$

A weighted reduction factor for failing to prime any number of drains was also calculated by using the following equations:

$$\text{weighted reduction factor} = \frac{\sum_{i=1}^{n_d} \varphi}{P_{PRIME}} \quad \text{Equation 9.8.1-4}$$

where

$$\varphi = \frac{[\delta_{SUCCESS} \times (n_d - i) + \delta_{FAIL} \times (i)]}{n_d} \times \left[\binom{n_d}{i} (P_{TRAP})^i (1 - P_{TRAP})^{n_d-i} \right] \quad \text{Equation 9.8.1-5}$$

where

$$\delta_{SUCCESS} = \text{reduction factor Successful Priming of All Traps} \quad \text{Equation 9.8.1-6}$$

$$\delta_{FAIL} = \text{reduction factor failure to Prime at least 1 Trap} \quad \text{Equation 9.8.1-7}$$

The MAR is the viral level present in the urine and feces generated in the AHR on a daily basis. The opportunity rate for this set of circumstances is 294 yr^{-1} , corresponding to the number of infectious days in the AHRs as the liquid waste from the two rooms is combined. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.1-3. The event tree is shown in Figure 9.8.1-4.

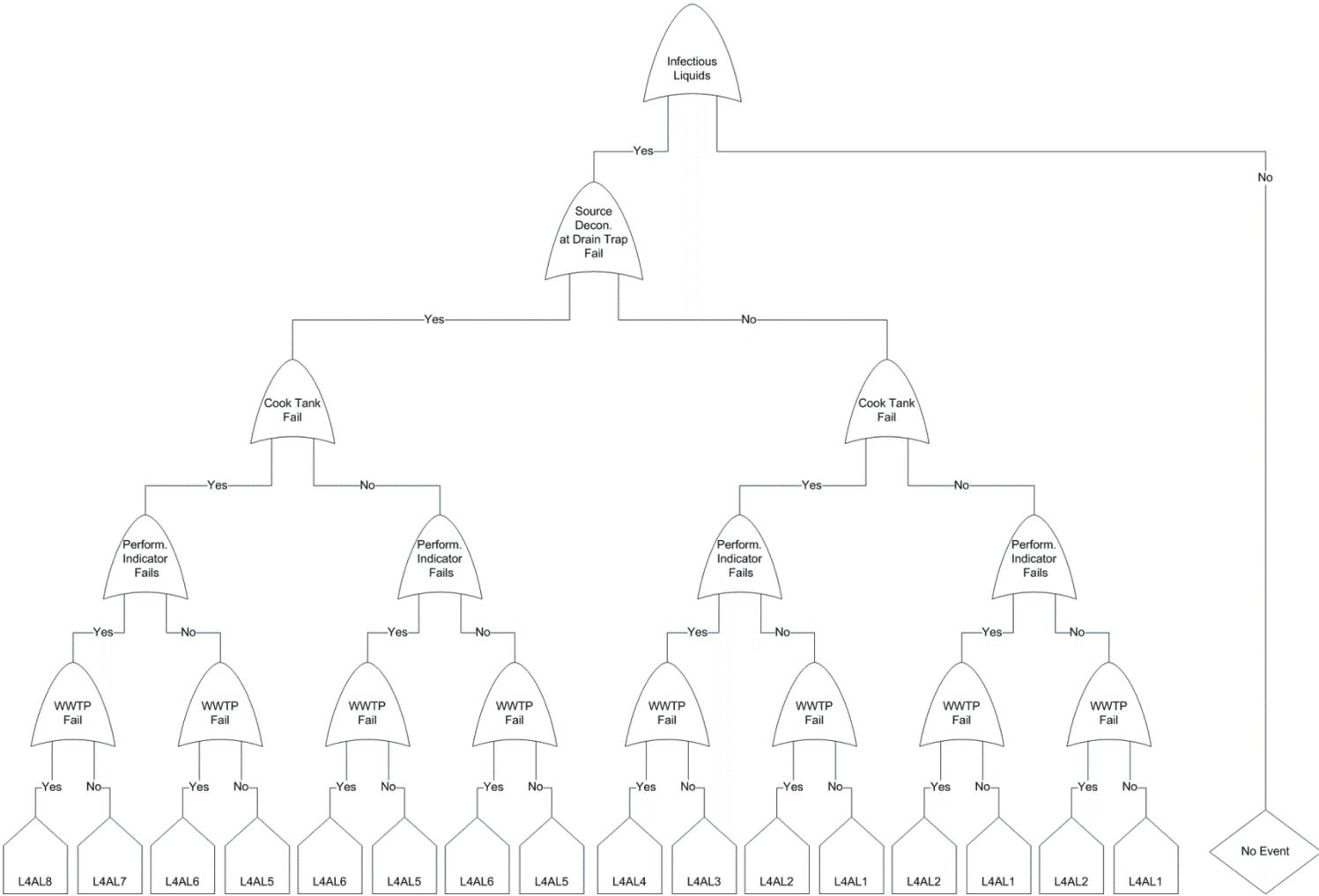


Figure 9.8.1-4: Event Tree for Liquid Waste Release in AHRs (L4AL)

Table 9.8.1-3: ABSL-4 Animal Holding Room Liquid Waste (L4AL)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4AL1	L4AL2	L4AL3	L4AL4	L4AL5	L4AL6	L4AL7	L4AL8
Source Decontamination at Drain Pipes	5.84E-02	9.4162E-01	1.00E-01	1.77E-01	WORK	WORK	WORK	WORK	FAIL	FAIL	FAIL	FAIL
Cook Tank	1.00E-05	9.9999E-01	1.00E-06	1.00E+00	WORK or	WORK or	FAIL	FAIL	WORK or	WORK or	FAIL	FAIL
Cook Tank Performance Indicator	1.00E-05	9.9999E-01	n/a	n/a	WORK	WORK	FAIL	FAIL	WORK	WORK	FAIL	FAIL
On Site Wastewater Treatment	1.00E-05	9.9999E-01	1.00E-01	1.00E+00	WORK	FAIL	WORK	FAIL	WORK	FAIL	WORK	FAIL
Overall Reduction Factor					1.000E 08	1.000E 07	1.000E 02	1.000E 01	1.771E 08	1.771E 07	1.771E 02	1.771E 01
Q_{Low} (PFU)					7.277E-03	7.277E-02	7.277E+03	7.277E+04	1.289E-02	1.289E-01	1.289E+04	1.289E+05
Q_{Medium} (PFU)					7.277E-02	7.277E-01	7.277E+04	7.277E+05	1.289E-01	1.289E+00	1.289E+05	1.289E+06
Q_{High} (PFU)					1.608E-01	1.608E+00	1.608E+05	1.608E+06	2.847E-01	2.847E+00	2.847E+05	2.847E+06
Probability (P_{Loss})					9.416E 01	9.416E 06	9.416E 11	9.416E 16	5.838E 02	5.838E 07	5.838E 12	5.838E 17
Frequency (F_{Loss}) (yr^{-1})					2.77E+02	2.77E 03	2.77E 08	2.77E 13	1.72E+01	1.72E 04	1.72E 09	1.72E 14

MAR Low = 7.28×10^5 PFU
 MAR Medium = 7.28×10^6 PFU
 MAR High = 1.61×10^7 PFU
 Opportunity Rate = $294 yr^{-1}$

9.8.1.4 Animal Holding Room – Solid Waste (L4AS)

The solid waste generated in the AHRs is sterilized by two autoclaves (one in the BSL-4 with a pass-through to the BSL-3E and the second in the BSL-3E) and then incinerated. The MAR is 20% of the liquid waste generated in the AHRs and transferred to disposable solid materials (e.g., PPE, towels). The opportunity rate for this set of circumstances is 294 yr⁻¹, corresponding to the number of infectious days in the AHRs as the solid waste from the two rooms is combined and autoclaved on a daily basis. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.1-4. The event tree is shown in Figure 9.8.1-5.

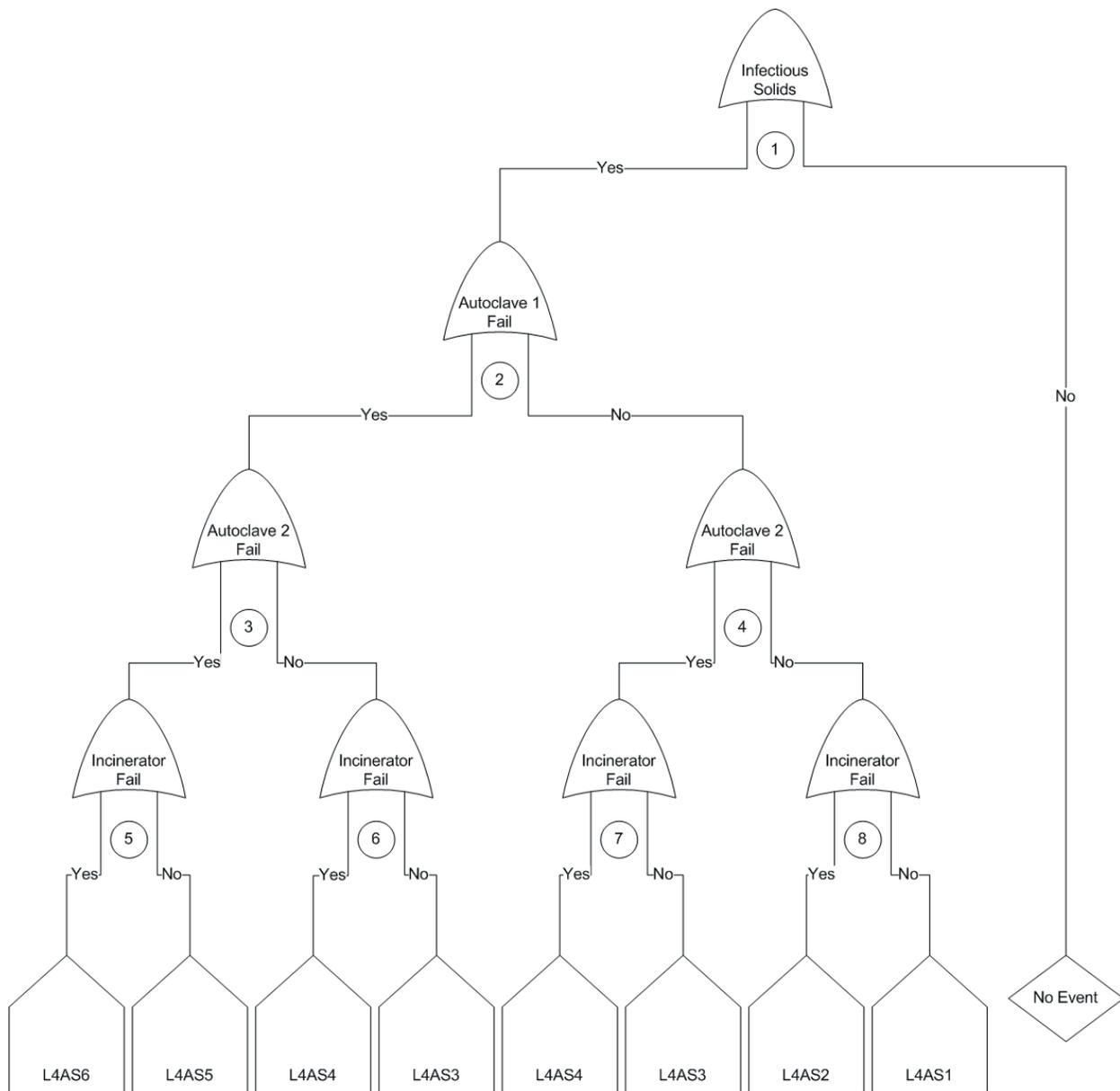


Figure 9.8.1-5: Event Tree for Solid Waste Release in AHRs (L4AS)

Table 9.8.1-4: ABSL-4 Animal Holding Room Solid Waste (L4AS)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4AS1	L4AS2	L4AS3 ^a	L4AS4 ^b	L4AS5	L4AS6
Autoclave #1 (BSL 4)	1.00E-05	9.9999E-01	1.00E-06	1.00E+00	WORK	WORK	WORK/FAIL	WORK/FAIL	FAIL	FAIL
Autoclave #2 (BSL 3E)	1.00E-05	9.9999E-01	1.00E-06	1.00E+00	WORK	WORK	FAIL/WORK	FAIL/WORK	FAIL	FAIL
Incinerator	1.00E-10	1.0000E+00	1.00E-09	1.00E+00	WORK	FAIL	WORK	FAIL	WORK	FAIL
Overall Reduction Factor					1.000E 21	1.000E 12	1.000E 15	1.000E 06	1.000E 09	1.000E+00
Q_{Low} (PFU)					1.455E-16	1.455E-07	1.455E-10	1.455E-01	1.455E-04	1.455E+05
Q_{Medium} (PFU)					1.455E-15	1.455E-06	1.455E-09	1.455E+00	1.455E-03	1.455E+06
Q_{High} (PFU)					3.215E-15	3.215E-06	3.215E-09	3.215E+00	3.215E-03	3.215E+06
Probability (P_{Loss})					9.9998E 01	9.9998E 11	2.0000E 05	2.0000E 15	1.0000E 10	1.0000E 20
Frequency (F_{Loss}) (yr ⁻¹)					2.94E+02	2.94E 08	5.88E 03	5.88E 13	2.94E 08	2.94E 18

^a Probability is the sum of all events in which one of the two autoclaves fails and the incinerator works.

^b Probability is the sum of all events in which one of the two autoclaves fails and the incinerator fails.

MAR Low = 1.46×10^5 PFU

MAR Medium = 1.46×10^6 PFU

MAR High = 3.22×10^6 PFU

Opportunity Rate = 294 yr⁻¹

9.8.1.5 Animal Holding Room – Transference (Injection from Inoculum) (L4ATli)

In this situation, the researcher enters the ABSL-4 AHR preparing to inoculate the animals. Prior to inoculation, the animals should be sedated and restrained in the squeeze chute. However, the researcher may have failed to sedate the animals or enters the AHR before the animals are sedated or after the sedation has worn off. In such a situation, if the researcher failed to appropriately restrain the animals, the animal may physically displace the researcher resulting in the inoculum syringe stabbing through the BSL-4 suit (PPE). If the BSL-4 suit does not protect the researcher, then the researcher may accidentally stab themselves and inject a fraction of the inoculum. For there to be a transference injection release, there must be a failure in the following four nodes: 1) failure to sedate the animals; 2) failure to appropriately restrain the animals in the squeeze chute; 3) failure to not stab themselves, specifically the BSL-4 suit; and 4) failure for the BSL-4 suit to protect against an injection. If there is an injection, the researcher must report the laboratory exposure and the appropriate medical response must be initiated. If the laboratory exposure is not reported, there will not be a medical response.

In such an event, it is assumed that a single drop of 50 μL from a 1 mL volume of inoculum was injected (5% transferred). The MAR is the full 1 mL volume of inoculum. The opportunity rate for this set of circumstances is 148 yr^{-1} , corresponding to the average number of animals to be in the AHRs over the course of a year, as each animal presents a single opportunity for release upon its inoculation. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.1-5. The event tree is shown in Figure 9.8.1-6.

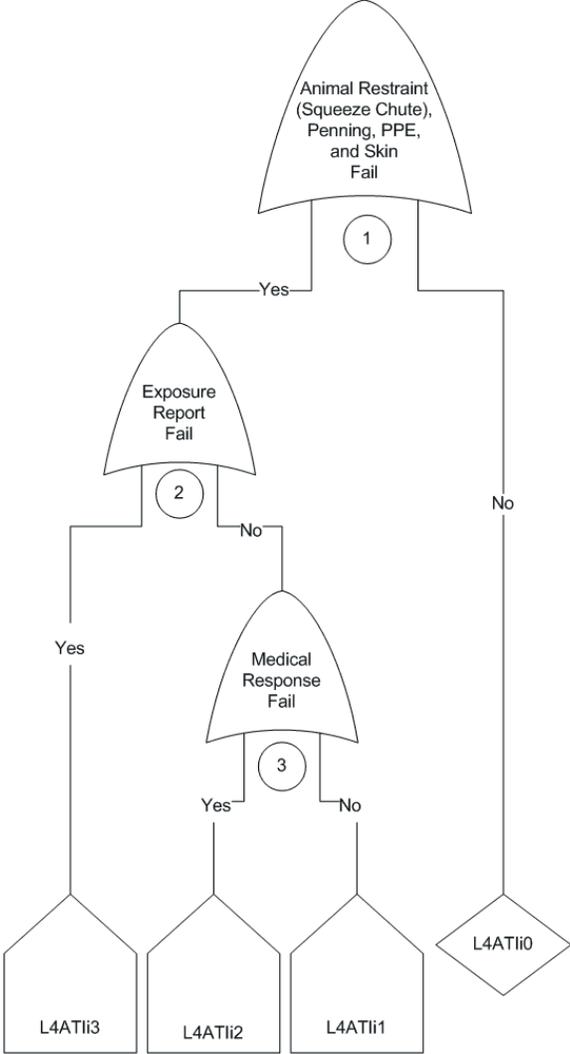


Figure 9.8.1-6: Event Tree for Transference Injection from Inoculum in AHRs (L4ATi)

Table 9.8.1-5: ABSL-4 Animal Holding Room Transference (Injection from Inoculum) (L4ATii)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4ATii0	L4ATii1	L4ATii2	L4ATii3
Failure to Properly Sedate	1.00E-02	9.900E-01	n/a	n/a	WORK or	FAIL	FAIL	FAIL
Failure of Squeeze Chutes to Restrain Animals	5.00E-03	9.950E-01	n/a	n/a	WORK or	FAIL	FAIL	FAIL
Probability of Stabbing Self with Syringe (given displacement from unrestrained animal)	5.00E-02	9.500E-01	n/a	n/a	WORK or	FAIL	FAIL	FAIL
PPE Suit Failing to Protect Skin Barrier (given stabbing event)	5.00E-01	5.000E-01	n/a	5.00E-02	WORK	FAIL	FAIL	FAIL
Laboratory Exposure is Reported	5.00E-03	9.950E-01	n/a	n/a	n/a	WORK	WORK	FAIL
Appropriate Medical Response to Injection	5.00E-03	9.950E-01	n/a	n/a	n/a	WORK	FAIL	n/a
Overall Reduction Factor					0.00E+00	5.0000E 02	5.0000E 02	5.0000E 02
Q_{Low} (PFU)					0.000E+00	9.954E-02	9.954E-02	9.954E-02
Q_{Medium} (PFU)					0.000E+00	1.312E+03	1.312E+03	1.312E+03
Q_{High} (PFU)					0.000E+00	1.728E+07	1.728E+07	1.728E+07
Probability (P_{Loss})					9.99999E 01	1.2375E 06	6.2188E 09	6.2500E 09
Frequency (F_{Loss}) (yr⁻¹)					1.48E+02	1.83E 04	9.20E 07	9.25E 07

MAR Low = 1.99×10^0 PFU
 MAR Medium = 2.62×10^4 PFU
 MAR High = 3.46×10^8 PFU
 Opportunity Rate = 148 yr⁻¹

9.8.1.6 Animal Holding Room – Transference (Respiratory from Cut Suit) (L4ATR)

In this situation, an animal handler or researcher enters the ABSL-4 AHR preparing to perform routine daily care or take samples from the animals and has their suit severely cut due to uncontrolled animals along with an entanglement of the hose, resulting in the loss of positive pressure and an exposure to the aerosol levels in the room. For there to be an uncontrolled animal, there has to be a failure to restrain the animals in the squeeze chute and a failure to pen the animals (e.g., gate is left unlatched). Next, the animal must either directly (e.g., cut, bite) or indirectly (e.g., suit gets torn on the penning) cause a severe cut in the positive-pressure suit and cause the hose to become entangled or disconnected from the suit. The severe cut will result in loss of positive pressure and the hose entanglement results in the lack of air flow around the respiratory region of the researcher. For this respiratory transference event, there must be a failure in the following four nodes: 1) failure to appropriately restrain the animals in the squeeze chute; 2) failure of the penning; 3) severe cut in the BSL-4 suit; and 4) hose entanglement. If there is a respiratory exposure, the researcher must report the laboratory exposure and the appropriate medical response must be initiated. If the laboratory exposure is not reported, there will not be a medical response.

In such an event, it is assumed that 5.7% of the aerosol levels in the room will be transferred to the researchers' respiratory tract (based on values from FMDv transference). The MAR is the viral concentration shredded per 30 min in the AHRs as it is assumed that the exposure will not last for longer than 30 minutes. (As data for the respiratory shedding levels of NiV and HeV virus from animals could not be found, the levels of FMDv were used to calculate the MAR.). The opportunity rate for this set of circumstances is $14,112 \text{ yr}^{-1}$, corresponding to 294 infectious days per AHR, two AHRs, two handlers dealing with four animals each in the morning per AHR, two handlers dealing with four animals each in the evening per AHR, and one researcher dealing with eight animals per AHR. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.1-6. The event tree is shown in Figure 9.8.1-7.

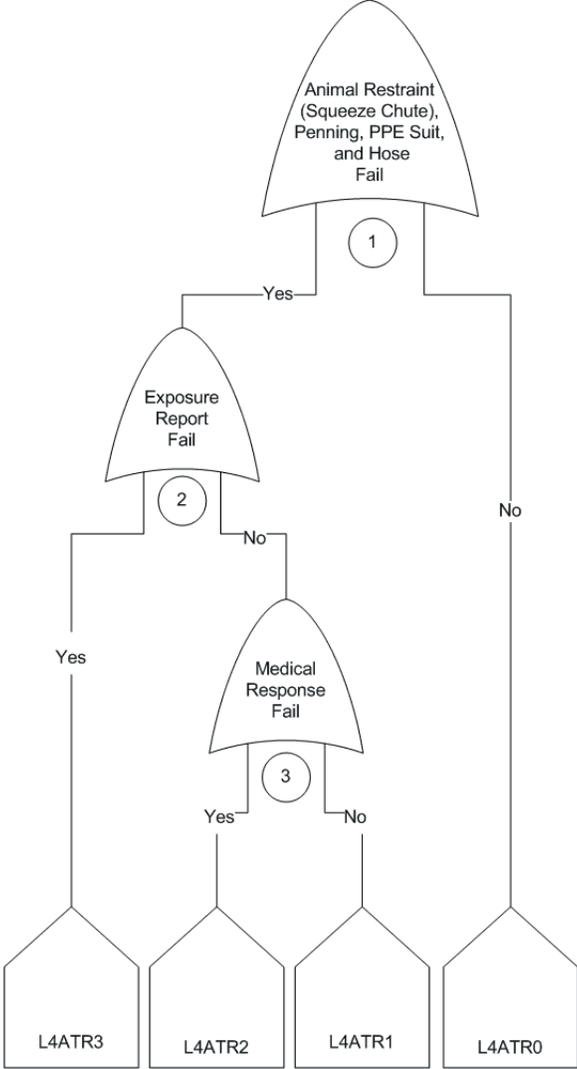


Figure 9.8.1-7: Event Tree for Transference Respiratory from Cut Suit in AHRs (L4ATR)

Table 9.8.1-6: ABSL-4 Animal Holding Room Transference (Respiratory from Cut Suit) (L4ATR)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4ATR0	L4ATR1	L4ATR2	L4ATR3
Failure of Squeeze Chutes to Restrain Animals	5.00E-03	9.9500E-01	n/a	n/a	WORK or	FAIL	FAIL	FAIL
Failure of Penning	5.00E-03	9.9500E-01	n/a	n/a	WORK or	FAIL	FAIL	FAIL
Suit is Cut due to Rogue Animal	1.00E-02	9.9000E-01	n/a	n/a	WORK or	FAIL	FAIL	FAIL
Hose Entanglement due to Uncontrolled Animal	5.00E-01	5.0000E-01	6.70E-06	5.70E-02	WORK	FAIL	FAIL	FAIL
Laboratory Exposure is Reported	5.00E-03	9.9500E-01	n/a	n/a	n/a	WORK	WORK	FAIL
Appropriate Medical Response to Exposure	5.00E-03	9.9500E-01	n/a	n/a	n/a	WORK	FAIL	n/a
Overall Reduction Factor					6.700E 06	5.700E 02	5.700E 02	5.700E 02
Q_{Low} (PFU)					5.357E-03	4.558E+01	4.558E+01	4.558E+01
Q_{Medium} (PFU)					9.049E-03	7.698E+01	7.698E+01	7.698E+01
Q_{High} (PFU)					1.404E+01	1.195E+05	1.195E+05	1.195E+05
Probability (P_{Loss})					9.999999E 01	1.2375E 07	6.2188E 10	6.2500E 10
Frequency (F_{Loss}) (yr^{-1})					1.41E+04	1.75E 03	8.78E 06	8.82E 06

MAR Low = 8.00×10^2 PFU
 MAR Medium = 1.35×10^3 PFU
 MAR High = 2.10×10^6 PFU
 Opportunity Rate = $14,112 \text{ yr}^{-1}$

9.8.1.7 Animal Holding Room – Transference (Injection from Animal Bite) (L4ATI)

In this situation, an animal handler or researcher enters the ABSL-4 AHR preparing to perform routine daily care or take samples from the animals and an animal becomes rogue. The rogue animal bites, kicks, or cuts the individual resulting in a transference injection event. For there to be a rogue animal, there has to be a failure to restrain the animals in the squeeze chute and a failure to pen the animals (e.g., gate is left unlatched). Next, the rogue animal must cut the BSL-4 suit (PPE) and the BSL-4 suit must not protect against the cut or bite breaking the skin barrier. For this injection transference event, there must be a failure in the following four nodes: 1) failure to appropriately restrain the animals in the squeeze chute; 2) failure of the penning; 3) cut through the PPE; and 4) PPE fails to protect against the cut or bite breaking the skin barrier. If there is a laboratory exposure, the researcher must report the exposure and the appropriate medical response must be initiated. If the laboratory exposure is not reported, there will not be a medical response.

In such an event, it is assumed that 10% of one gram of the infectious material present in the oral/nasal region of an infected animal will be injected into the researcher through the bite. The opportunity rate for this set of circumstances is $14,112 \text{ yr}^{-1}$, corresponding to 294 infectious days per AHR, two AHRs, two handlers dealing with four animals each in the morning per AHR, two handlers dealing with four animals each in the evening per AHR, and one researcher dealing with eight animals per AHR. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.1-7. The event tree is shown in Figure 9.8.1-8.

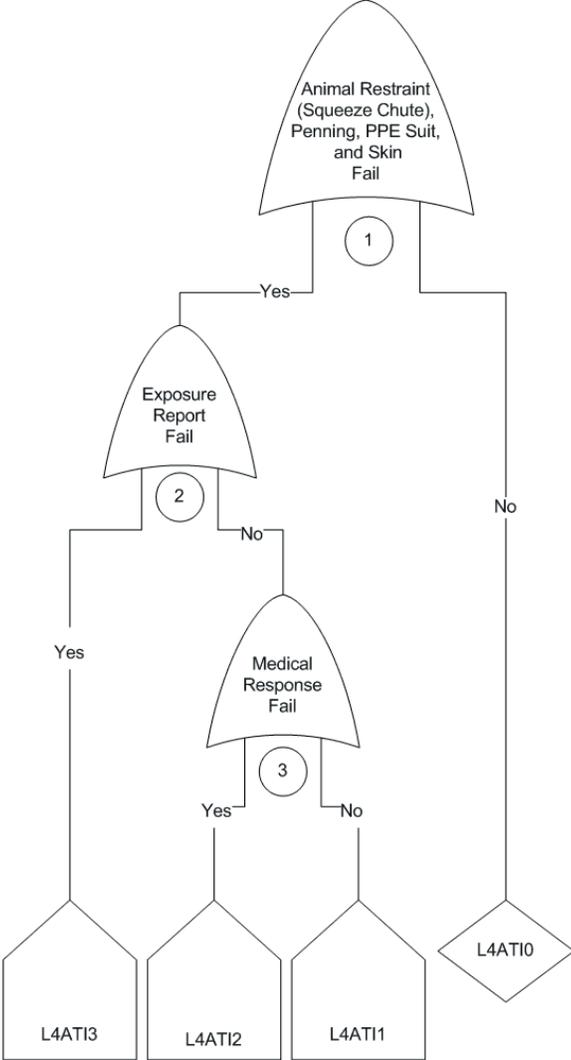


Figure 9.8.1-8: Event Tree for Transference Injection from Animal Bite in AHRs (L4ATI)

Table 9.8.1-7: ABSL-4 Animal Holding Room Transference (Injection from Animal Bite) (L4ATI)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4ATI0	L4ATI1	L4ATI2	L4ATI3
Failure of Squeeze Chutes to Restrain Animals	5.00E-03	9.950E-01	0.00E+00	n/a	WORK or	FAIL	FAIL	FAIL
Failure of Penning	5.00E-03	9.950E-01	0.00E+00	n/a	WORK or	FAIL	FAIL	FAIL
Suit is Cut by Rogue Animal	1.00E-02	9.900E-01	0.00E+00	n/a	WORK or	FAIL	FAIL	FAIL
PPE Fails to Protect Skin Barrier	5.00E-01	5.000E-01	0.00E+00	1.00E-01	WORK	FAIL	FAIL	FAIL
Laboratory Exposure is Reported	5.00E-03	9.950E-01	n/a	n/a	n/a	WORK	WORK	FAIL
Appropriate Medical Response to Exposure	5.00E-03	9.950E-01	n/a	n/a	n/a	WORK	FAIL	n/a
Overall Reduction Factor					0.0000E+00	1.0000E 01	1.0000E 01	1.0000E 01
Q_{Low} (PFU)					0.000E+00	1.000E-03	1.000E-03	1.000E-03
Q_{Medium} (PFU)					0.000E+00	1.000E+01	1.000E+01	1.000E+01
Q_{High} (PFU)					0.000E+00	1.067E+03	1.067E+03	1.067E+03
Probability (P_{Loss})					9.999999E 01	1.2375E 07	6.2188E 10	6.2500E 10
Frequency (F_{Loss}) (yr⁻¹)					1.41E+04	1.75E 03	8.78E 06	8.82E 06

MAR Low = 1.00×10^2 PFUMAR Medium = 1.00×10^2 PFUMAR High = 1.07×10^4 PFUOpportunity Rate = 14,112 yr⁻¹

9.8.1.8 Animal Holding Room – Transference (Respiratory through Suit Tear) (L4ATRs)

In this situation, an animal handler or researcher enters the ABSL-4 AHR and either fails to test the suit prior to entry and the suit has a leak, or in moving around the AHR the suit gets caught on the penning causing a small tear. These set of circumstances has five nodes: 1) failure to test the BSL-4 suit prior to entry; 2) probability of suit having a leak (dependent upon not testing the suit); 3) probability of tearing a small hole in the suit; 4) reporting the respiratory exposure; and 5) appropriate medical response (dependent upon reporting the exposure).

In such an event, it is assumed that 5.7% of the aerosol levels in the room will be transferred to the researchers' respiratory tract (based on values from FMDv transference). The MAR is the viral concentration shed per 4 hours in the AHRs as it is assumed that the exposure may not be recognized for some period due to its small size. (As data for the respiratory shedding levels of NiV and HeV from animals could not be found, the levels of FMDv were used to calculate the MAR.). The opportunity rate for this set of circumstances is $2,940 \text{ yr}^{-1}$, corresponding to 294 infectious days per AHR, two AHRs, two handlers entering the room in the morning per AHR, two handlers entering the room in the evening per AHR, and one researcher entering the room per day per AHR. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.1-8. The event tree is shown in Figure 9.8.1-9.

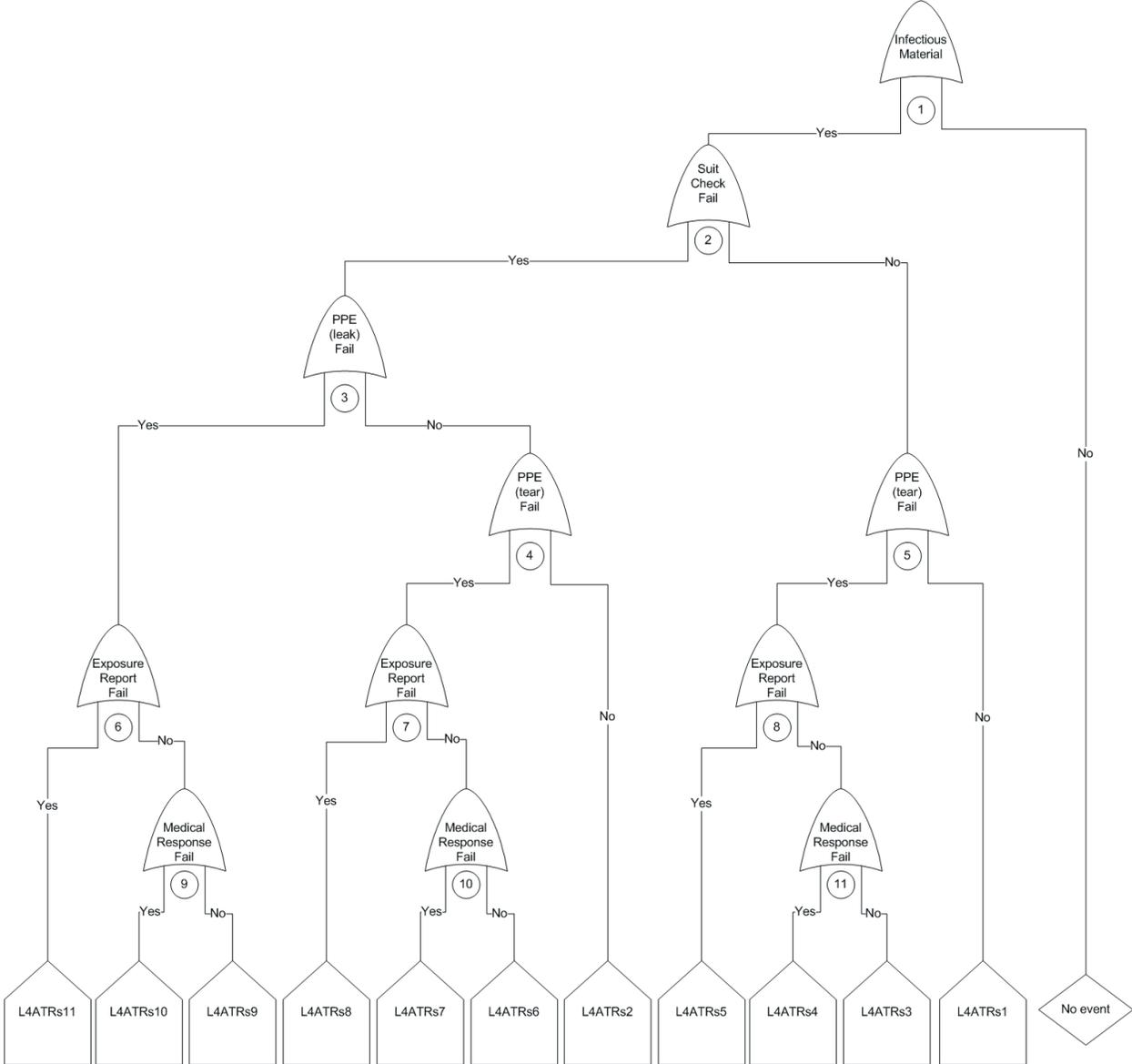


Figure 9.8.1-9: Event Tree for Transference Respiratory from Suit Tear in AHRs (L4ATRs)

Table 9.8.1-8: ABSL-4 Animal Holding Room Transference (Respiratory through Suit Tear) (L4ATRs)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4ATRs1	L4ATRs2	L4ATRs3	L4ATRs4	L4ATRs5	L4ATRs6	L4ATRs7	L4ATRs8	L4ATRs9	L4ATRs10	L4ATRs11
Failure to Test Suit	5.00E-03	9.950E-01	n/a	n/a	WORK	FAIL	WORK	WORK	WORK	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
Probability of Suit Having a Leak	1.00E-03	9.990E-01	6.70E-06	1.00E-03	n/a	WORK	n/a	n/a	n/a	WORK	WORK	WORK	FAIL	FAIL	FAIL
Probability of Tearing Small Hole in Suit	5.00E-03	9.950E-01	6.70E-06	1.00E-03	WORK	WORK	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL	n/a	n/a	n/a
Laboratory Exposure is Reported	5.00E-03	9.950E-01	n/a	n/a	n/a	n/a	WORK	WORK	FAIL	WORK	WORK	FAIL	WORK	WORK	FAIL
Appropriate Medical Response to Exposure	5.00E-03	9.950E-01	n/a	n/a	n/a	n/a	WORK	FAIL	n/a	WORK	FAIL	n/a	WORK	FAIL	n/a
Transfer Percentage	n/a	n/a	n/a	n/a	5.7%	5.7%	5.7%	5.7%	5.7%	5.7%	5.7%	5.7%	5.7%	5.7%	5.7%
Overall Reduction Factor					3.819E 07	3.819E 07	5.700E 05								
Q_{Low} (PFU)					2.443E-03	2.443E-03	3.646E-01								
Q_{Medium} (PFU)					4.126E-03	4.126E-03	6.159E-01								
Q_{High} (PFU)					6.404E+00	6.404E+00	9.558E+02								
Probability (P_{Loss})					9.900E 01	4.970E 03	4.925E 03	2.475E 05	2.488E 05	2.473E 05	1.243E 07	1.249E 07	4.950E 06	2.488E 08	2.500E 08
Frequency (F_{Loss}) (yr⁻¹)					2.91E+03	1.46E+01	1.45E+01	7.28E 02	7.31E 02	7.27E 02	3.65E 04	3.67E 04	1.46E 02	7.31E 05	7.35E 05

MAR Low = 6.40×10^3 PFU
 MAR Medium = 1.08×10^4 PFU
 MAR High = 1.68×10^7 PFU
 Opportunity Rate = 2,940 yr⁻¹

9.8.2 Necropsy

9.8.2.1 Necropsy – Aerosol Release (L4NA)

In this situation, infectious aerosolized material will be released in the necropsy room due to cutting of the tissue and carcasses. This infectious aerosol is mitigated by the HEPA filters and the same ten events associated with HEPA filters are used as presented in Section 4 for the BSL-3 laboratories and as presented in Section 9.8.1 apply for the ABSL-4 necropsy room. The event MAR is 10 times the aerosolized release portion of 1% of the tissue MAR, plus the aerosolized release portion of 50% of the blood MAR. The opportunity rate for this set of circumstances is 50.13 yr^{-1} , corresponding to the average number of necropsy days in a year. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.2-1. The event tree is shown in Figure 9.8.2-1.

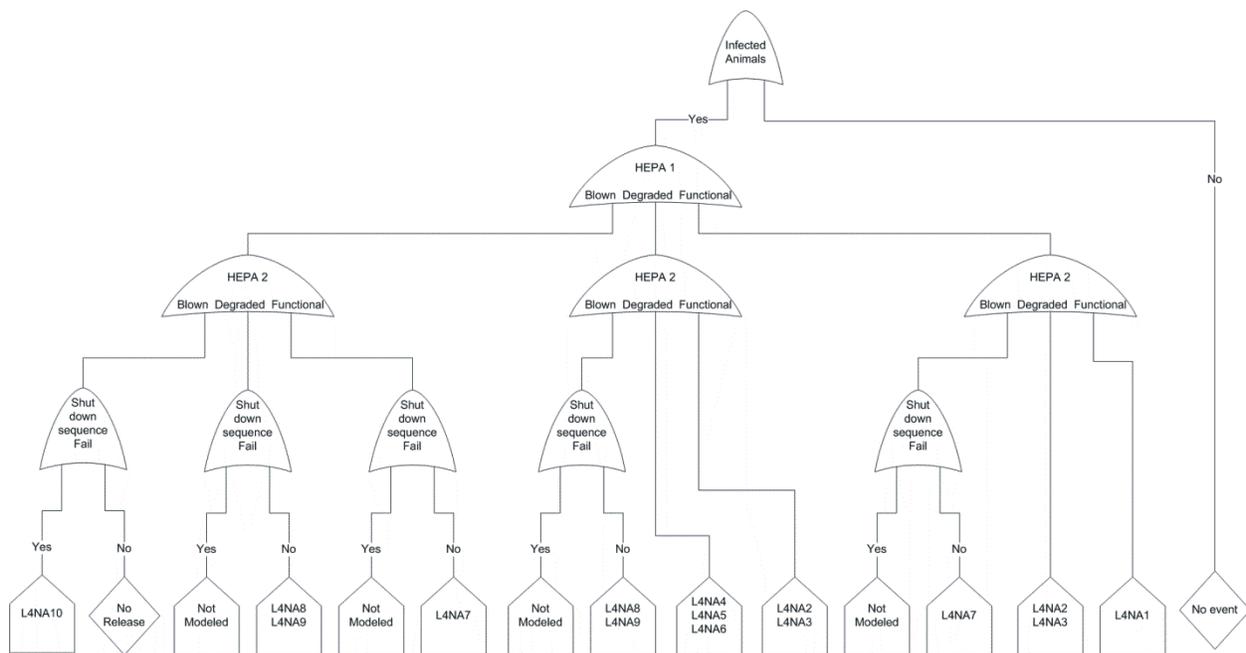


Figure 9.8.2-1: Event Tree for Aerosol Release from Aerosolized Tissue and Blood in Necropsy (L4NA)

Table 9.8.2-1: ABSL-4 Necropsy Aerosol Release (L4NA)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor	L4NA1	L4NA2	L4NA3	L4NA4	L4NA5	L4NA6	L4NA7	L4NA8	L4NA9	L4NA10
HEPA Specific Failure Probabilities	n/a	n/a	n/a	9.410E-01	5.732E-02	4.365E-04	8.730E-04	1.330E-05	5.063E-08	3.880E-04	1.182E-05	9.000E-08	1.000E-34
HEPA Specific Reduction Factors	n/a	n/a	n/a	1.000E-10	1.350E-09	3.385E-08	2.598E-09	3.509E-08	6.761E-08	1.000E-10	2.598E-09	6.761E-08	1.000E+00
Overall Reduction Factor				1.000E 10	1.350E 09	3.385E 08	2.598E 09	3.509E 08	6.761E 08	1.000E 10	2.598E 09	6.761E 08	1.000E+00
	Q_{Low} (PFU)			1.953E-12	2.637E-11	6.610E-10	5.072E-11	6.852E-10	1.320E-09	1.953E-12	5.072E-11	1.320E-09	1.953E-02
	Q_{Medium} (PFU)			5.068E-09	6.843E-08	1.716E-06	1.316E-07	1.779E-06	3.426E-06	5.068E-09	1.316E-07	3.426E-06	5.068E+01
	Q_{High} (PFU)			3.497E-03	4.723E-02	1.184E+00	9.085E-02	1.227E+00	2.365E+00	3.497E-03	9.085E-02	2.365E+00	3.497E+07
	Probability (P_{Loss})			9.410E 01	5.732E 02	4.365E 04	8.730E 04	1.330E 05	5.063E 08	3.880E 04	1.182E 05	9.000E 08	1.000E 34
	Frequency (F_{Loss}) (yr ⁻¹)			4.72E+01	2.87E+00	2.19E 02	4.38E 02	6.67E 04	2.54E 06	1.95E 02	5.92E 04	4.51E 06	5.01E 33

MAR Low = 1.95×10^{-2} PFU
 MAR Medium = 5.07×10^1 PFU
 MAR High = 3.50×10^7 PFU
 Opportunity Rate = 50.13 yr⁻¹

9.8.2.2 Necropsy – Liquid Waste (L4NL)

The liquid waste generated in the necropsy room is also decontaminated by the EDS. During necropsy, a fraction of the liquid waste (e.g., blood) is drained through pipes which are primed with a chemical disinfectant. The liquid waste is then combined with other liquid waste streams and decontaminated in a cook tank and the cook tank performance verified prior to the contents being released and subjected to the on-site wastewater treatment. The four mitigating nodes are the priming of the drain pipes, the cook tank, the redundant and orthogonal cook tank performance indicator, and the wastewater treatment plant.

As there are 11 total drains which need to be primed in the animal holding rooms each with an independent failure rate of 5×10^{-3} (human error rate), an overall probability of failing to prime the drains was calculated. Failure to prime the drains was defined as failing to prime any number (1 – 11) of drains (P_{PRIME}) by the following equations:

$$P_{PRIME} = \sum_{i=1}^{n_d} \left[\binom{n_d}{i} (P_{TRAP})^i (1 - P_{TRAP})^{n_d-i} \right] \quad \text{Equation 9.8.2-1}$$

where

$$P_{TRAP} = \text{Probability of failing to prime a single trap} = 5 \times 10^{-3} \quad \text{Equation 9.8.2-2}$$

$$n_d = \text{number of drains in A s with infected animals} = 11 \quad \text{Equation 9.8.2-3}$$

A weighted reduction factor for failing to prime any number of drains was also calculated by using the following equations:

$$\text{weighted reduction factor} = \frac{\sum_{i=1}^{n_d} \varphi}{P_{PRIME}} \quad \text{Equation 9.8.2-4}$$

where

$$\varphi = \frac{[\delta_{SUCCESS} \times (n_d - i) + \delta_{FAIL} \times (i)]}{n_d} \times \left[\binom{n_d}{i} (P_{TRAP})^i (1 - P_{TRAP})^{n_d-i} \right] \quad \text{Equation 9.8.2-5}$$

where

$$\delta_{SUCCESS} = \text{reduction factor Successful Priming of All Traps} \quad \text{Equation 9.8.2-6}$$

$$\delta_{FAIL} = \text{reduction factor failure to Prime at least 1 Trap} \quad \text{Equation 9.8.2-7}$$

The MAR is the viral levels present in 50% of the blood of the necropsied animals. The opportunity rate for this set of circumstances is 50.13 yr^{-1} , corresponding to the average number of necropsy days in a year. The probabilities (P_{LOSS}), reduction factors, Q values, and frequencies of loss-of-containment (F_{LOSS}) for the events included in this set of circumstances are detailed in Table 9.8.2-2. The event tree is shown in Figure 9.8.2-2.

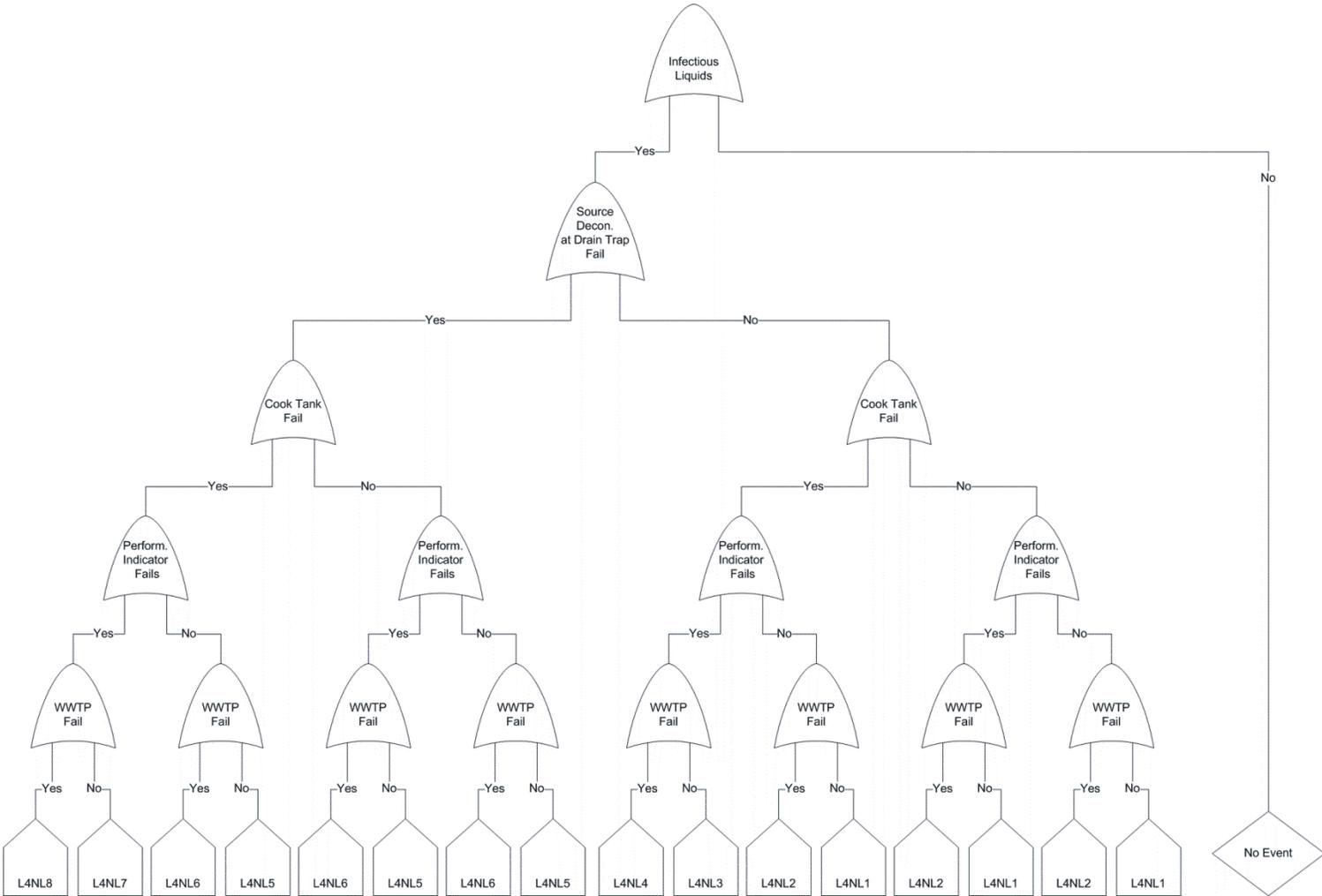


Figure 9.8.2-2: Event Tree for Liquid Waste Release in Necropsy (L4NL)

Table 9.8.2-2: ABSL-4 Necropsy Liquid Waste (L4NL)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4NL1	L4NL2	L4NL3	L4NL4	L4NL5	L4NL6	L4NL7	L4NL8
Source Decontamination at Drain Pipes	5.36E-02	9.4635E-01	1.00E-03	9.41E-02	WORK	WORK	WORK	WORK	FAIL	FAIL	FAIL	FAIL
Cook Tank	1.00E-05	9.9999E-01	1.00E-06	1.00E+00	WORK or	WORK or	FAIL	FAIL	WORK or	WORK or	FAIL	FAIL
Cook Tank Performance Indicator	1.00E-05	9.9999E-01	n/a	n/a	WORK	WORK	FAIL	FAIL	WORK	WORK	FAIL	FAIL
On Site Wastewater Treatment	1.00E-05	9.9999E-01	1.00E-01	1.00E+00	WORK	FAIL	WORK	FAIL	WORK	FAIL	WORK	FAIL
Overall Reduction Factor					1.000E 10	1.000E 09	1.000E 04	1.000E 03	9.411E 09	9.411E 08	9.411E 03	9.411E 02
Q_{Low} (PFU)					1.945E-11	1.945E-10	1.945E-05	1.945E-04	1.831E-09	1.831E-08	1.831E-03	1.831E-02
Q_{Medium} (PFU)					1.945E-11	1.945E-10	1.945E-05	1.945E-04	1.831E-09	1.831E-08	1.831E-03	1.831E-02
Q_{High} (PFU)					1.945E-07	1.945E-06	1.945E-01	1.945E+00	1.831E-05	1.831E-04	1.831E+01	1.831E+02
Probability (P_{Loss})					9.463E 01	9.464E 06	9.463E 11	9.464E 16	5.364E 02	5.365E 07	5.364E 12	5.365E 17
Frequency (F_{Loss}) (yr⁻¹)					4.74E+01	4.74E 04	4.74E 09	4.74E 14	2.69E+00	2.69E 05	2.69E 10	2.69E 15

MAR Low = 1.95 × 10⁻¹ PFU
 MAR Medium = 1.95 × 10⁻¹ PFU
 MAR High = 1.95 × 10³ PFU
 Opportunity Rate = 50.13 yr⁻¹

9.8.2.3 Necropsy – Solid Waste from Red Biohazard Bags (L4NSW)

The solid waste generated in the necropsy room, which is transferred to disposable materials (e.g., PPE, towels, disposable tools) is sterilized by two autoclaves (one in the BSL-4 with a pass-through to the BSL-3E and the second in the BSL-3E) and then incinerated. The MAR is 20% of the overall MAR in the tissue and carcasses of the infected animals. The opportunity rate for this set of circumstances is 50.13 yr^{-1} , corresponding to the number of necropsy days. For each day of necropsy, all solid red bag waste will be sterilized (i.e., one autoclave run per necropsy day). The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.2-3. The event tree is shown in Figure 9.8.2-3.

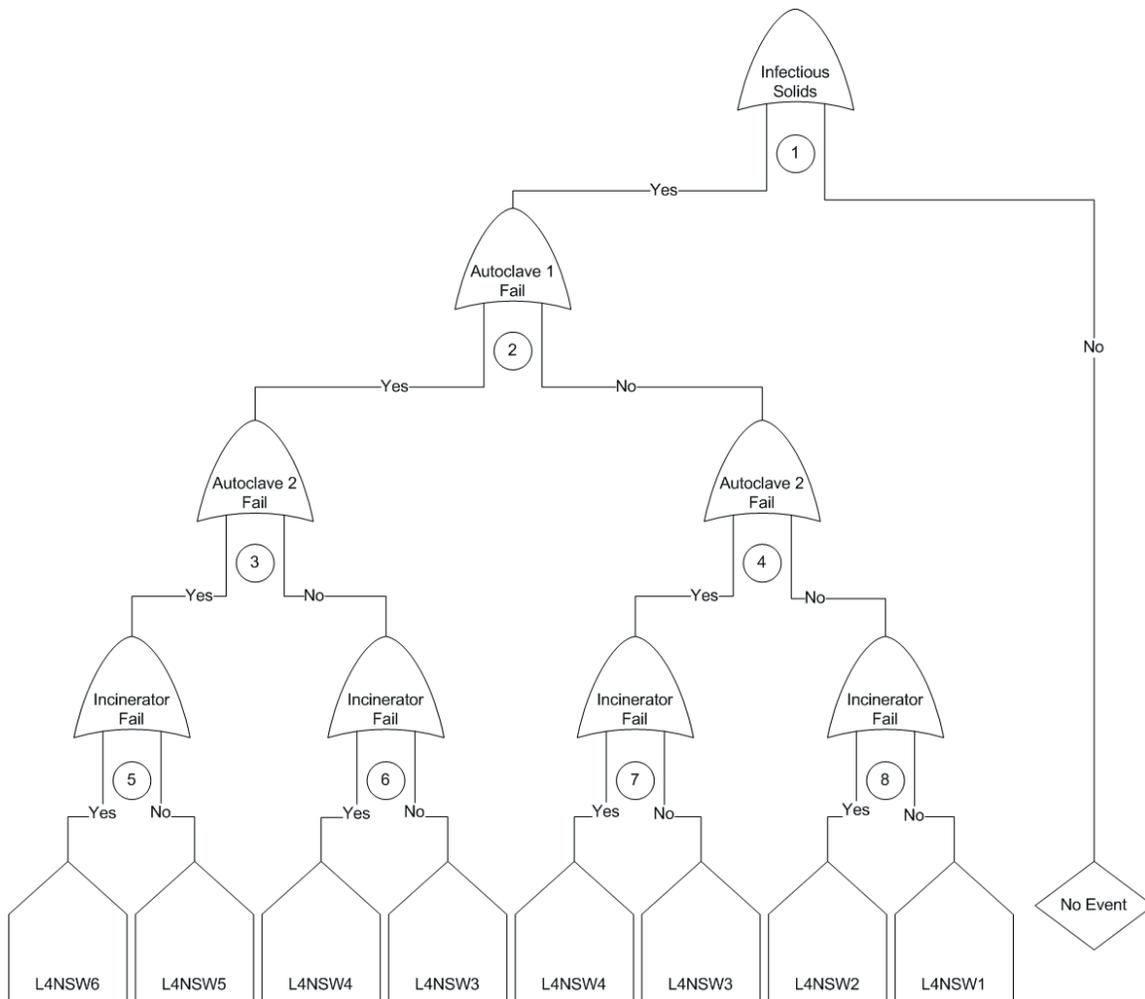


Figure 9.8.2-3. Event Tree for Solid (Red Bag) Waste Release in Necropsy (L4NSW)

Table 9.8.2-3: ABSL-4 Necropsy Solid Red Bag Waste (L4NSW)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4NSW1	L4NSW2	L4NSW3 ^a	L4NSW4 ^b	L4NSW5	L4NSW6
Autoclave #1 (BSL 4)	1.00E-05	9.9999E-01	1.00E-06	1.00E+00	WORK	WORK	WORK/FAIL	WORK/FAIL	FAIL	FAIL
Autoclave #2 (BSL 3E)	1.00E-05	9.9999E-01	1.00E-06	1.00E+00	WORK	WORK	FAIL/WORK	FAIL/WORK	FAIL	FAIL
Incinerator	1.00E-10	1.0000E+00	1.00E-09	1.00E+00	WORK	FAIL	WORK	FAIL	WORK	FAIL
Overall Reduction Factor					1.000E 21	1.000E 12	1.000E 15	1.000E 06	1.000E 09	1.000E+00
Q_{Low} (PFU)					1.468E-21	1.468E-12	1.468E-15	1.468E-06	1.468E-09	1.468E+00
Q_{Medium} (PFU)					1.013E-15	1.013E-06	1.013E-09	1.013E+00	1.013E-03	1.013E+06
Q_{High} (PFU)					6.995E-10	6.995E-01	6.995E-04	6.995E+05	6.995E+02	6.995E+11
Probability (P_{Loss})					9.9998E 01	9.9998E 11	2.0000E 05	2.0000E 15	1.0000E 10	1.0000E 20
Frequency (F_{Loss}) (yr ⁻¹)					5.01E+01	5.01E 09	1.00E 03	1.00E 13	5.01E 09	5.01E 19

^a Probability is the sum of all events in which one of the two autoclaves fails and the incinerator works.

^b Probability is the sum of all events in which one of the two autoclaves fails and the incinerator fails.

MAR Low = 1.47×10^0 PFU

MAR Medium = 1.01×10^6 PFU

MAR High = 6.99×10^{11} PFU

Opportunity Rate = 50.13 yr^{-1}

9.8.2.4 Necropsy – Solid Waste from Tissue and Carcasses (L4NST)

The tissue and carcasses of infected animals are sterilized by a tissue autoclave and then incinerated. The MAR is 80% of the overall MAR in the tissue and carcasses of the infected animals. The opportunity rate for this set of circumstances is 20 yr⁻¹, corresponding to the number of ABS-4 studies. For each study, all tissue and carcasses of the animals in that study will be sterilized (i.e., one tissue autoclave run per study). The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.2-4. The event tree is shown in Figure 9.8.2-4.

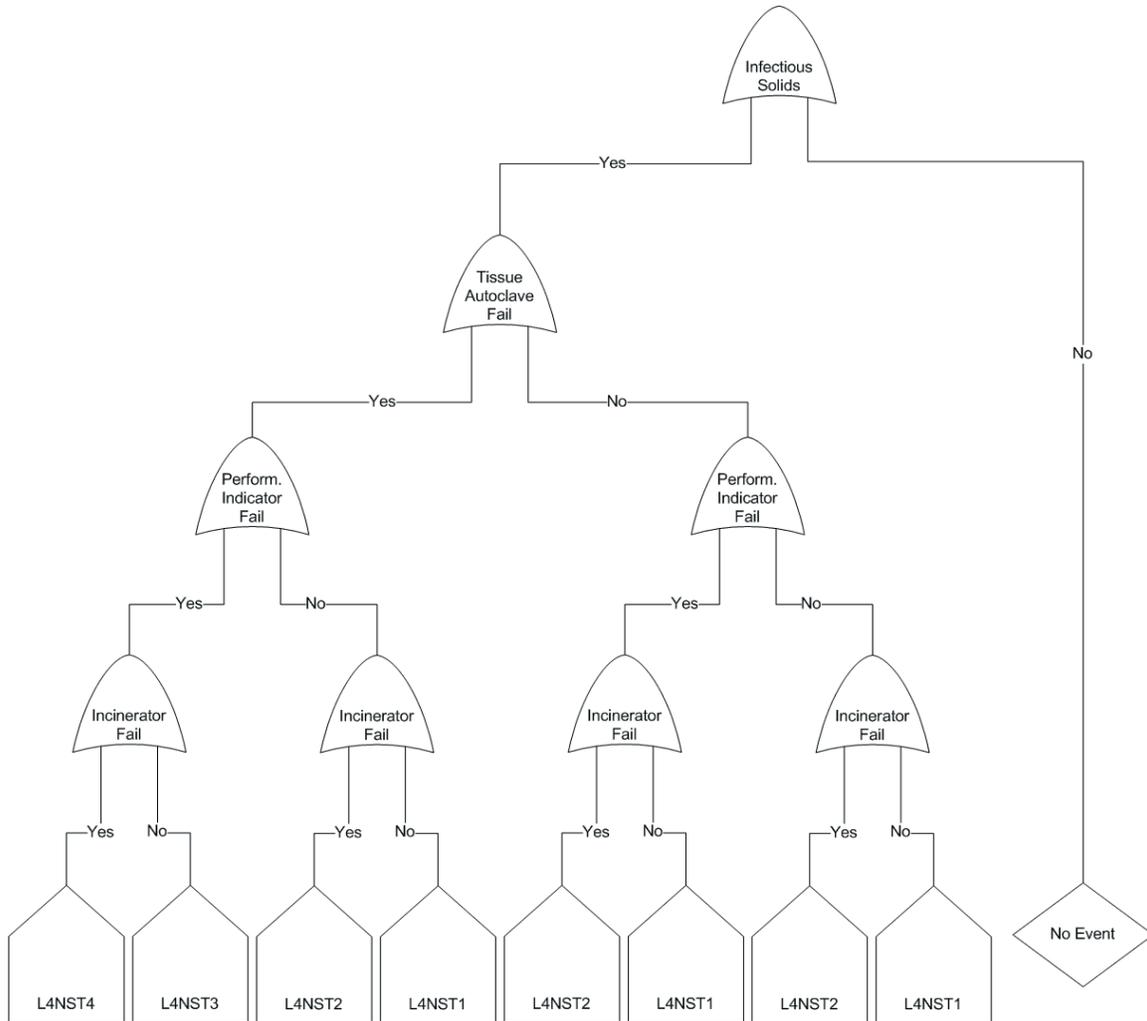


Figure 9.8.2-4: Event Tree for Solid Tissue Waste Release in Necropsy (L4NST)

Table 9.8.2-4: ABSL-4 Necropsy Solid Waste from Tissue and Carcasses (L4NST)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4NST1	L4NST2	L4NST3	L4NST4
Tissue Autoclave (BSL 4)	1.00E-05	9.9999E-01	1.00E-06	1.00E+00	WORK	WORK	FAIL	FAIL
Tissue Autoclave Performance Indicator	1.00E-05	9.9999E-01	n/a	n/a	or WORK	or WORK	FAIL	FAIL
Incinerator	1.00E-10	1.000E+00	1.00E-09	1.00E+00	WORK	FAIL	WORK	FAIL
Overall Reduction Factor					1.000E 15	1.000E 06	1.000E 09	1.000E+00
Q_{Low} (PFU)					1.472E-14	1.472E-05	1.472E-08	1.472E+01
Q_{Medium} (PFU)					1.016E-08	1.016E+01	1.016E-02	1.016E+07
Q_{High} (PFU)					7.013E-03	7.013E+06	7.013E+03	7.013E+12
Probability (P_{Loss})					1.0000E+00	1.0000E 10	1.0000E 10	1.0000E 20
Frequency (F_{Loss}) (yr⁻¹)					2.00E+01	2.00E 09	2.00E 09	2.00E 19

MAR Low = 1.47×10^1 PFU
 MAR Medium = 1.02×10^7 PFU
 MAR High = 7.01×10^{12} PFU
 Opportunity Rate = 20 yr^{-1}

9.8.2.5 Necropsy – Transference (Respiratory through Suit Leak) (L4NTRs)

In this situation, a researcher enters the ABSL-4 necropsy room and fails to test the suit prior to entry and the suit has a leak. This set of circumstances has four nodes: 1) failure to test the BSL-4 suit prior to entry; 2) probability of suit having a leak (dependent upon not testing the suit); 3) reporting the respiratory exposure; and 4) appropriate medical response (dependent upon reporting the exposure).

In such an event, it is assumed that 5.7% of the aerosol levels in the room will be transferred to the researchers’ respiratory tract (based on values from FMDv transference). The MAR is the viral concentrations from the cut tissue and aerosolized portion of the blood during a necropsy day. The opportunity rate for this set of circumstances is 100.3 yr^{-1} , corresponding to the number of necropsy days and two researchers in the necropsy room. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.2-5. The event tree is shown in Figure 9.8.2-5.

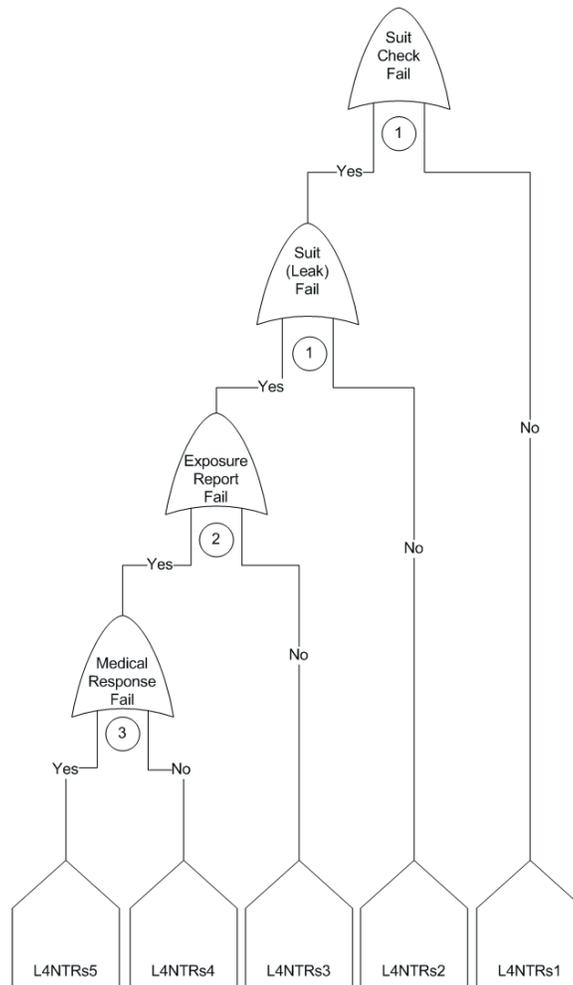


Figure 9.8.2-5: Event Tree for Transference Respiratory through Suit Leak in Necropsy (L4NTRs)

Table 9.8.2-5: ABSL-4 Necropsy Transference (Respiratory through Suit Leak) (L4NTRs)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4NTRs1	L4NTRs2	L4NTRs3	L4NTRs4	L4NTRs5
Failure to Test Suit	5.00E-03	9.9500E-01	6.70E-06	n/a	WORK	FAIL	FAIL	FAIL	FAIL
Probability of Suit Having a Leak	1.00E-03	9.9900E-01	6.70E-06	1.00E-03	n/a	WORK	FAIL	FAIL	FAIL
Laboratory Exposure is Reported	5.00E-03	9.9500E-01	n/a	n/a	n/a	n/a	WORK	WORK	FAIL
Appropriate Medical Response to Exposure	5.00E-03	9.9500E-01	n/a	n/a	n/a	n/a	WORK	FAIL	n/a
Transfer Percentage	n/a	n/a	n/a	n/a	5.7%	5.7%	5.7%	5.7%	5.7%
Overall Reduction Factor					3.819E 07	3.819E 07	5.700E 05	5.700E 05	5.700E 05
	Q_{Low} (PFU)				7.457E-09	7.457E-09	1.113E-06	1.113E-06	1.113E-06
	Q_{Medium} (PFU)				1.935E-05	1.935E-05	2.889E-03	2.889E-03	2.889E-03
	Q_{High} (PFU)				1.336E+01	1.336E+01	1.993E+03	1.993E+03	1.993E+03
	Probability (P_{Loss})				9.950E 01	4.995E 03	4.950E 06	2.488E 08	2.500E 08
	Frequency (F_{Loss}) (yr^{-1})				9.98E+01	5.01E 01	4.96E 04	2.49E 06	2.51E 06

MAR Low = 1.95×10^{-2} PFU
 MAR Medium = 5.07×10^1 PFU
 MAR High = 3.50×10^7 PFU
 Opportunity Rate = $100.3 yr^{-1}$

9.8.2.6 Necropsy – Transference (Injection from Cut with Tool) (L4NTI)

In this situation, a necropsy worker cuts their BSL-4 suit with a tool and the suit fails to prevent the mishandling of the tool from breaking the skin barrier. These set of circumstances have four nodes: 1) the researcher cutting through the PPE suit; 2) the cut going through the skin of the researcher; 3) reporting the laboratory injection exposure; and 4) appropriate medical response (dependent upon reporting the exposure).

In such an event, it is assumed that 100% of the material on the tool would be transferred into the person. The amount of material available was estimated to be 1 g of which 40% was transferred to the tool. The original MAR is the average concentration of NiV and HeV in 1 g of tissue. The opportunity rate for this set of circumstances is $14,789 \text{ yr}^{-1}$, which was calculating the product of the number of necropsy days per day (50.13), the number of researchers performing necropsy (2), the average number of animals processed per necropsy day (2.95), and an average of 50 cuts per researcher per animal. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.2-6. The event tree is shown in Figure 9.8.2-6.

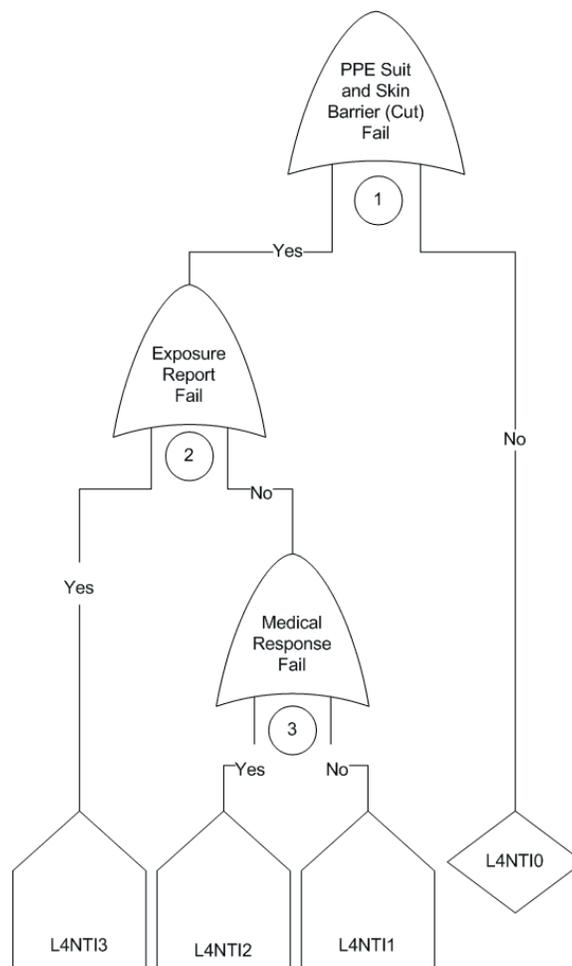


Figure 9.8.2-6: Event Tree for Transference Injection from Cut with Tool in Necropsy (L4NTI)

Table 9.8.2-6: ABSL-4 Necropsy Transference (Injection from Cut with Tool) (L4NTI)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4NTI0	L4NTI1	L4NTI2	L4NTI3	
Researcher Cuts Themselves and PPE Suit	5.00E-03	9.9500E-01	n/a	n/a	WORK	FAIL	FAIL	FAIL	
Cut Breaks Skin Barrier	5.00E-01	5.0000E-01	0.00E+00	1.00E+00	WORK	FAIL	FAIL	FAIL	
Laboratory Exposure is Reported	5.00E-03	9.9500E-01	n/a	n/a	n/a	WORK	WORK	FAIL	
Appropriate Medical Response to Exposure	5.00E-03	9.9500E-01	n/a	n/a	n/a	WORK	FAIL	n/a	
Overall Reduction Factor					0.00E+00	1.00E+00	1.00E+00	1.00E+00	
					Q_{Low} (PFU)	0.000E+00	6.263E-06	6.263E-06	6.263E-06
					Q_{Medium} (PFU)	0.000E+00	4.324E+00	4.324E+00	4.324E+00
					Q_{High} (PFU)	0.000E+00	2.985E+06	2.985E+06	2.985E+06
					Probability (P_{Loss})	9.975E 01	2.475E 03	1.244E 05	1.250E 05
					Frequency (F_{Loss}) (yr⁻¹)	1.48E+04	3.66E+01	1.84E 01	1.85E 01

MAR Low = 6.26×10^{-6} PFU
 MAR Medium = 4.32×10^0 PFU
 MAR High = 2.98×10^6 PFU
 Opportunity Rate = 14,789 yr⁻¹

9.8.2.7 Necropsy – Transference (Contact with Palm through Cut PPE) (L4NTCp)

As presented in Section 9.8.2.6, it is possible that after cutting a BSL-4 suit with a tool during a routine necropsy procedure, the contaminated tool comes in contact with the skin (e.g., palm) of the researcher. In this specific set of circumstances, the researcher accidentally cuts through the PPE suit but the skin barrier is not broken, yet there is a contact event. Upon contact, the researcher may or may not report the exposure. If the exposure is reported (i.e., the researcher is aware of the contact) and the proper medical response is received, they will undergo a chemical spot treatment and two soap and water body showers prior to leaving containment at a time deemed appropriate by the medical responders. If there is a failed medical response, it is assumed that the researcher, being aware of the contact exposure, will perform a chemical spot disinfection and will go through two body showers prior to leaving containment (one between the BSL-4 and the BSL-3E, and one to leave BSL-3E containment). If the exposure is not reported, it is assumed that the researcher is not aware of the potential risks with the contact exposure and no chemical spot treatment will be performed. Without any awareness, the researcher may or may not go through the two body showers prior to leaving containment.

The MAR is derived from 1 g of infectious tissue (average of NiV and HeV concentrations in tissue) of which 40% is transferred to the tool. Upon contact with the skin, 40% is transferred. The opportunity rate for this set of circumstances is $14,789 \text{ yr}^{-1}$, the same as presented for the injection circumstances in the necropsy room (Section 9.8.2.6). The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.2-7. The event tree is shown in Figure 9.8.2-7.

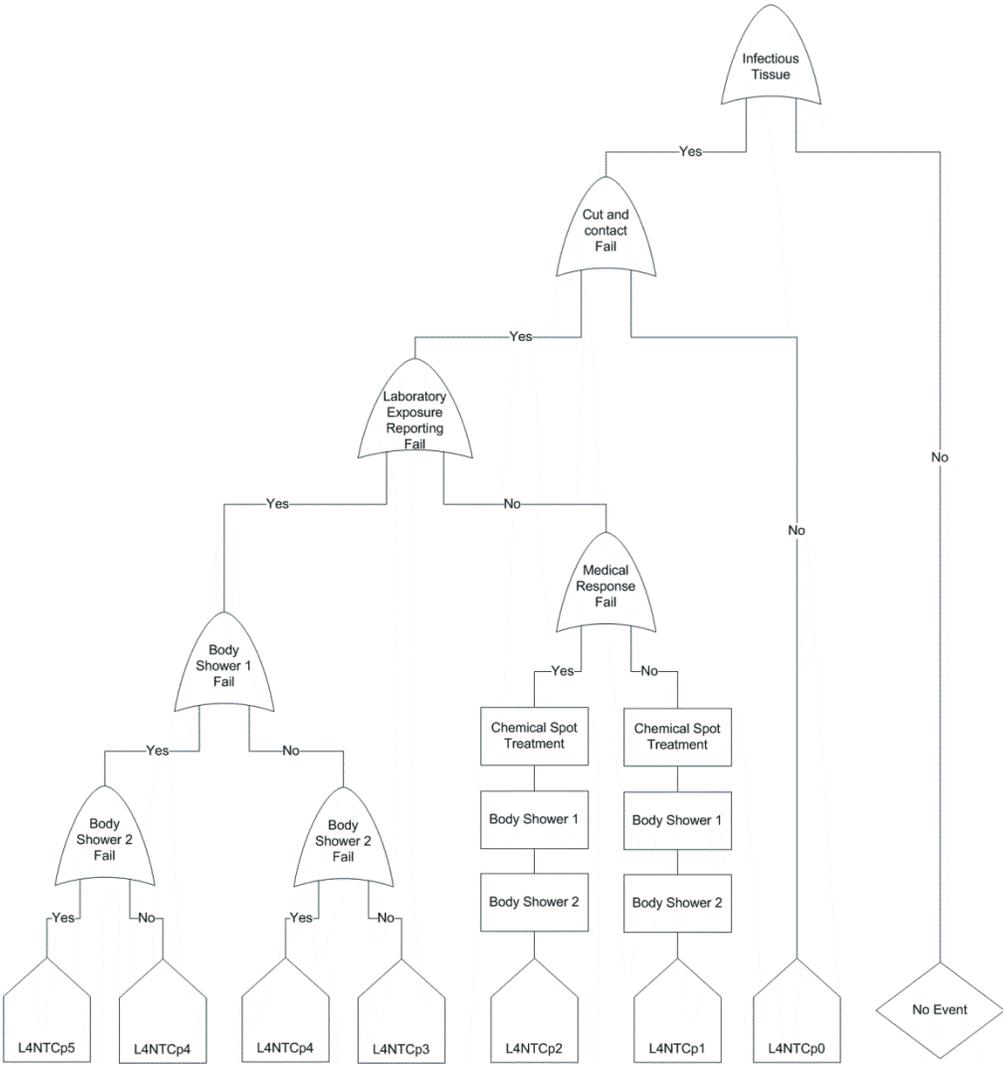


Figure 9.8.2-7: Event Tree for Transference Contact with Palm in Necropsy (L4NTCp)

Table 9.8.2-7: ABSL-4 Necropsy Transference (Contact with Palm through Cut PPE) (L4NTCp)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4NTCp0	L4NTCp1	L4NTCp2	L4NTCp3	L4NTCp4 ^a	L4NTCp5
Researcher Cuts Themselves	5.00E-03	9.950E-01	0.00E+00	n/a	WORK	FAIL	FAIL	FAIL	FAIL	FAIL
Contact with Skin	1.00E+00	0.000E+00	0.00E+00	4.00E-01	n/a	FAIL	FAIL	FAIL	FAIL	FAIL
Appropriate Medical Response to Exposure	5.00E-03	9.950E-01	n/a	n/a	n/a	WORK	WORK	FAIL	FAIL	FAIL
Laboratory Exposure Reported (i.e., researcher not aware of contact event)	5.00E-00	9.950E-01	n/a	n/a	n/a	WORK	FAIL	n/a	n/a	n/a
Chemical Spot Treatment	5.00E-03	9.950E-01	1.00E-05	1.00E+00	n/a	(WORK)	(WORK)	n/a	n/a	n/a
Body Shower #1 (BSL 4 to BSL 3E)	5.00E-03	9.950E-01	1.01E-01	1.00E+00	n/a	(WORK)	(WORK)	WORK	WORK	FAIL
Body Shower #2 (BSL 3E to Non Containment)	5.00E-03	9.950E-01	1.01E-01	1.00E+00	n/a	(WORK)	(WORK)	WORK	FAIL	FAIL
Overall Reduction Factor					0.000E+00	4.080E 08	4.080E 08	4.080E 03	4.040E 02	4.000E 01
Q_{Low} (PFU)					0.000E+00	2.556E-13	2.556E-13	2.556E-08	2.530E-07	2.505E-06
Q_{Medium} (PFU)					0.000E+00	1.764E-07	1.764E-07	1.764E-02	1.747E-01	1.729E+00
Q_{High} (PFU)					0.000E+00	1.218E-01	1.218E-01	1.218E+04	1.206E+05	1.194E+06
Probability (P_{Loss})					9.9500E 01	4.9501E 03	2.4875E 05	2.475E 05	2.488E 07	6.250E 10
Frequency (F_{Loss}) (yr^{-1})					1.47E+04	7.32E+01	3.68E 01	3.66E 01	3.68E 03	9.24E 06

^a Probability is the sum of two events in which one out of two body showers are a success.

MAR Low = 6.26×10^{-6} PFU

MAR Medium = 4.32×10^0 PFU

MAR High = 2.98×10^6 PFU

Opportunity Rate = 14,789 yr^{-1}

9.8.2.8 Necropsy – Transference (Contact with Fomite) (L4NTCf)

When a sample is sent from the BSL-4 of the NBAF (e.g., necropsy sample of infectious material) to another BSL-4 laboratory, it must be properly packaged and contained prior to shipment. During the packaging, infectious material may be transferred to the outer surface of the container and could result in a fomite transference event. All samples to be shipped from the BSL-4 will go through the chemical shower and then be disinfected in a chemical dunk tank to leave the BSL-4 into the BSL-3E. To exit the BSL-3E, the sample will go through two more dunk tank disinfections. Each of these nodes reduces the quantity of material depending on their success or failure.

The MAR is derived from 1 g of infectious tissue (average of NiV and HeV concentrations in tissue) which is spread out on the surface of the outer container. The opportunity rate for this set of circumstances is 148 yr⁻¹, estimating that one sample will be sent out of the BSL-4 of the NBAF to another BSL-4 laboratory. The probabilities (P_{Loss}), reduction factors, Q values, and frequencies of loss-of-containment (F_{Loss}) for the events included in this set of circumstances are detailed in Table 9.8.2-8. The event tree is shown in Figure 9.8.2-8.

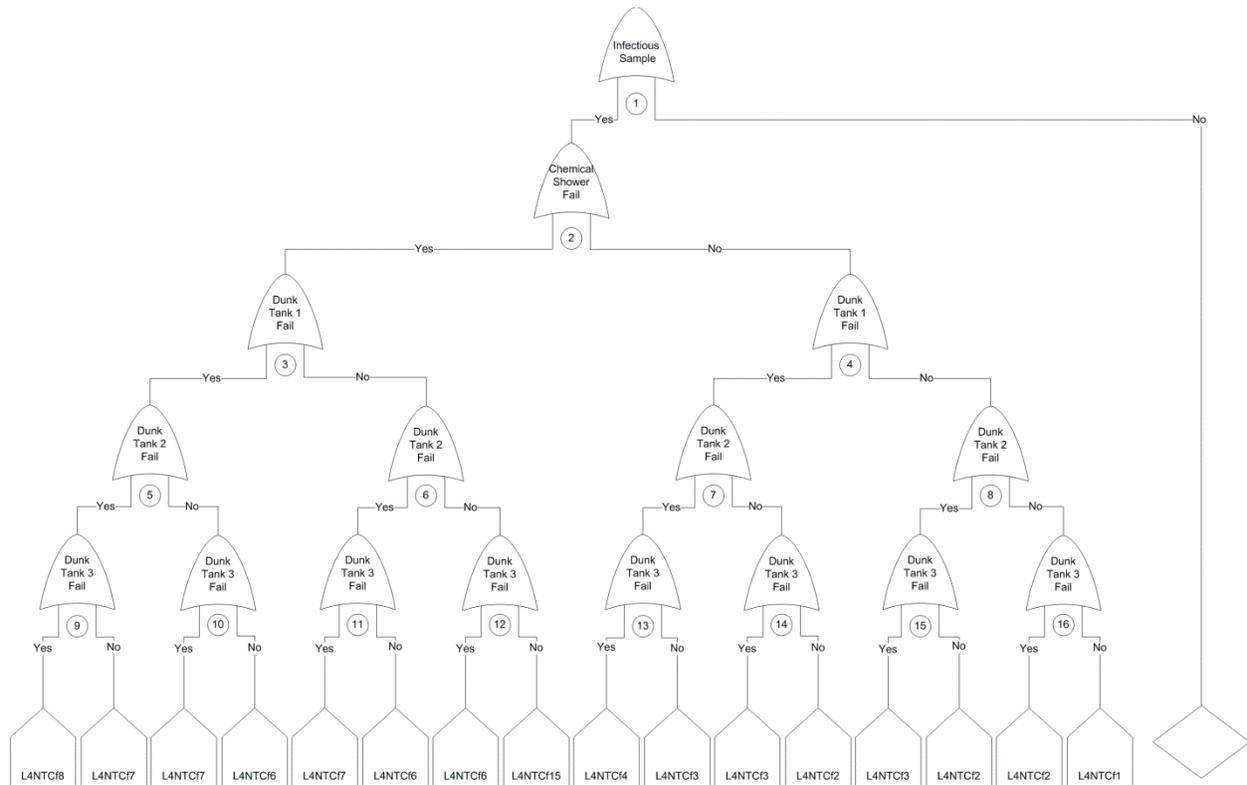


Figure 9.8.2-8: Event Tree for Transference Contact with Fomite in Necropsy (L4NTCf)

Table 9.8.2-8: ABSL-4 Necropsy Transference (Contact with Fomite) (L4NTCF)

Node/Mitigation System	Probability of Failure	Probability of Success	Reduction Factor (Success)	Reduction Factor (Failure)	L4NTCF1	L4NTCF2 ^a	L4NTCF3 ^b	L4NTCF4	L4NTCF5	L4NTCF6 ^c	L4NTCF7 ^d	L4NTCF8
Chemical Shower (ABSL 4 to BSL 4)	1.00E-05	9.9999E-01	1.00E-05	1.00E+00	WORK	WORK	WORK	WORK	FAIL	FAIL	FAIL	FAIL
Dunk Tank #1 (BSL 4 to BSL 3E)	5.00E-03	9.9500E-01	1.00E-05	1.00E+00	WORK	WORK	WORK	FAIL	WORK	WORK	WORK	FAIL
Dunk Tank #2 (BSL 3E)	5.00E-03	9.9500E-01	1.00E-05	1.00E+00	WORK	WORK	FAIL	FAIL	WORK	WORK	FAIL	FAIL
Dunk Tank #3 (BSL 3E to Non containment)	5.00E-03	9.9500E-01	1.00E-05	1.00E+00	WORK	FAIL	FAIL	FAIL	WORK	FAIL	FAIL	FAIL
Overall Reduction Factor					1.000E 20	1.000E 15	1.000E 10	1.000E 05	1.000E 15	1.000E 10	1.0000 05	1.000E+00
Q_{Low} (PFU)					1.566E-25	1.566E-20	1.566E-15	1.566E-10	1.566E-20	1.566E-15	1.566E-10	1.566E-05
Q_{Medium} (PFU)					1.081E-19	1.081E-14	1.081E-09	1.081E-04	1.081E-14	1.081E-09	1.081E-04	1.081E+01
Q_{High} (PFU)					7.462E-14	7.462E-09	7.462E-04	7.462E+01	7.462E-09	7.462E-04	7.462E+01	7.462E+06
Probability (P_{Loss})					9.851E 01	1.485E 02	7.462E 05	1.250E 07	9.851E 06	1.485E 07	7.463E 10	1.250E 12
Frequency (F_{Loss}) (yr⁻¹)					1.46E+02	2.20E+00	1.10E 02	1.85E 05	1.46E 03	2.20E 05	1.10E 07	1.85E 10

^a Probability is the sum of all events in which the chemical shower works and two out of three dunk tanks are a success.

^b Probability is the sum of all events in which the chemical shower works and one out of three dunk tanks are a success.

^c Probability is the sum of all events in which the chemical shower fails and two out of three dunk tanks are a success.

^d Probability is the sum of all events in which the chemical shower fails and one out of three dunk tanks are a success.

MAR Low = 1.57 × 10⁻⁵ PFU

MAR Medium = 1.08 × 10¹ PFU

MAR High = 7.46 × 10⁶ PFU

Opportunity Rate = 148 yr⁻¹

9.9 ABSL-4 Impact Analyses

To estimate the impact that a release of viable material from the ABSL-4 spaces at the NBAF may have on the surrounding area, a two-phased approach was taken. First a review of documented outbreaks of HeV and NiV was conducted to: identify and present known impacts of an outbreak (including the metric); understand key factors that influence transmission of the disease; and estimate the potential impact of reservoir hosts to the persistence of HeV or NiV within a geographic region. The second phase focused on extrapolation of the historical data in conjunction with review of the source terms determined in the event analysis to apply to and identify the key factors necessary to estimate an outbreak impact relevant to the Manhattan, Kansas location of the NBAF. The two main paramyxoviruses to be studied at the NBAF, HeV and NiV, have caused sporadic outbreaks in domestic animals and people, with high case-fatality rates, and evidence of human-to human transmission for NiV [Plowright, 2011].

9.9.1 The Historical Perspective

The first cases of HeV and NiV were identified in 1994 and 1998, respectively; both are considered (relatively) recently emerged pathogens. Research is just beginning to characterize the transmission, stability, and pathogenesis of these agents – thus the need for containment facilities such as the NBAF that may perform research on them. Sufficient data do not yet exist that lends them to full epidemiological or economic modeling to understand the impact that an outbreak of these pathogens may have in the United States (specifically Manhattan, Kansas). Data do exist, however, on the impact that outbreaks of these pathogens have had in other parts of the world such as Malaysia, Bangladesh, Singapore and Australia. Although the human demographics, distribution of host and reservoir species, farming practices and medical and veterinary response dynamics, do differ significantly in Kansas from these known outbreak location, they currently offer the best available information by which to estimate the kind of impact an outbreak in Kansas may have and thus are presented here.

9.9.1.1 Summary of HeV and NiV Outbreak Impact

The two paramyxoviruses to be studied at the NBAF, HeV and NiV, have caused sporadic outbreaks in domestic animals and people, with high case-fatality rates, and evidence of human-to human transmission for NiV [Plowright, 2011]. The following summaries of these outbreaks provide a perspective regarding the impact of the outbreaks in terms of the resulting number of human and susceptible animal infections and fatalities.

Hendra virus was first identified in Australia during an outbreak involving humans and horses for which the disease is lethal. All reported HeV outbreaks thus far have been confined to Australia. As of this writing, there have been thirty reported outbreaks of HeV in Australia – all outbreaks involved transmission of virus from flying foxes to a primary case horse. Five events led to transmission from horses to humans [Plowright, 2011]. A summary of the HeV outbreaks reported as of August 2001 are provided in Table 9.9.1-1. Note that overall, each outbreak resulted in on average less than 1 human infection (0.23), with an average case fatality rate of 57% and an average ~2 horse infections (all of which were ultimately euthanized if they did not succumb to the disease first).

Table 9.9.1-1: Impact of the Hendra Outbreaks
(Adapted from Plowright [2011] and Pallister [2011])

Location	Month, Year	# Infected	
		Humans (% Fatalities)	Horses
Mackay	Aug. 1994	1 (100)	2
Brisbane (HeV)	Sept. 1994	2 (50)	20
Cairns (Trinity Beach)	Jan. 1999	0	1
Cairns (Gordonvale)	Oct. 2004	1 (0)	1
Townsville	Dec. 2004	0	1
Peachester	June 2006	0	1
Murwillumbah	Oct. 2006	0	1
Peachester	June 2007	0	1
Cairns (Clifton Beach)	July 2007	0	1
Brisbane (Redlands)	July 2008	2 (50%)	5
Proserpine	July 2008	0	3
Rockhampton	July 2008	1 (100%)	3
Bowen	Sept. 2009	0	3 ^a
Tewantin	May 2010	0	1
Logan Reserve	June 2011	0	1
Kerry	June 2011	0	1
McLeans Ridge	June 2011	0	2
Mt. Alford	July 2011	0	3 (+1 Dog)
Utungan	July 2011	0	1
Park Ridge	July 2011	0	1
Kuranda	July 2011	0	1
Hervey Bay	July 2011	0	1
Corndale	July 2011	0	1
Boondall	July 2011	0	1
Chinchilla	July 2011	0	1
Mullumbimby	July 2011	0	1
Newrybar	Aug.2011	0	1
Pimlico	Aug.2011	0	2
Mullumbimby	Aug.2011	0	1
Currumbin Valley	Aug.2011	0	1
Average per Outbreak		0.23 ± 0.57 (57%)	2.13 ± 3.51

^a Note that Plowright 2011 indicated 2 horse infections compared to 3 reported by Pallister; to be conservative the highest number of reported infections was used in this assessment.

Evidence suggests that transmission of the virus from horses to people, albeit rare, occurs through physical contact with nasal and oral secretions from sick, dying or recently expired infected horses [Hanna, 2006]. Of the four persons known to be infected with HeV between 1994-2007; all were subject to direct exposure to secretions or tissues from ill, dying or recently expired horses, and two were directly involved in autopsies where they experienced heavy contamination (one veterinarian reported using no PPE). Two of the four died, and the remaining two suffered a relatively minor form of the illness

[Hanna 2006]. During the July 2008 Brisbane HeV outbreak; two horses were quarantined at a veterinary clinic after suspicion of HeV infection, which resulted in the subsequent transmission to three other horses (all of which either died or were euthanized). Two veterinary workers (equine veterinarian and a veterinary nurse) associated with this outbreak became ill, resulting in one death [Playford, 2010] see Table 9.9-1. Interestingly, during this July 2008 HeV outbreak, the known contacts with infected horses (83 persons) and infected humans (9 healthcare workers and domestic contacts) were assessed and none developed symptoms or expressed antibodies against the virus when tested (beyond the two human index cases discussed previously). Included among these contacts was one veterinary worker who suffered a direct percutaneous blood exposure during euthanasia on an HeV-infected horse. As a precaution, this person was treated with antiviral ribavirin and never showed indication of HeV infection. Even when exposed during high-risk procedures, the infection rate for HeV during this outbreak was relatively low (7%) when the appropriate respiratory droplet and mucosal protection precautions were taken [Playford, 2010]. The high-risk activities that did lead to the two infected patients included performing daily nasal cavity lavage on an infected horse and participation in a necropsy of an infected horse.

Roughly half (16/30) of the reported HeV outbreaks presented in Table 9.9.1-1 have occurred in 2011, none of which resulted in any human infections (presumably associated with increased awareness, knowledge of and adherence to, proper handling of infected animals and animal products gained since the first outbreaks in 1994) but did result in one to three horse infections per outbreak. The Mt. Alford outbreak included the only confirmed HeV infection in a dog. Other than this event, HeV had exclusively been isolated from bats, humans and horses in nature [Pallister 2011] – although laboratory exposures have indicated the ability of HeV to replicate in other mammalian hosts.

Human NiV infection was first recognized during a large outbreak in peninsular Malaysia and Singapore where it was isolated from a patient within the Sungai NiV village during this outbreak which occurred from September 1998 to June 1999 [Luby, 2009]. In Malaysia, infected reservoir bats were suspected to have transmitted the virus to pigs resulting in a swine epidemic, spread through the movement (sale) of animals, and leading to a human epidemic (from exposure to infected pigs and in some instances infected persons).

The Malaysia outbreak was controlled when infections were identified and direct contact with infected pigs (and presumably persons) was ceased. This case study indicated that when infections are identified, culling infected animals, exercising the appropriate level of PPE precaution and/or avoiding contact with infected animals altogether, and ceasing movement of infected animals were successful at controlling the further spread of disease. Even with the fairly rapid identification of index NiV cases, the Malaysia outbreak resulted in over 265 reported human cases, with 105 deaths and the culling of more than one million pigs followed by a 3 month active surveillance program as presented in Table 9.9.1-2 [Chua, 2003; Luby, 2009]. The Malaysia outbreak had a high case fatality rate (~40%), a high rate of symptomatic infection (data not reported) and an infection rate in pigs near 100% [Chua, 2003; Sahani 2001]. It was not until approximately 2.5 years after the onset of the outbreak that Malaysia was declared free of NiV in the livestock population by OIE (occurred in June 2001).

Table 9.9.1-2: Summary of 1998-2001 NiV Outbreak Impacts

Outbreak	# Humans Infected	% Fatalities	# Animals Culled (Porcine)	Comments	Reference(s)
1998-1999 Malaysia	265	40% ^a (105/265)	>1 million (porcine); and 3 month surveillance across 9 farms	Malaysia declared free of NiV virus in the livestock population in June 2001 by OIE. Human cases associated with handling infected porcine.	Chua, 2003; Luby 2009; Pallister 2011a
2001-2008 Bangladesh (over 8 outbreaks)	122-135 ^b	73% (98/135)	None reported	More severe disease reported – increased respiratory abnormalities, ventilation support and subsequent neurological dysfunction [Luby, 2009]. Human cases with no known association with infected porcine.	Luby 2009; Homaira 2010; Pallister 2011a
Siliguri, West Bengal India, 2001	92	73% ^c (67/92)	None reported		Chadha 2006.;Luby 2009; Harit 2006; Pallister 2011a;
India 2007	50	10% (5/50)	None reported		Pallister 2011a; Promed 20070508.1484 (2007) NiV virus, fatal-India (West Bengal).
2010 Bangladesh	3	100% (3/3)	None reported		Pallister 2011a; Promed 20100122.0250 (2010) NiV virus, fatal – Bangladesh; (Faridpur)
Jan 2011 Bangladesh	5	80% (4/5)	None reported		Pallister 2011a; Promed 20110204.0402 (2011) Nipah virus, fatal – Bangladesh (Faridpur,Rajbari).
Feb 2011 Bangladesh	21 ^d	Uncertain	None reported		Pallister 2011a; Promed 20110204.0408 2011 -Rangpur
Total	571		1,000,000		
Average (over 14 outbreaks)	41 ± 69	51% (282/550)	71,400 ± 258,300		

^a Pallister [2011] reported the Malaysia outbreak fatality rate at 40% vs. 38.5% reported by Chua 2003 – in this assessment, any human infection was considered in the impact ratio – regardless of the outcome (recovery or death), the fatality rate is presented for information only and was not used in the calculation of impact (the same value of human life was applied to all infected patients, even those that recovered).

^b Homaira [2010] reported 122 cases with 86 deaths (71% fatality rate); Pallister reported 128 cases in Bangladesh from April 2001-March 2008 (with a 73% fatality rate) and Luby reported 135 human infections from 2001-2008 with 73% fatality rate. To be conservative the largest number of human infections reported with these outbreaks was used to estimate the impact (135 cases).^c

^c Luby and Harit cited a fatality rate of 68% versus 74% reported in Pallister [2011; referencing Chadha (2006)].

^d This represents the reported number of deaths, the total number of cases (or associated % fatality) was not reported; as such the number of deaths reported was used to represent the known number of human infections from this outbreak.

Following the 1998 Malaysian outbreak, no new cases of NiV in Malaysia have been identified; however additional cases have been reported in Bangladesh from 2001 through February 2011. In contrast to the Malaysia and Singapore NiV outbreaks, the vast majority of case patients in the Bangladesh outbreaks did not have any contact with infected pigs or pig excrement. This was reportedly due to the fact that many of the Bangladesh population are practicing Muslims who do not consume pork or physically contact pigs [Montgomery, 2008]. The majority of the reported index cases in the Bangladesh NiV outbreaks were linked not to contact with infected pigs, but with ingestion of NiV containing fresh date palm sap. In Bangladesh, *P. giganteus* bats reportedly lick the sap during collection and transmit the virus followed by a customary drinking of the raw palm sap. In other cases, direct contact with NiV – infected bat secretions was the attributed cause of the exposures [Luby 2009]. The impact in the Bangladesh outbreaks was therefore limited to human illness and death; as opposed to the additional economic impact to the pig farming industry observed in the Malaysian NiV outbreak.

In Siliguri, West Bengal India, between 31 January and 23 February, 2001 a total of 92 probable NiV cases and 67 subsequent deaths were reported [Chadha, 2006; Harit, 2006; Luby 2009; Pallister 2011a;] (see Table 9.9.1-2). A single patient admitted to the local Male Medical Ward in January 2001 is the suspected source of the outbreak – which subsequently transmitted infection to other patients and visitors to the ward. Similar to the Bangladesh outbreaks, no concurrent illness in animals or exposure to ill domestic animals was reported. This outbreak resulted in purported “widespread panic” [Harit, 2006] among the residents, and led to the closure of private health facilities. Although difficult to quantify the impact in any specific metric, the closure of private health facilities would certainly lead to a significant economic impact (especially in developed nations) and increase in the number of infected patients that don’t receive adequate medical care (potentially leading to a higher fatality rate) or isolation (potentially leading to subsequent transmission).

In summary, the impact from any given reported HeV outbreak was limited in terms of the number of human infections, ranging from 1-2 human infections with a 57% fatality rate overall. For HeV outbreaks there were a greater potential for horse infections, ranging from 1 to 20 horses infected per outbreak, all of which were sacrificed regardless of whether or not they recovered from the illness. Although fewer persons and animals were reportedly impacted per outbreak for HeV (relative to NiV), the recurrence of spillover due to the established reservoir host in that area, continues to demand presumably significant resources to continually monitor and respond to the recurring events (16 of which have happened in June-August 2011 alone). In contrast to HeV, the majority of NiV outbreaks have led to far more human infections and fatalities, ranging from 3-265 (average of 41±69) with high case fatality rates ranging from 10-100% (average of 80%). Only one of the reported NiV outbreaks (out of 14) affected the livestock industry, however when it did affect livestock the impact was significant – leading to the culling of over one million pigs followed by additional resources expended to perform active surveillance until the OIE declared the area NiV-free.

9.9.1.2 Documented Outbreak Transmission Factors

Due to the high sequence homology, similar genome organization and other similar biological characteristics, both HeV and NiV have recently been placed in a newly characterized genus Henipaviurs [Wong, 2009]. Several disease transmission related similarities exist between the two pathogens. First, NiV and HeV share the same natural host reservoir as indicated by wildlife species surveillance studies, namely genus *Pteropid* fruit bats which inhabit northern Australia, southeast Asia, the Indian subcontinent and eastern Africa (but not the US) [Wong, 2009]. Specifically, island flying foxes (*Pteropus hypomelanus*) and the Malayan flying foxes (*Pteropus vampyrus*) have been confirmed as the natural reservoir in Malaysian outbreaks. In these instances NiV has been confirmed within the urine and saliva of the bat reservoirs which then in turn contaminate animal and human food that when consumed provide a source of virus capable of causing infection [Lam, 2002]. Thus pig farms in proximity to fruit orchards and fruit trees that draw these bat species should be avoided, and their co-location should be considered a risk factor to the reintroduction of NiV into these pig populations. Additionally, ingestion of NiV contaminated fresh date palm sap (*P. giganteus* bats reportedly lick the sap during collection and transmit the virus) or direct contact with bat secretions are specific documented modes of NiV transmission that should be avoided [Luby, 2009]. Similar to NiV, Australia's flying foxes (genus *Pteropus*) also exhibit an infectious period during which they excrete HeV in urine, saliva, feces and placental fluid [Plowright, 2011]. Transmission of HeV from flying foxes to horses is through horse ingestion of pasture, feed or water contaminated with the HeV bat secretions noted above [Plowright, 2011].

Increased human encroachment into bat habitats previously undisturbed (such as forests) has led to urbanization of flying foxes, reduction in flying fox migration patterns and an increase in the overlap of human, horse and flying fox populations. This is reported as now particularly evident in Australia's east coast cities and across many major towns – where previously flying fox populations were not observed [Plowright, 2011]. The changes in flying fox ecology observed in Australia have been linked to the observations of more intense and lethal HeV outbreaks in both people and horses. As best stated by Plowright et.al, 2011 “*the risk of pathogen emergence from a reservoir host to a new host species is affected by 1) the number of reservoir hosts infected, 2) the encounter rate between reservoir and novel hosts and 3) the infection dynamics and transmission biology of the pathogen*” [Plowright 2011]. Thirteen of the 14 evaluated HeV spill-over events were within foraging radius of continuously occupied (9) or seasonally occupied (4) urban flying fox camps [Plowright, 2011] – which undoubtedly contributed to an increased encounter rate and possibly the number of reservoir hosts infected. The general pattern of transmission from bats to animals and infected animals to humans is similar for HeV and NiV; although HeV primarily affects horses while NiV primarily affects pigs. For HeV, evidence suggests that transmission of the virus from horses to people, albeit rare, occurs through physical contact with nasal and oral secretions from sick, dying or recently expired infected horses [Hanna, 2006]. Of the four persons known to be infected with HeV between 1994-2007; all were subject to direct exposure to secretions or tissues from ill, dying or recently expired horses, and two were directly involved in autopsies where they experienced heavy contamination (one veterinarian reported using no PPE).

The Malaysian NiV outbreak indicated that NiV infections are spread from pig to man via infected body fluids through direct body contact as well as via respiratory droplets at close range [Kay-Sin, 1999]. The case study indicated that NiV caused disease with a high infection rate, affecting 33% of the household members of infected farms. Workers with direct contact with the sick animals (ear tagging, pig breeding, administering medication, etc.) were more likely to become infected (51%) as were family members of the infected (56%). Contact with live infected pigs (or close contact with infected persons) was key to the transmission. Pigs were the predominant agent of transmission of NiV from animal to man; however, according to Sahani [2001] infected dogs have also shown to transmit the virus. Other domestic species including cats, horses and goats were effectively considered “dead-end” hosts [Lam, 2002]. Infected pigs may be asymptomatic or only mildly affected. NiV infection was not rampant among abattoir workers in this outbreak – only seven of 435 tested were antibody-positive and those workers were associated with locations of active pig farm infections and five of the seven reported contact with live pigs [Sahani, 2001]. The spread of the virus among pig farms within and between states of Peninsular Malaysia was due to movement of pigs [Chau, 2003], farms even in close proximity to infected farms that did not receive animals with suspected infection remained NiV free. Similar to HeV, transmission of NiV between animals within a farm was attributed to direct contact with infectious urine, saliva, pharyngeal and lung secretions [Chau, 2003].

Likely the most notable documented difference between the modes of transmission of NiV and HeV is evidence of person-to-person transmission of NiV that is lacking in HeV outbreaks [Plowright, 2011]. This is most clearly explained via a discussion of the NiV cases that occurred between 31 January and 23 February, 2001 in Siliguri, India [Harit, 2006]. A case admitted to the local Male Medical Ward in January 2001 is the suspected source of the outbreak – which then transmitted infection to other patients and visitors to the ward. Similar to the Bangladesh outbreaks, no concurrent illness in animals or exposure to ill domestic animals was reported. This outbreak demonstrated ability to transmit NiV in hospital settings; however this particular case is unique in that regard. Other studies [Mounts, 2001] report that the risk of nosocomial infections of NiV was low – even with reported unprotected exposures to potentially infected secretions of NiV patients, no transmission of NiV to these studied healthcare workers was reported. Given the variability in the reported instances of person-to-person transmission in hospital settings, the documented instances of NiV transmission to persons in close contact with and/or caring for the sick [Homaira, 2010], with the knowledge that NiV is found in various bodily secretions indicates at a minimum a potential of transmission of the virus to healthcare providers, proximal patients in a hospital setting or other persons in close contact with those infected with NiV and thus this impact must be considered and evaluated. If people are in contact with the infected towards the last days of illness when respiratory symptoms are present (i.e., coughing) – it has been suggested that the probability of NiV transmission is amplified during these last stages of illness when respiratory symptoms (e.g., coughing) are more prominent [Homaira, 2010]. It is likely that given the standard personal protective precautions exercised in the U.S. medical system when a respiratory infectious disease is suspected, that the risk of person to person transmission could be reduced below that which was observed during the Indian outbreak. However, in cases where the NiV infection has not yet been

recognized, not reported, or has been misdiagnosed, the potential for person-to-person transmission of NiV still needs to be evaluated.

9.9.2 Estimating the Impact at the NBAF

With consideration of the transmission characteristics previously presented regarding documented NiV and HeV outbreaks, several factors were considered in estimating the impact of a BSL-4 pathogen release from the NBAF. Three major categories of information considered to estimate an outbreak impact included: 1) the expected frequency at which an exposure to a person within the NBAF or a release from the NBAF results in a loss-of-containment; 2) the probability that an infection event (or index case) occurs, given a loss of containment; and 3) the relative impact of an infection event based on the likelihood for subsequent transmission of the disease (to people or host species), given an index case. Sections 9.6 through 9.8 describe the loss-of-containment scenarios considered, based on the activities and experiments expected to be performed in the ABSL-4 AHRs and necropsy room in the NBAF and as identified by ABSL-4 containment experts. The expected frequencies associated with each of these loss-of-containment scenarios, as well as the amount of pathogenic material potentially involved in each loss-of-containment outcome, are presented in Section 9.8. Section 9.9.2.1 describes the specific sub-factors and assumptions associated with estimating the probability of an infection event, given a loss-of-containment. Section 9.9.2.2 presents the impact evaluation, and Section 9.9.2.3 discusses special considerations for emerging or unknown pathogens.

9.9.2.1 Probability of an Index Case

P_i is the conditional probability that a given loss-of-containment outcome results in at least one infection (i.e., an index case of either a human or susceptible animal host). The details associated with estimating P_i vary by pathway and are described in more detail later in this section. Regardless of the pathway, the same general methodology applies and involves estimating the probability of infection (P_i) (of a human or susceptible animal host) given a loss of containment (either an exposure within the NBAF or a release from the NBAF), several factors were considered.

- First, for each potential loss of containment outcome, the amount of pathogen potentially involved (referred to as the source term or Q value, and presented in Section 9.7) was used to compute the probability that an infectious dose was present. This component of the probability of infection (P_i) is referred to as P_i-1_Q .
 - In regards to estimating whether or not an infectious dose could be delivered to an animal or human host given the source term, two additional sub-considerations were applied; namely the pathway by which the Q is released (aerosol release from the HEPA filtered stacks, solid waste release, liquid waste release or transference event by which an individual or fomite is directly or indirectly exposed) and how the infectious dose is administered to the host (via inhalation, ingestion or injection); all of these sub-components were considered in determination of P_i-1_Q .
- Second, as not only does an infectious dose have to be available in the loss-of-containment, a susceptible species must be proximal to the pathogen in order to inhale, ingest, or inject it as

indicated by the pathway of release and individual circumstances associated with the loss. This proximity component of the probability of infection (P_i) is referred to as $P_{i-2_{proximal}}$.

Each of these components is discussed in more detail below.

Probability of Infection (P_{i-1Q})

Probability of infection (P_i) is the conditional probability that a given loss-of-containment outcome results in at least one infection (i.e., an index case). The approaches for estimating P_i vary by pathway and are described in more detail in subsequent sections. The first component evaluated was the probability that an infectious dose was present in the accident Q term (P_{i-1}). There are no specific data available regarding the infectious dose of NiV and HeV for human and large animal species, however there has been documented research performed in small mammals to determine the lethal doses and this data (Table 9.9.2-1) was leveraged to estimate the infectious dose for NiV and HeV in large mammals (humans, equine, porcine) [Rockx et al., 2011; Guillaume et al., 2009]. The lethal dose data available from Rockx and Guillaume was used to estimate the total Q term needed to be released from the NBAF (via aerosol, liquid, or solid) or to be transferred to an individual at the NBAF (via inhalation or injection) to result in an infectious dose.

In Syrian hamsters, Rockx et al. calculated the lethal dose at which 50% of the animals succumbed to infection (LD_{50}) to be 6 $TCID_{50}$ (~4.2 PFU) intraperitoneally or less than 1 $TCID_{50}$ (~0.7 PFU) intranasally for both NiV and HeV [Rockx et al., 2011]. Guillaume et al. calculated the LD_{50} for Syrian hamsters to HeV to be 12 PFU via intraperitoneal inoculation [Guillaume et al., 2009]. Using the average of these two studies, the LD_{50} of 8.1 PFU via the intraperitoneal route was normalized to the average mass of a Syrian hamster (110 g) to yield an LD_{50} of 73.6 PFU/kg. As infectious dose data of NiV and HeV are not available, these LD_{50} values were used as the infectious dose thresholds. For the purpose of this risk assessment, the mass of an average human male (86.6 kg) was used to calculate a single infectious dose threshold of 6.38×10^3 PFU for animals and humans. Similarly, the infectious dose via intranasal exposure was calculated to be 6.36 PFU/kg and the infectious dose threshold for animals and humans was calculated to be 5.51×10^2 PFU. These values are summarized in Table 9.9.2-1.

Table 9.9.2-1: Infectious Dose Thresholds for NiV and HeV

Exposure Route	LD_{50} ($TCID_{50}$) ^a	LD_{50} (PFU) ^b	Average LD_{50} (PFU/hamster)	Mass of Syrian Hamster (g)	Average LD_{50} (PFU/kg)	Large Mammal Mass (kg)	Infectious Dose (PFU)
Intraperitoneally (Ingestion, Injection)	6	12	8.1	110	73.6	86.6	6.36×10^3
Intranasally (Inhalation)	< 1	---	< 0.7		6.30		5.46×10^2

^a Rockx et al., 2011. ^b Guillaume et al., 2009

For the aerosol pathway through the HEPA filters, virus particles will most likely undergo degradation and will be diluted in the air released from the NBAF stacks (at 85 ft) before it reaches a potential animal or human host. To account for this, a 10^{-3} degradation and dilution factor of the Q term due to viral desiccation, UV degradation, and/or dilution in the atmosphere post-release from the NBAF was assumed. (Note that this degradation and dilution factor is an assumption; no published data on the stability of NiV or HeV in the atmosphere are currently available.) For the inhalation or respiratory exposures, the intranasal inoculation ID_{50} values were used. This resulted in an estimated Q of greater than or equal to 5.46×10^5 PFU needed before at least 5.46×10^2 PFU was expected to survive in the atmosphere until it could be inhaled by a susceptible species located nearest the NBAF. For reference, the aerosol fate and transport modeling performed for FMDv in the BSL-3 Ag assessment indicated that no infectious doses (even at the low threshold) reached any farm location near the NBAF until the release Q value from the NBAF location was at least 1.00×10^5 PFU.

Estimation of infectious doses along the solid and liquid waste pathways (i.e., ingestion infectious dose values) was calculated using the intraperitoneal inoculation infectious dose values as no specific ingestion LD_{50} values were reported in the literature. As the infectious material in the solid and liquid are diluted and degraded along their system pathways, an animal must either ingest a large amount of waste or there must be a high concentration of infectious material at the release from the NBAF (i.e., high Q value). Susceptible species potentially coming into contact with the potential liquid pathway releases (e.g., due to a failure of the wastewater treatment pond on the NBAF campus or a leak in a pipe along the sewage line) are assumed to ingest 1 gallon of water. Based on the typical daily throughput of waste at the NBAF for the BSL-4 specific effluent decontamination system of 37,099 gallons [NDP, October 2011], the threshold Q value from the NBAF was determined to be 2.36×10^8 PFU/day (results in a concentration of 6.36×10^3 PFU/gallon in the liquid waste). (No additional loss due to degradation in the wastewater stream was assumed.)

The susceptible species coming into contact with NBAF solid waste either along the road to the landfill where it is ultimately dumped or at the landfill itself are assumed to ingest 1 lb of material (see Section 5.0 for maps of the liquid effluent and solid waste routes from the NBAF to the municipal wastewater treatment facility and land fill respectively). For the solid waste pathway, the NBAF is expected to generate 21,000 lbs of ash from the incineration process per year [NDP, June 2010] with a total expected weekly solid waste ash delivery from the NBAF to the landfill of 404 lbs (based on 52 work weeks/year). On a per day basis, approximately 57.7 lbs of ash are produced. Given these assumptions, the resulting Q value needed to potentially result in an infectious dose through ingestion of the solid waste was calculated to be 3.67×10^5 PFU/day (results in a concentration of 6.36×10^3 PFU/lb in the solid waste). (No additional loss due to degradation in the solid waste pathway was assumed.)

Table 9.9.2-2 summarizes the threshold Q values for determining whether the viral material released via these pathways is greater than the infectious dose.

Table 9.9.2-2: Threshold Q Values for Infectious Dose to Large Mammal ^a					
Exposure Route	Infectious Dose (PFU)	Dilution/ Degradation Factor	Waste Produced Per Day	Amount Consumed	Threshold Q
Inhalation (NBAF Stacks)	5.46×10^2	10^{-3}	n/a	n/a	5.46×10^5
Inhalation (Direct Exposure)	5.46×10^2	n/a	n/a	n/a	5.46×10^2
Liquid Waste	6.36×10^3	n/a	37,099 gallons	1 gallon	2.36×10^8
Solid Waste	6.36×10^3	n/a	57.7 lbs	1 lb	3.67×10^5
Injection	6.36×10^3	n/a	n/a	n/a	6.36×10^3
Contact Transference	6.36×10^3	n/a	n/a	n/a	6.36×10^3

^a large mammal mass of 86.6 kg, adult human male

The Q value thresholds shown in Table 9.9.2-2 were used as the baseline for assigning the probability that the low, medium or high source term (Q) of each event was greater than or equal to the infectious dose threshold per route of exposure. These corresponding P_{r-1Q} probabilities represent 99.9% confidence (6σ) that **either** the low, medium or high Q source term is greater than or equal to the estimated corresponding threshold. This conservative approach in probability assignment accounts for uncertainty in the source term estimation (i.e., the 95th percentile Q term which in some instances was several orders of magnitude greater than the 5th percentile Q term was always considered a possibility for release and as such the corresponding P_{r-1Q} values may be overestimated relative to if the 50th percentile Q term was chosen; however to represent the worse-case the 95th percentile Q terms were included. The probability of exceeding the threshold was computed by first computing the z-score associated with the threshold (i.e., the threshold minus the expected value for Q divided by the estimated standard deviation for Q) and then computing the probability of observing a z-score as high as or higher than that obtained, assuming a standard normal distribution. Specifically, the z-score and P_{r-1Q} were computed as follows:

$$z = \frac{(\text{Threshold} - Q_M)}{\left(\frac{Q_H - Q_M}{2}\right)}$$

Equation 9.9.2-1

$$P_{i-1Q} = P(x \geq z) \text{ where } x \sim N(0,1)$$

Equation 9.9.2-2

These resulting P_{i-1Q} probabilities represent the probability that the observed source term in a given loss of containment occurrence (Q) will be greater than or equal to the estimated threshold required to result in a potential infection. For each loss-of-containment scenario, the calculated P_{i-1Q} values can be viewed in Table 9.9.2-4 (of the following section).

Probability that Release Occurs in Proximity to Susceptible Species ($P_{i-2_{proximal}}$)

For each loss-of-containment occurrence, the proximity of a susceptible species to the release point was factored into the probability of subsequent infection. If there was not sufficient contact, no infection would occur regardless of the Q source term value. The following paragraphs outline the assumptions associated with determining the probability that susceptible species will be proximal to the release points at the NBAF. The probabilities assigned based on those assumptions are presented in Table 9.9.2-3.

Table 9.9.2-3: Probability that Susceptible Species are Proximal to the Release ($P_{i-2_{proximal}}$)

Pathogen	Index Species	Pathway			
		Aerosol	Solid or Liquid	Transference	
				Report/Contact Precaution	No Report/Contact Precaution
NiV	Human	0.9	0.001	0.001	0.900
	Animal	0.9	0.900	0.000	0.000
HeV	Human	0.9	0.001	0.001	0.001
	Animal	0.9	0.900	0.000	0.000

For events along the aerosol release pathway, it was assumed that all potential index species could be proximal to the release point (either in the laboratory during a breach in suit function or on or around the NBAF grounds should a release occur from the HEPA filtered stacks).

For events involving releases along the solid and liquid waste stream; it was assumed that no humans would ingest liquid effluent or solid waste. Therefore the probability that humans will become infected via these routes was assigned a low probability regardless of their proximity to the breach in the system ($P_{i-2_{proximal}} = 0.001$). The assignment of a non-zero probability reflects the small possibility that a person could become exposed through inadvertent exposure, via ingestion or secondary aerosolization, to these materials. The same probability was assigned to both NiV and HeV.

For events along the solid or liquid waste streams, special consideration was given to the proximity of susceptible animal species. Given the location of the Manhattan, Kansas, sewage treatment line and the road leading to the landfill from the NBAF (see Section 5.0 for the detailed figures of these paths) it is possible (albeit somewhat unlikely) that domestic livestock will leave a farm (through a barrier fence) and travel to the site of the breach of the solid or liquid pathway (the nearest farm is 300m from the NBAF). It is also possible that susceptible wildlife (e.g., feral pigs) may contact these locations as they are not contained within farms. However, given the vast number of farms that contains livestock susceptible to NiV, as evident, for example, by the number of pig farms in Kansas (see Figure 9.9.2-1), coupled with the prevalence of feral pigs in the Midwest, it was considered likely that susceptible animals are sufficiently proximal to any NiV releases along the, solid or liquid pathways such that an exposure could occur. Given this proximity, it was also assumed that if pathogen was released from the NBAF HEPA filtered stacks (aerosol release pathway), that it was likely to come into contact with susceptible species on nearby farms. Note that for these events $P_{r-2proximal}$ was set to 0.9.

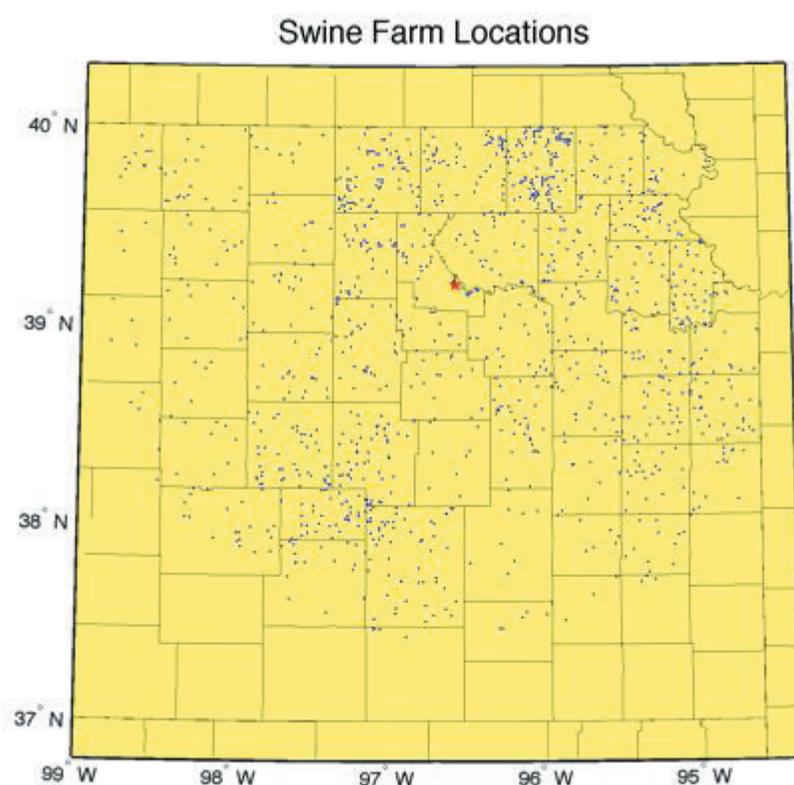


Figure 9.9.2-1: Swine Farms within a 200km Radius of the NBAF

Similarly, horses' susceptibility to Henipaviruses is significant to note in regards to the equine industry of Manhattan, Kansas. With more than 103,000 horses participating in over 28,000 equine events and activities on more than 944,000 acres, these animals play a significant role in the agricultural and tourism industry of the state of Kansas (KSU online). K-State located in Manhattan, Kansas, houses the Kansas State University Equine Program, for undergraduate and graduate students. This program

combines hands on experience, research, community involvement, and equine-focused clubs and teams. Manhattan is also home to the Kansas Horse Council, which connects horse lovers and owners from all over the state. Given that the K-State campus is adjacent to the NBAF, it was also considered that susceptible species (primarily horses) are sufficiently proximal to any potential aerosol, solid or liquid pathways from the NBAF. Based on these considerations, the probability that the release will occur in proximity to a susceptible animal species ($P_{i-2proximal}$) was assigned as to a value of 0.90 for all animal-related solid, liquid, and aerosol loss-of-containment occurrences for HeV.

For events involving transference of pathogen via fomite contacts, the same probabilities for transference of a laboratory human exposure when reporting or subsequent medical response failed were assumed. It was assumed that if a worker was aware that pathogen still remained on a fomite, they would not remove it from the laboratory. If they were unaware that viable pathogen still remained on the fomite (assumed for all these events) then the fomite would move unrestricted out of containment with the same probability of an individual who was not under medical monitoring or exercising contact precautions (see Table 9.9.1-5, Transference No Report/Contact Precautions values). It was also assumed that only people (as opposed to both people and susceptible livestock) would be handling these fomites (e.g., a package to be shipped to another laboratory), and therefore probabilities regarding proximity to these materials were set to zero for animals.

Given the differences in person-to-person transmission potential for NiV and HeV; the following assumptions were also applied. For NiV human infections not reported (where contact precautions were not exercised, person-to-person transmission was considered likely ($P_{i-2proximal} = 0.900$)). For HeV, the occurrence of person-to-person transmission is reportedly negligible and therefore this was assigned a $P_{i-2proximal}$ value of 0.001 regardless of whether there was appropriate medical response (i.e., contact precautions or protective PPE and practices suitable to prevent subsequent transmission).

Overall Probability of an Index Case (P_i)

The probabilities assigned to P_{i-1Q} and $P_{i-2proximal}$ were applied to each of the loss-of-containment occurrences considered in the ABSL-4 assessment and those values presented in Table 9.9.2-4. For each pathogen and index species (human or animal), P_i was computed as the product of P_{i-1Q} and $P_{i-2proximal}$. Table 9.9.2-4 also presents the resulting index case frequencies (F_{event}) which are the product of the P_i and the frequency of the loss-of-containment event (F_{loss}).

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4AAi0	AHR	Aerosol (Inoculum)	Sedation works or squeeze chute works or no dropped inoculum or container works. No inoculum released	0.00E+00	0.00E+00	0.00E+00	1.480E+02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AAi1	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; all 4 HEPA filters normal	1.99E-14	2.62E-10	3.46E-06	3.482E-05	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AAi2	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; three filters are normal, 1 filter is degraded	2.69E-13	3.54E-09	4.67E-05	2.121E-06	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AAi3	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; both filters in one column are normal while both filters in the other column are degraded	6.74E-12	8.88E-08	1.17E-03	1.615E-08	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AAi4	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one filters in each column is normal, one filter in each column is degraded	5.17E-13	6.81E-09	8.98E-05	3.230E-08	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AAi5	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; three filters are degraded, 1 filter is normal	6.99E-12	9.21E-08	1.21E-03	4.920E-10	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AAi6	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; all 4 filters are degraded	1.35E-11	1.77E-07	2.34E-03	1.873E-12	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AAi7	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one column fails (but at least one alarm works) while both filters in the other column are normal	1.99E-14	2.62E-10	3.46E-06	1.436E-08	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AAi8	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one column fails (but at least one alarm works) while in the other column one filter is normal and one filter is degraded	5.17E-13	6.81E-09	8.98E-05	4.373E-10	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4AAi9	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one column fails (but at least one alarm works) while both filters in the other column are degraded	1.35E-11	1.77E-07	2.34E-03	3.330E-12	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AAi10	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; total HEPA failure	1.99E-04	2.62E+00	3.46E+04	3.700E-39	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA1	AHR	Aerosol	All 4 filters are normal	3.84E-06	6.48E-06	1.01E-02	5.533E+02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA2	AHR	Aerosol	Three filters are normal, 1 filter is degraded	5.18E-05	8.75E-05	1.36E-01	3.371E+01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA3	AHR	Aerosol	Both filters in one column are normal while both filters in the other column are degraded	1.30E-03	2.19E-03	3.41E+00	2.567E-01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA4	AHR	Aerosol	One filters in each column is normal, one filters in each column is degraded	9.97E-05	1.68E-04	2.61E-01	5.133E-01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA5	AHR	Aerosol	Three filters are degraded, 1 filter is normal	1.35E-03	2.28E-03	3.53E+00	7.818E-03	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA6	AHR	Aerosol	All 4 filters are degraded	2.59E-03	4.38E-03	6.80E+00	2.977E-05	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA7	AHR	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are normal	3.84E-06	6.48E-06	1.01E-02	2.281E-01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA8	AHR	Aerosol	One column fails (but at least one alarm works) while in the other column one filter is normal and one filter is degraded	9.97E-05	1.68E-04	2.61E-01	6.949E-03	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA9	AHR	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are degraded	2.59E-03	4.38E-03	6.80E+00	5.292E-05	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AA10	AHR	Aerosol	Total HEPA failure	3.84E+04	6.48E+04	1.01E+08	5.880E-32	4.96E-01	9.00E-01	9.00E-01	9.00E-01	9.00E-01	2.63E-32	2.63E-32	2.63E-32	2.63E-32
L4AL1	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment works	7.28E-03	7.28E-02	1.61E-01	2.768E+02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4AL2	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment fails	7.28E-02	7.28E-01	1.61E+00	2.768E-03	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AL3	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment works	7.28E+03	7.28E+04	1.61E+05	2.768E-08	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AL4	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment fails	7.28E+04	7.28E+05	1.61E+06	2.768E-13	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AL5	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment works	1.29E-02	1.29E-01	2.85E-01	1.716E+01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AL6	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment fails	1.29E-01	1.29E+00	2.85E+00	1.716E-04	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AL7	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment works	1.29E+04	1.29E+05	2.85E+05	1.716E-09	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AL8	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment fails	1.29E+05	1.29E+06	2.85E+06	1.716E-14	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AS1	AHR	Solid Waste	Autoclave #1 works, Autoclave #2 works, Incinerator works	1.46E-16	1.46E-15	3.22E-15	2.940E+02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AS2	AHR	Solid Waste	Autoclave #1 works, Autoclave #2 works, Incinerator fails	1.46E-07	1.46E-06	3.22E-06	2.940E-08	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AS3	AHR	Solid Waste	One of two autoclaves, Incinerator works	1.46E-10	1.46E-09	3.22E-09	5.880E-03	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AS4	AHR	Solid Waste	One of two autoclaves, Incinerator fails	1.46E-01	1.46E+00	3.22E+00	5.880E-13	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AS5	AHR	Solid Waste	Both autoclaves fail, Incinerator works	1.46E-04	1.46E-03	3.22E-03	2.940E-08	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4AS6	AHR	Solid Waste	Both autoclaves fail, Incinerator fails	1.46E+05	1.46E+06	3.22E+06	2.940E-18	8.92E-01	1.00E-03	9.00E-01	1.00E-03	9.00E-01	2.62E-21	2.36E-18	2.62E-21	2.36E-18
L4ATii0	AHR	Transference (Injection, Inoculation)	Sedation works or squeeze chute works or PPE works or no stabbing through skin. No inoculum injected.	0.00E+00	0.00E+00	0.00E+00	1.480E+02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4ATii1	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure reported and appropriate medical response	9.95E-02	1.31E+03	1.73E+07	1.832E-04	5.00E-01	1.00E-03	0.00E+00	1.00E-03	0.00E+00	9.15E-08	0.00E+00	9.15E-08	0.00E+00
L4ATii2	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure reported and failed medical response	9.95E-02	1.31E+03	1.73E+07	9.204E-07	5.00E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	4.14E-07	0.00E+00	4.60E-10	0.00E+00
L4ATii3	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure not reported; no medical response	9.95E-02	1.31E+03	1.73E+07	9.250E-07	5.00E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	4.16E-07	0.00E+00	4.62E-10	0.00E+00
L4ATRO	AHR	Transference (Respiratory)	Squeeze chute works or penning works or suit is not cut or hose is not entangled. No respiratory exposure	5.36E-03	9.05E-03	1.40E+01	1.411E+04	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4ATR1	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is reported and appropriate medical response	4.56E+01	7.70E+01	1.19E+05	1.746E-03	4.97E-01	1.00E-03	0.00E+00	1.00E-03	0.00E+00	8.68E-07	0.00E+00	8.68E-07	0.00E+00
L4ATR2	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is reported and failed medical response	4.56E+01	7.70E+01	1.19E+05	8.776E-06	4.97E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	3.92E-06	0.00E+00	4.36E-09	0.00E+00
L4ATR3	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is not reported; no medical response	4.56E+01	7.70E+01	1.19E+05	8.820E-06	4.97E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	3.94E-06	0.00E+00	4.38E-09	0.00E+00
L4ATI0	AHR	Transference (Injection)	Squeeze chute works or penning works or suit is not cut by animals or skin barrier is not broken. No laboratory injection	0.00E+00	0.00E+00	0.00E+00	1.41E+04	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4AT11	AHR	Transference (Injection)	Squeeze chute failure, penning failure, rogue animal cuts, kicks, bites through PPE suit and through skin barrier. Injection exposure is reported and appropriate medical response	1.00E-03	1.00E+01	1.07E+03	1.75E-03	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AT12	AHR	Transference (Injection)	Squeeze chute failure, penning failure, rogue animal cuts, kicks, bites through PPE suit and through skin barrier. Injection exposure is reported and failed medical response	1.00E-03	1.00E+01	1.07E+03	8.78E-06	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4AT13	AHR	Transference (Injection)	Squeeze chute failure, penning failure, rogue animal cuts, kicks, bites through PPE suit and through skin barrier. Injection exposure is not reported and no medical response	1.00E-03	1.00E+01	1.07E+03	8.82E-06	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4ATRs1	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is not torn during movement in ABSL-4 AHR.	2.44E-03	4.13E-03	6.40E+00	2.91E+03	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4ATRs2	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is not torn during movement in ABSL-4 AHR.	2.44E-03	4.13E-03	6.40E+00	1.46E+01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4ATRs3	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and appropriate medical response	3.65E-01	6.16E-01	9.56E+02	1.45E+01	1.27E-01	1.00E-03	0.00E+00	1.00E-03	0.00E+00	1.84E-03	0.00E+00	1.84E-03	0.00E+00
L4ATRs4	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and failed medical response	3.65E-01	6.16E-01	9.56E+02	7.28E-02	1.27E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	8.31E-03	0.00E+00	9.24E-06	0.00E+00
L4ATRs5	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is not reported and no medical response	3.65E-01	6.16E-01	9.56E+02	7.31E-02	1.27E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	8.35E-03	0.00E+00	9.28E-06	0.00E+00
L4ATRs6	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and appropriate medical response	3.65E-01	6.16E-01	9.56E+02	7.27E-02	1.27E-01	1.00E-03	0.00E+00	1.00E-03	0.00E+00	9.23E-06	0.00E+00	9.23E-06	0.00E+00

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4ATRs7	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and failed medical response	3.65E-01	6.16E-01	9.56E+02	3.65E-04	1.27E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	4.17E-05	0.00E+00	4.64E-08	0.00E+00
L4ATRs8	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is not reported and no medical response	3.65E-01	6.16E-01	9.56E+02	3.67E-04	1.27E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	4.19E-05	0.00E+00	4.66E-08	0.00E+00
L4ATRs9	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and appropriate medical response	3.65E-01	6.16E-01	9.56E+02	1.46E-02	1.27E-01	1.00E-03	0.00E+00	1.00E-03	0.00E+00	1.85E-06	0.00E+00	1.85E-06	0.00E+00
L4ATRs10	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and failed medical response	3.65E-01	6.16E-01	9.56E+02	7.31E-05	1.27E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	8.35E-06	0.00E+00	9.28E-09	0.00E+00
L4ATRs11	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is not reported and no medical response	3.65E-01	6.16E-01	9.56E+02	7.35E-05	1.27E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	8.40E-06	0.00E+00	9.33E-09	0.00E+00
L4NA1	Necropsy	Aerosol	All 4 filters are normal	1.95E-12	5.07E-09	3.50E-03	4.72E+01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NA2	Necropsy	Aerosol	Three filters are normal, 1 filter is degraded	2.64E-11	6.84E-08	4.72E-02	2.87E+00	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NA3	Necropsy	Aerosol	Both filters in one column are normal while both filters in the other column are degraded	6.61E-10	1.72E-06	1.18E+00	2.19E-02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NA4	Necropsy	Aerosol	One filters in each column is normal, one filters in each column is degraded	5.07E-11	1.32E-07	9.08E-02	4.38E-02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NA5	Necropsy	Aerosol	Three filters are degraded, 1 filter is normal	6.85E-10	1.78E-06	1.23E+00	6.67E-04	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NA6	Necropsy	Aerosol	All 4 filters are degraded	1.32E-09	3.43E-06	2.36E+00	2.54E-06	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NA7	Necropsy	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are normal	1.95E-12	5.07E-09	3.50E-03	1.95E-02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4NA8	Necropsy	Aerosol	One column fails (but at least one alarm works) while in the other column one filter is normal and one filter is degraded	5.07E-11	1.32E-07	9.08E-02	5.92E-04	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NA9	Necropsy	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are degraded	1.32E-09	3.43E-06	2.36E+00	4.51E-06	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NA10	Necropsy	Aerosol	Total HEPA failure	1.95E-02	5.07E+01	3.50E+07	5.01E-33	4.88E-01	9.00E-01	9.00E-01	9.00E-01	9.00E-01	2.20E-33	2.20E-33	2.20E-33	2.20E-33
L4NL1	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment works	1.95E-11	1.95E-11	1.95E-07	4.74E+01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NL2	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment fails	1.95E-10	1.95E-10	1.95E-06	4.74E-04	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NL3	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment works	1.95E-05	1.95E-05	1.95E-01	4.74E-09	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NL4	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment fails	1.95E-04	1.95E-04	1.95E+00	4.74E-14	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NL5	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment works	1.83E-09	1.83E-09	1.83E-05	2.69E+00	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NL6	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment fails	1.83E-08	1.83E-08	1.83E-04	2.69E-05	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NL7	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment works	1.83E-03	1.83E-03	1.83E+01	2.69E-10	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NL8	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment fails	1.83E-02	1.83E-02	1.83E+02	2.69E-15	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NSW1	Necropsy	Solid Waste (Red Bag)	Autoclave #1 works, Autoclave #2 works, Incinerator works	1.47E-21	1.01E-15	6.99E-10	5.01E+01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4NSW2	Necropsy	Solid Waste (Red Bag)	Autoclave #1 works, Autoclave #2 works, Incinerator fails	1.47E-12	1.01E-06	6.99E-01	5.01E-09	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NSW3	Necropsy	Solid Waste (Red Bag)	One of two autoclaves, Incinerator works	1.47E-15	1.01E-09	6.99E-04	1.00E-03	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NSW4	Necropsy	Solid Waste (Red Bag)	One of two autoclaves, Incinerator fails	1.47E-06	1.01E+00	6.99E+05	1.00E-13	1.47E-01	1.00E-03	9.00E-01	1.00E-03	9.00E-01	1.47E-17	1.33E-14	1.47E-17	1.33E-14
L4NSW5	Necropsy	Solid Waste (Red Bag)	Both autoclaves fail, Incinerator works	1.47E-09	1.01E-03	6.99E+02	5.01E-09	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NSW6	Necropsy	Solid Waste (Red Bag)	Both autoclaves fail, Incinerator fails	1.47E+00	1.01E+06	6.99E+11	5.01E-19	5.00E-01	1.00E-03	9.00E-01	1.00E-03	9.00E-01	2.51E-22	2.26E-19	2.51E-22	2.26E-19
L4NST1	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave or performance indicator works, incinerator works	1.47E-14	1.02E-08	7.01E-03	2.00E+01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NST2	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave or performance indicator works, incinerator fails	1.47E-05	1.02E+01	7.01E+06	2.00E-09	4.58E-01	1.00E-03	9.00E-01	1.00E-03	9.00E-01	9.17E-13	8.25E-10	9.17E-13	8.25E-10
L4NST3	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave and performance indicator fails, incinerator works	1.47E-08	1.02E-02	7.01E+03	2.00E-09	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NST4	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave and performance indicator fails, incinerator fails	1.47E+01	1.02E+07	7.01E+12	2.00E-19	5.00E-01	1.00E-03	9.00E-01	1.00E-03	9.00E-01	1.00E-22	9.00E-20	1.00E-22	9.00E-20
L4NTRs1	Necropsy	Transference (Respiratory, Suit Failure)	Suit is tested before entry. No exposure	7.46E-09	1.94E-05	1.34E+01	1.99E+01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTRs2	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry and suit does not leak. No exposure	7.46E-09	1.94E-05	1.34E+01	9.99E-02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTRs3	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and appropriate medical response	1.11E-06	2.89E-03	1.99E+03	9.90E-05	2.92E-01	1.00E-03	0.00E+00	1.00E-03	0.00E+00	2.89E-08	0.00E+00	2.89E-08	0.00E+00

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4NTRs4	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and failed medical response	1.11E-06	2.89E-03	1.99E+03	4.98E-07	2.92E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	1.31E-07	0.00E+00	1.45E-10	0.00E+00
L4NTRs5	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is not reported and no medical response	1.11E-06	2.89E-03	1.99E+03	5.00E-07	2.92E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	1.31E-07	0.00E+00	1.46E-10	0.00E+00
L4NT10	Necropsy	Transference (Injection)	Researcher does not cut through the PPE or does not cut through the skin barrier. No exposure.	0.00E+00	0.00E+00	0.00E+00	1.48E+04	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NT11	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is reported and appropriate medical response	6.26E-06	4.32E+00	2.98E+06	3.66E+01	4.98E-01	1.00E-03	0.00E+00	1.00E-03	0.00E+00	1.82E-02	0.00E+00	1.82E-02	0.00E+00
L4NT12	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is reported and failed medical response	6.26E-06	4.32E+00	2.98E+06	1.84E-01	4.98E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	8.25E-02	0.00E+00	9.17E-05	0.00E+00
L4NT13	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is not reported and no medical response	6.26E-06	4.32E+00	2.98E+06	1.85E-01	4.98E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	8.29E-02	0.00E+00	9.21E-05	0.00E+00
L4NTCp0	Necropsy	Transference (Contact, Palm)	Researcher does not cut their PPE suit and there is no contact transference event	0.00E+00	0.00E+00	0.00E+00	1.47E+04	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTCp1	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is reported, there is the appropriate medical response. Due to the appropriate medical response and researcher awareness of the exposure, there is a chemical spot treatment and 2 body showers prior to leaving containment.	2.56E-13	1.76E-07	1.22E-01	7.32E+01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTCp2	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is reported, there is a failed medical response. Due to the researcher awareness of the exposure, there is a chemical spot treatment and 2 body showers prior to leaving containment	2.56E-13	1.76E-07	1.22E-01	3.68E-01	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4NTCp3	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. All body showers (2) are performed prior to leaving containment.	2.56E-08	1.76E-02	1.22E+04	3.66E-01	1.48E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	4.88E-02	0.00E+00	5.42E-05	0.00E+00
L4NTCp4	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. 1/2 body showers are performed prior to leaving containment.	2.53E-07	1.75E-01	1.21E+05	3.68E-03	4.58E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	1.52E-03	0.00E+00	1.68E-06	0.00E+00
L4NTCp5	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. 0/2 body showers are performed prior to leaving containment.	2.51E-06	1.73E+00	1.19E+06	9.24E-06	4.96E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	4.12E-06	0.00E+00	4.58E-09	0.00E+00
L4NTCf1	Necropsy	Transference (Contact, Fomite)	Chemical shower, 3 dunk tank disinfections	1.57E-25	1.08E-19	7.46E-14	1.46E+02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTCf2	Necropsy	Transference (Contact, Fomite)	Chemical shower, 2/3 dunk tank disinfections	1.57E-20	1.08E-14	7.46E-09	2.20E+00	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTCf3	Necropsy	Transference (Contact, Fomite)	Chemical shower, 1/3 dunk tank disinfections	1.57E-15	1.08E-09	7.46E-04	1.10E-02	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTCf4	Necropsy	Transference (Contact, Fomite)	Chemical shower, 0/3 dunk tank disinfections	1.57E-10	1.08E-04	7.46E+01	1.85E-05	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTCf5	Necropsy	Transference (Contact, Fomite)	No chemical shower, 3 dunk tank disinfections	1.57E-20	1.08E-14	7.46E-09	1.46E-03	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTCf6	Necropsy	Transference (Contact, Fomite)	No chemical shower, 2/3 dunk tank disinfections	1.57E-15	1.08E-09	7.46E-04	2.20E-05	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event

Table 9.9.2-4: Probability of Infection and Frequency of Infection by Event

Event ID	Originating Location	Pathway	Description	Q Values			Frequency (F_{Loss}) (yr^{-1})	$P_i 1_Q$	$P_i 2_{Prox}$				Index Case Frequency (F_{Event})			
				Low	Medium	High			NiV		HeV		NiV		HeV	
									Human	Animal	Human	Animal	Human	Animal	Human	Animal
L4NTCf7	Necropsy	Transference (Contact, Fomite)	No chemical shower, 1/3 dunk tank disinfections	1.57E-10	1.08E-04	7.46E+01	1.10E-07	0.00E+00	--	--	--	--	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event
L4NTCf8	Necropsy	Transference (Contact, Fomite)	No chemical shower, 0/3 dunk tank disinfections	1.57E-05	1.08E+01	7.46E+06	1.85E-10	4.99E-01	9.00E-01	0.00E+00	1.00E-03	0.00E+00	8.31E-11	0.00E+00	9.24E-14	0.00E+00

9.9.2.2 *Relative Impact*

To estimate the relative impact of an outbreak, an impact ratio was developed that roughly accounted for and normalized against: the differences in impact between loss of a human life and loss of livestock (through application of an estimated value to each) and the differences in impact across the pathogens under consideration (NiV and HeV). Note that emerging pathogens were considered for completeness. However the outbreak impact of an emerging pathogen is unknown and therefore was qualitatively discussed at the end of this section.

To account for the differences in value between a human life and the life of livestock, the average number of human lives lost or animals culled reported in the historical case reviews (Section 9.9.1.1) were multiplied by the estimated value of a human life and the estimated value of livestock at auction. The estimated value of an adult human life (\$9.1 million) was determined by the EPA in 2010 during the performance of a regulatory impact analysis [EPA 452/R-10-002 February 2010]. For NiV outbreaks this resulted in an average relative impact of \$373,100,000 ($41 \times \$9,100,000 = \$373,100,000$) per outbreak. For HeV this resulted in an overall relative impact of \$2,093,000 ($0.23 \times \$9,100,000 = \$2,093,000$) per average outbreak.

Similarly, the average number of livestock infections and cullings reported for NiV and HeV outbreaks were multiplied by the current list price per lb of these commodities (USDA / Ag. Marketing Service - report LS-HG200 for swine reported \$67.59/cwt at 240 lbs each (\$162.22) and the Centennial Livestock Auction, Granby, CO 26 October 2011, cited up to \$21.50/cwt at 1400 lbs (\$301) for non high-performance horses. When averaged across all NiV outbreaks reported, this resulted in an average relative livestock impact of \$11,587,212 ($71,429 \times \$162.22 = \$11,587,212$) and for HeV this resulted in an average livestock relative impact of \$641.13 ($2.13 \times \$301 = 641.13$). Note that these are estimated impacts intended to provide a relative difference between the impact of a NiV outbreak and a HeV outbreak (as they are reportedly different) and is no way intended to indicate the absolute impact of either such an event should a release occur from the NBAF.

From these values, a relative impact score was calculated to convey relative impact across pathogen type, size of outbreak (single infection vs. multiple), and whether it impacted humans, animals or both. This was estimated by normalizing the impact values to that of a single HeV infected animal (\$301), i.e., all impact values were divided by \$301 to provide a relative scoring. The resulting scores are presented in Table 9.9.2-5, the inputs to which were described in the preceding paragraphs.

Table 9.9.2-5: Relative Impact Score Calculations

Description	Single or Average Outbreak	Species	Relative Impact Score ^a		Assumptions
			NiV	HeV	
Events unlikely to result in transmission beyond index case	Single Human or Animal	Human	30,233 (\$9.1M / \$301)	30,233 (\$9.1M / \$301)	Based on assumed relative impact of a single human or single animal infection per pathogen type
		Animal	0.54 (\$162 / \$301)	1 (\$301 / \$301)	
		Total	30,234	30,234	
Events likely to result in subsequent transmission beyond index case	Average Outbreak	Human	1,239,535 (\$373.1M / \$301)	6,953 (\$2.09M / \$301)	Based on average reported impact across documented NiV or HeV outbreaks – not specific to the NBAF
		Animal	38,496 (\$11.6M / \$301)	2.13 (\$641 / \$303)	
		Total	1,278,031	6,956	

The assumptions applied across the events in assigning these impact ratios are detailed in the following bullets:

- In general it was assumed that if the person was aware of the infection/exposure (as indicated by reporting it and receiving proper medical response), they would maintain proper contact precaution rules such that 1) workers would not come into contact with susceptible species for at least 3 days and that no transference to subsequent species would be observed (i.e., the probability unlikely) and 2) proper medical response including medical monitoring, limited contacts (contact precautions) proper PPE and contact precautions would be adhered to such that subsequent person to person transmission were *unlikely* (i.e., the relative impact score shown in the *Events unlikely to result in subsequent transmission* row of Table 9.9.2-5 applies).
- If the worker/animal was unaware of an exposure, or failed to report the incident or failed to receive proper medical response, the worker was considered less reliable in regards to following the contact precaution/quarantine rule and subsequent transmission potential considered *likely* (i.e., the relative impact score shown in the *Events likely to result in subsequent transmission* row of Table 9.9.2-5 applies).

- For events where there was a potential for initial animal infection (i.e., release along the solid, liquid or aerosol pathways); it was assumed likely that there would be subsequent animal-animal transference, given the large number of farms/stables and density of susceptible species (pigs, horses) in Manhattan, Kansas (i.e., the relative impact score shown in the *Events likely to result in subsequent transmission* row of Table 9.9.2-5 applies).

The described relative impact scores were applied to each event according to the assumptions detailed above by pathogen type (NiV and HeV) and host species (human and animal). These relative impact scores represent the relative consequence value (C) and were used in the calculation of risk described in Section 9.10 and presented within Table 9.10.1-1.

9.9.2.3 Special Consideration for Emerging Pathogens

As the NBAF will be the most current ABSL-4 containment facility of its type in the U.S., the NBAF will have a very significant role in evaluating and responding to emerging zoonotic disease threats in animals. Therefore it is important to at least begin the discussion of the potential impact of working with new or emerging pathogens to inform future operations. For emerging or unknown pathogens, previously recognized symptoms of illness may go unnoticed or misdiagnosed leading to prolonged time to quarantine, and unprotected exposures, both of which would likely increase the overall impact of an outbreak. Delayed recognition of HeV as the cause among sick horses (because they experienced neurologic symptoms rather than the normal and expected respiratory equine symptoms) was cited as one of the contributors to the human illnesses observed during the 2008 HeV outbreak [Playford, 2010].

Furthermore, emerging or genetically modified pathogens may exhibit a more efficient person-to-person transmission, a more efficient animal-to-person transmission, a greater resistance to antiviral therapy, resistance to countermeasures such as vaccination, or evade current diagnostic assays for proper and expedient diagnoses. Thus until such a time as these properties are better defined for the emerging/modified pathogens, one should conservatively assume a significant impact given any release of such a modified or emerging threat. Even if an exposure is known and reported – due to the fact that an emerging pathogen may possess unexpected characteristics (increased virulence, increased stability, increased transmission efficiency, increased potential to cross species barriers and be isolated from unexpected hosts ,etc.,) to err on the side of caution is prudent.

The probability of pathogen sustainment within the environment due to the presence of reservoir hosts (domestic or uncontrolled wildlife) is a concern for emerging pathogens and was considered in the NiV and HeV assessment. The only small or flying wildlife known to be hosts (reservoirs) to NiV or HeV are fruit bats - seroconversion and isolation of HeV and NiV-like viruses from fruit bats of the *Pteropus* genus have established this bat as the natural reservoir for both viruses [Bossart et al., 2007]. This genus of bat is geographically found in all locations where HeV and NiV outbreaks have occurred [Bossart et al., 2007]. Flying foxes have been found from Madagascar, India, Southeast Asia (including Malaysia and Singapore), Bangladesh, the East Indies, the Philippines, and Australia to the Samoan and Cook Islands [Constantine, 2003; Lehle, 2007]. A U.S. Geological Survey lists three species of flying foxes to have been found in the United States Pacific island territories [O'Shea et al., 2003], but no literature was found to

suggest that flying foxes are found anywhere in the U.S., including Manhattan, Kansas. As such, the relative impact ratio scores used in this ABSL-4 assessment may overestimate the impact at the NBAF – as the contribution of reservoir hosts to sustain the pathogen in the environment contributing to spillover events is represented in the average historical outbreaks used to develop the impact ratio at the NBAF. It is possible however, that Henipavirus will cross the species barrier to infect new hosts, such as bats or other mammals that do inhabit Kansas or the surrounding states. In such a case, the impact ratios applied in this assessment address this potentiality, as well as the potentiality that for emerging agents, reservoir host species may inhabit the Manhattan, Kansas area.

9.10 Risk Ranking, Conclusions and Recommendations:

In accordance with the DHS Risk Lexicon [September 2010] risk is determined by two key components: the *probability* of an unwanted incident, event, or occurrence, and the *consequence* of such an event. In this assessment, the consequence (C) is represented by a relative impact score, given that a loss-of-containment outcome is realized *and* an infection event ensues. The following describes the basic approach to performing the ABSL-4 risk calculations. The approach for the ABSL-4 assessment follows closely that which was performed for the FMDv assessment, with the exception that uncertainties were not quantitatively estimated in the ABSL-4 evaluation, and the consequence values were based on relative impacts and cannot be interpreted as expected absolute economic (or other metric) impact. Following the risk calculations, the risk associated with each event was ranked and associated conclusions and recommendations presented herein.

9.10.1 Risk Calculations and Risk Ranking

There are three parameters presented in Section 9.8 associated with each outcome in each fault tree that are relevant to the risk calculations:

- F_{loss} is the expected frequency of a given loss-of-containment outcome (i.e., event probability)³. The probability of each loss-of-containment outcome is computed based on the probabilities associated with each step in the sequence that leads to that outcome. This probability is multiplied by the number of opportunities per year, to obtain F_{loss} .
- Q represents the amount of NiV or HeV involved in each loss-of-containment outcome. Low, medium, and high Q terms are computed for each loss-of-containment outcome, and typically represent the 5th percentile, the mean, and the 95th percentiles of virus involved in the loss or release. These are referred to as Q_L , Q_M , and Q_H .
- In addition to the parameters above, two additional parameters associated with each outcome for each fault tree that are key to risk calculations include the following:
- P_i is the conditional probability that a given loss-of-containment outcome results in an infection (i.e., an index case). The approaches for estimating P_i varied by pathway, pathogen type and host

³ In some fault trees, one or more outcomes may be considered to be “no loss” outcomes. In order to be complete, all outcomes are included.

species (human or animal) as described previously in Section 9.9. For each event, a separate estimate for P_i was computed to indicate the probability that: 1) the Q source term was greater than or equal to the established infectious dose threshold; and 2) the probability that the release event occurred proximal to susceptible species. The resulting conditional probabilities are listed as: P_{i-1Q} , and $P_{i-2Proximal}$ respectively. P_i is the product of these two terms for a given pathogen and host species.

- C is the relative consequence by pathogen (NiV and HeV), given that the loss-of-containment outcome is realized *and* an infection (of either human or animal) ensues. For this assessment, C is taken to be equal to the relative impact score presented in Section 9.9.2.2. Note that if the conditional probability of an infection for a given loss-of-containment event was zero, the corresponding consequence was not modeled and the corresponding C terms were set equal to “no inf. event” (i.e., no infection event).

These parameters were used to compute the risk for each event and pathogen as the sum of the expected impact for an animal host plus the expected impact for a human host, minus the expected impact of a simultaneous human and animal infection. The equation applied is shown below:

$$Risk = F_{loss}(P_i C)_{Human} + F_{loss}(P_i C)_{Animal} - F_{loss}(P_i)_{Human}(P_i)_{Animal} \cdot (C_{Human} + C_{Animal})$$

Equation 9.10.1-1

The result of these risk calculations performed for all of the ABSL-4 events assessed as well as a description of each event are presented in Table 9.10.1-1. This table includes the calculated frequency of a loss-of-containment event (F_{loss}) per year, the index case frequency (F_{event}) by pathogen type and host species, the impact score (C) by pathogen type and host species, and risk by pathogen. Events in which the Q_H term did not exceed the infectious dose threshold were indicated by a “no infection event” entry within the Index Case Frequency column; and no further calculations performed. All of these events resulted in a final risk ranking of “no infection event.” All event frequencies were included; meaning even those event frequencies occurring less than one time per one billion years (and beyond) are presented for completeness. However, practically, these events are not considered credible and therefore were not prioritized for additional mitigation recommendations. The data in Table 9.10.1-1 are presented according to originating location and pathway, in order of events assessed; no data sorting (e.g., highest to lowest risk) was performed.

Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4AAi0	AHR	Aerosol (Inoculum)	Sedation works or squeeze chute works or no dropped inoculum or container works. No inoculum released	1.48E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi1	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; all 4 HEPA filters normal	3.48E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi2	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; three filters are normal, 1 filter is degraded	2.12E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi3	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; both filters in one column are normal while both filters in the other column are degraded	1.62E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi4	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one filters in each column is normal, one filters in each column is degraded	3.23E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi5	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; three filters are degraded, 1 filter is normal	4.92E-10	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi6	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; all 4 filters are degraded	1.87E-12	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi7	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one column fails (but at least one alarm works) while both filters in the other column are normal	1.44E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi8	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one column fails (but at least one alarm works) while in the other column one filter is normal and one filter is degraded	4.37E-10	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi9	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one column fails (but at least one alarm works) while both filters in the other column are degraded	3.33E-12	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi10	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; total HEPA failure	3.70E-39	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA1	AHR	Aerosol	All 4 filters are normal	5.53E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA2	AHR	Aerosol	Three filters are normal, 1 filter is degraded	3.37E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4AA3	AHR	Aerosol	Both filters in one column are normal while both filters in the other column are degraded	2.57E-01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA4	AHR	Aerosol	One filters in each column is normal, one filters in each column is degraded	5.13E-01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA5	AHR	Aerosol	Three filters are degraded, 1 filter is normal	7.82E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA6	AHR	Aerosol	All 4 filters are degraded	2.98E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA7	AHR	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are normal	2.28E-01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA8	AHR	Aerosol	One column fails (but at least one alarm works) while in the other column one filter is normal and one filter is degraded	6.95E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA9	AHR	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are degraded	5.29E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA10	AHR	Aerosol	Total HEPA failure	5.88E-32	2.63E-32	2.63E-32	2.63E-32	2.63E-32	1.24E+06	3.85E+04	6.95E+03	2.13E+00	3.356E-27	1.826E-28
L4AL1	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment works	2.77E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL2	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment fails	2.77E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL3	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment works	2.77E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL4	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment fails	2.77E-13	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL5	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment works	1.72E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL6	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment fails	1.72E-04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL7	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance	1.72E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4AL8	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment fails	1.72E-14	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS1	AHR	Solid Waste	Autoclave #1 works, Autoclave #2 works, Incinerator works	2.94E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS2	AHR	Solid Waste	Autoclave #1 works, Autoclave #2 works, Incinerator fails	2.94E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS3	AHR	Solid Waste	One of two autoclaves fail, Incinerator works	5.88E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS4	AHR	Solid Waste	One of two autoclaves fail, Incinerator fails	5.88E-13	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS5	AHR	Solid Waste	Both autoclaves fail, Incinerator works	2.94E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS6	AHR	Solid Waste	Both autoclaves fail, Incinerator fails	2.94E-18	2.62E-21	2.36E-18	2.62E-21	2.36E-18	1.24E+06	3.85E+04	6.95E+03	2.13E+00	9.109E-14	2.326E-17
L4ATi0	AHR	Transference (Injection, Inoculation)	Sedation works or squeeze chute works or PPE works or no stabbing through skin. No inoculum injected.	1.48E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATi1	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure reported and appropriate medical response	1.83E-04	9.15E-08	0.00E+00	9.15E-08	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	2.767E-03	2.767E-03
L4ATi2	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure reported and failed medical response	9.20E-07	4.14E-07	0.00E+00	4.60E-10	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.131E-01	3.198E-06
L4ATi3	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure not reported; no medical response	9.25E-07	4.16E-07	0.00E+00	4.62E-10	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.157E-01	3.214E-06
L4ATR0	AHR	Transference (Respiratory)	Squeeze chute works or penning works or suit is not cut or hose is not entangled. No respiratory exposure	1.41E+04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATR1	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is reported and appropriate medical response	1.75E-03	8.68E-07	0.00E+00	8.68E-07	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	2.623E-02	2.623E-02

Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4ATR2	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is reported and failed medical response	8.78E-06	3.92E-06	0.00E+00	4.36E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	4.864E+00	3.032E-05
L4ATR3	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is not reported; no medical response	8.82E-06	3.94E-06	0.00E+00	4.38E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	4.889E+00	3.047E-05
L4AT10	AHR	Transference (Injection)	Squeeze chute works or penning works or suit is not cut by animals or skin barrier is not broken. No laboratory injection	1.41E+04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AT11	AHR	Transference (Injection)	Squeeze chute failure, penning failure, rogue animal cuts, kicks, bites through PPE suit and through skin barrier. Injection exposure is reported and appropriate medical response	1.75E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AT12	AHR	Transference (Injection)	Squeeze chute failure, penning failure, rogue animal cuts, kicks, bites through PPE suit and through skin barrier. Injection exposure is reported and failed medical response	8.78E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AT13	AHR	Transference (Injection)	Squeeze chute failure, penning failure, rogue animal cuts, kicks, bites through PPE suit and through skin barrier. Injection exposure is not reported and no medical response	8.82E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATRs1	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is not torn during movement in ABSL-4 AHR.	2.91E+03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATRs2	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is not torn during movement in ABSL-4 AHR.	1.46E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATRs3	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and appropriate medical response	1.45E+01	1.84E-03	0.00E+00	1.84E-03	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	5.556E+01	5.556E+01
L4ATRs4	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and failed medical response	7.28E-02	8.31E-03	0.00E+00	9.24E-06	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.030E+04	6.422E-02

Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4ATRs5	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is not reported and no medical response	7.31E-02	8.35E-03	0.00E+00	9.28E-06	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.035E+04	6.454E-02
L4ATRs6	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and appropriate medical response	7.27E-02	9.23E-06	0.00E+00	9.23E-06	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	2.789E-01	2.789E-01
L4ATRs7	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and failed medical response	3.65E-04	4.17E-05	0.00E+00	4.64E-08	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.172E+01	3.224E-04
L4ATRs8	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is not reported and no medical response	3.67E-04	4.19E-05	0.00E+00	4.66E-08	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.198E+01	3.240E-04
L4ATRs9	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and appropriate medical response	1.46E-02	1.85E-06	0.00E+00	1.85E-06	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	5.584E-02	5.584E-02
L4ATRs10	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and failed medical response	7.31E-05	8.35E-06	0.00E+00	9.28E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.035E+01	6.454E-05
L4ATRs11	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is not reported and no medical response	7.35E-05	8.40E-06	0.00E+00	9.33E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.041E+01	6.487E-05
L4NA1	Necropsy	Aerosol	All 4 filters are normal	4.72E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA2	Necropsy	Aerosol	Three filters are normal, 1 filter is degraded	2.87E+00	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA3	Necropsy	Aerosol	Both filters in one column are normal while both filters in the other column are degraded	2.19E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA4	Necropsy	Aerosol	One filters in each column is normal, one filters in each column is degraded	4.38E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4NA5	Necropsy	Aerosol	Three filters are degraded, 1 filter is normal	6.67E-04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA6	Necropsy	Aerosol	All 4 filters are degraded	2.54E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA7	Necropsy	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are normal	1.95E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA8	Necropsy	Aerosol	One column fails (but at least one alarm works) while in the other column one filter is normal and one filter is degraded	5.92E-04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA9	Necropsy	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are degraded	4.51E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA10	Necropsy	Aerosol	Total HEPA failure	5.01E-33	2.20E-33	2.20E-33	2.20E-33	2.20E-33	1.24E+06	3.85E+04	6.95E+03	2.13E+00	2.811E-28	1.530E-29
L4NL1	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment works	4.74E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL2	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment fails	4.74E-04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL3	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment works	4.74E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL4	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment fails	4.74E-14	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL5	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment works	2.69E+00	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL6	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment fails	2.69E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL7	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment works	2.69E-10	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL8	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment fails	2.69E-15	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NSW1	Necropsy	Solid Waste (Red)	Autoclave #1 works, Autoclave #2 works, Incinerator works	5.01E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4NSW2	Necropsy	Solid Waste (Red Bag)	Autoclave #1 works, Autoclave #2 works, Incinerator fails	5.01E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NSW3	Necropsy	Solid Waste (Red Bag)	One of two autoclaves fail, Incinerator works	1.00E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NSW4	Necropsy	Solid Waste (Red Bag)	One of two autoclaves fail, Incinerator fails	1.00E-13	1.47E-17	1.33E-14	1.47E-17	1.33E-14	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.120E-10	1.307E-13
L4NSW5	Necropsy	Solid Waste (Red Bag)	Both autoclaves fail, Incinerator works	5.01E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NSW6	Necropsy	Solid Waste (Red Bag)	Both autoclaves fail, Incinerator fails	5.01E-19	2.51E-22	2.26E-19	2.51E-22	2.26E-19	1.24E+06	3.85E+04	6.95E+03	2.13E+00	8.707E-15	2.224E-18
L4NST1	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave or performance indicator works, incinerator works	2.00E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NST2	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave or performance indicator works, incinerator fails	2.00E-09	9.17E-13	8.25E-10	9.17E-13	8.25E-10	1.24E+06	3.85E+04	6.95E+03	2.13E+00	3.184E-05	8.131E-09
L4NST3	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave and performance indicator fails, incinerator works	2.00E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NST4	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave and performance indicator fails, incinerator fails	2.00E-19	1.00E-22	9.00E-20	1.00E-22	9.00E-20	1.24E+06	3.85E+04	6.95E+03	2.13E+00	3.474E-15	8.871E-19
L4NTRs1	Necropsy	Transference (Respiratory, Suit Failure)	Suit is tested before entry. No exposure	1.99E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTRs2	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry and suit does not leak. No exposure	9.99E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTRs3	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and appropriate medical response	9.90E-05	2.89E-08	0.00E+00	2.89E-08	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	8.742E-04	8.742E-04

Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4NTRs4	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and failed medical response	4.98E-07	1.31E-07	0.00E+00	1.45E-10	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.621E-01	1.010E-06
L4NTRs5	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is not reported and no medical response	5.00E-07	1.31E-07	0.00E+00	1.46E-10	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.629E-01	1.015E-06
L4NTI0	Necropsy	Transference (Injection)	Researcher does not cut through the PPE or does not cut through the skin barrier. No exposure.	1.48E+04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTI1	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is reported and appropriate medical response	3.66E+01	1.82E-02	0.00E+00	1.82E-02	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	5.514E+02	5.514E+02
L4NTI2	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is reported and failed medical response	1.84E-01	8.25E-02	0.00E+00	9.17E-05	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.023E+05	6.373E-01
L4NTI3	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is not reported and no medical response	1.85E-01	8.29E-02	0.00E+00	9.21E-05	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.028E+05	6.406E-01
L4NTCp0	Necropsy	Transference (Contact, Palm)	Researcher does not cut their PPE suit and there is no contact transference event	1.47E+04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCp1	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is reported, there is the appropriate medical response. Due to the appropriate medical response and researcher awareness of the exposure, there is a chemical spot treatment and 2 body showers prior to leaving containment.	7.32E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCp2	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is reported, there is a failed medical response. Due to the researcher awareness of the exposure, there is a chemical spot treatment and 2 body showers prior to leaving containment	3.68E-01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCp3	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. All body showers (2) are performed prior to leaving containment.	3.66E-01	4.88E-02	0.00E+00	5.42E-05	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	6.049E+04	3.771E-01

Table 9.10.1-1: Frequency of Infection, Impact, and Risk by Event

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4NTCp4	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. 1/2 body showers are performed prior to leaving containment.	3.68E-03	1.52E-03	0.00E+00	1.68E-06	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.880E+03	1.172E-02
L4NTCp5	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. 0/2 body showers are performed prior to leaving containment.	9.24E-06	4.12E-06	0.00E+00	4.58E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.112E+00	3.186E-05
L4NTCf1	Necropsy	Transference (Contact, Fomite)	Chemical shower, 3 dunk tank disinfections	1.46E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf2	Necropsy	Transference (Contact, Fomite)	Chemical shower, 2/3 dunk tank disinfections	2.20E+00	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf3	Necropsy	Transference (Contact, Fomite)	Chemical shower, 1/3 dunk tank disinfections	1.10E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf4	Necropsy	Transference (Contact, Fomite)	Chemical shower, 0/3 dunk tank disinfections	1.85E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf5	Necropsy	Transference (Contact, Fomite)	No chemical shower, 3 dunk tank disinfections	1.46E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf6	Necropsy	Transference (Contact, Fomite)	No chemical shower, 2/3 dunk tank disinfections	2.20E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf7	Necropsy	Transference (Contact, Fomite)	No chemical shower, 1/3 dunk tank disinfections	1.10E-07	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf8	Necropsy	Transference (Contact, Fomite)	No chemical shower, 0/3 dunk tank disinfections	1.85E-10	8.31E-11	0.00E+00	9.24E-14	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.031E-04	6.423E-10

It is important to stress that the risk presented in Table 9.10.1-1 is an estimated risk and should not be mistaken for absolute risk. At this stage in the NBAF development, and with the maturity of available data for NiV and HeV, a risk ranking is appropriate and offers a means by which to identify areas of focus for DHS in regards to additional operational, design, or mitigation strategies. Furthermore, the event analyses alone, which estimated the frequency of accidental releases for each event (F_{loss}), provide valuable information. Understanding the failures that can lead to a release are as critical, if not more so than estimating the impact, in regards to the identification of relevant strategies to prevent their occurrence. The impact analyses, although based on historical data, comes with a level of uncertainty given the outbreaks reported have occurred in nations with grossly different farming and medical practices than what exists at and around the NBAF. However, the impact analyses performed do provide a means of ranking the estimated risk of the ABSL-4 events such that DHS can begin prioritizing efforts on the events that exhibit the most significant risk and/or occur with the greatest frequency. As more data for NiV, HeV, and/or emerging pathogens become available, the event and impact analyses performed herein can easily be adapted to accommodate updated source terms, probabilities of infection, and impact estimates. The following section presents the conclusions and recommendations resulting from the further analysis of the data presented in Table 9.10.1-1.

9.10.2 Conclusions and Recommendations

The conclusions regarding risk from release of pathogen from the ABSL-4 along the aerosol, solid, liquid and transference pathways are presented in the following text and corresponding tables and figures.

Regarding the aerosol pathway, no infection events resulted from any of the aerosol events generated through the loss of NiV or HeV material during animal inoculation activities (represented by events L4AAi0-L4AAi9 of Table 9.10.2-1). Furthermore, no infection events resulted from any of the aerosol release events generated from ABSL-4 AHR or necropsy due to pathogen contributions from the animals themselves (within AHRs), or through aerosolization of pathogen during necropsy activities when the HEPA filtration system was functioning nominally, or when it was degraded under any of the potential permutations of degradation (events L4AA1-L4AA9 for AHR and L4AN1-L4AN9 for necropsy, as shown in Table 9.10.2-2).

Only two aerosol events out of the 30 evaluated resulted in any risk, namely L4AA10 and L4AN10, which represent a total failure of the HEPA filtration caisson in ABSL-4 AHR and ABSL-4 necropsy respectively. For completeness, total HEPA failure had to be evaluated in the event analysis. However, the frequency of total HEPA failure given the redundancy of the HEPA caisson system in place at the NBAF, make these two extremely unlikely events (loss-of-containment frequencies of $6 \times 10^{-32} \text{ yr}^{-1}$ and $5 \times 10^{-33} \text{ yr}^{-1}$) with corresponding risk values approaching zero (ranging from 1.5×10^{-29} to 3.4×10^{-27}). As such, these events are considered “not credible” events. The observation that no aerosol events considered resulted in any credible risk ranking is noteworthy in that it is reflective of the sentiments of the containment community expressed during the 14 September 2011 NAS meeting and again during the 08 November 2011 ABSL-4 Assessment SME solicitation meeting. While participants suggested that containment facilities have great confidence in HEPA filtration, and although it was agreed that for completeness, that all pathways of release must be considered, the panel did not expect aerosol release events via the

HEPA filtration system to represent a significant risk regarding ABSL-4 activities. ***The risk mitigation of redundant in-series and in-parallel HEPA filtration caissons planned within the NBAF 65% Design appears to provide significant protection against release along this pathway from ABSL-4 AHR and necropsy rooms.***

Table 9.10.2-1: Frequency of Infection, Impact, and Risk by Aerosol (Dropped Inoculum) Pathway (Sorted by NiV Risk, Low to High)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4AAi0	AHR	Aerosol (Inoculum)	Sedation works or squeeze chute works or no dropped inoculum or container works. No inoculum released	1.48E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi1	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; all 4 HEPA filters normal	3.48E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi2	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; three filters are normal, 1 filter is degraded	2.12E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi3	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; both filters in one column are normal while both filters in the other column are degraded	1.62E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi4	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one filters in each column is normal, one filters in each column is degraded	3.23E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi5	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; three filters are degraded, 1 filter is normal	4.92E-10	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi6	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; all 4 filters are degraded	1.87E-12	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi7	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one column fails (but at least one alarm works) while both filters in the other column are normal	1.44E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi8	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one column fails (but at least one alarm works) while in the other column one filter is normal and one filter is degraded	4.37E-10	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi9	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; one column fails (but at least one alarm works) while both filters in the other column are degraded	3.33E-12	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AAi10	AHR	Aerosol (Inoculum)	Sedation failure, squeeze chute failure, dropped inoculum, container failure; total HEPA failure	3.70E-39	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Table 9.10.2-2: Frequency of Infection, Impact, and Risk by Aerosol Pathway (Sorted by NiV Risk, Low to High)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4AA10	AHR	Aerosol	Total HEPA failure	5.88E-32	2.63E-32	2.63E-32	2.63E-32	2.63E-32	1.24E+06	3.85E+04	6.95E+03	2.13E+00	3.36E-27	1.83E-28
L4NA10	Necropsy	Aerosol	Total HEPA failure	5.01E-33	2.20E-33	2.20E-33	2.20E-33	2.20E-33	1.24E+06	3.85E+04	6.95E+03	2.13E+00	2.81E-28	1.53E-29
L4AA1	AHR	Aerosol	All 4 filters are normal	5.53E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA2	AHR	Aerosol	Three filters are normal, 1 filter is degraded	3.37E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA3	AHR	Aerosol	Both filters in one column are normal while both filters in the other column are degraded	2.57E-01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA4	AHR	Aerosol	One filters in each column is normal, one filters in each column is degraded	5.13E-01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA5	AHR	Aerosol	Three filters are degraded, 1 filter is normal	7.82E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA6	AHR	Aerosol	All 4 filters are degraded	2.98E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA7	AHR	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are normal	2.28E-01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA8	AHR	Aerosol	One column fails (but at least one alarm works) while in the other column one filter is normal and one filter is degraded	6.95E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AA9	AHR	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are degraded	5.29E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA1	Necropsy	Aerosol	All 4 filters are normal	4.72E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA2	Necropsy	Aerosol	Three filters are normal, 1 filter is degraded	2.87E+00	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA3	Necropsy	Aerosol	Both filters in one column are normal while both filters in the other column are degraded	2.19E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Table 9.10.2-2: Frequency of Infection, Impact, and Risk by Aerosol Pathway (Sorted by NiV Risk, Low to High)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4NA4	Necropsy	Aerosol	One filters in each column is normal, one filters in each column is degraded	4.38E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA5	Necropsy	Aerosol	Three filters are degraded, 1 filter is normal	6.67E-04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA6	Necropsy	Aerosol	All 4 filters are degraded	2.54E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA7	Necropsy	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are normal	1.95E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA8	Necropsy	Aerosol	One column fails (but at least one alarm works) while in the other column one filter is normal and one filter is degraded	5.92E-04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NA9	Necropsy	Aerosol	One column fails (but at least one alarm works) while both filters in the other column are degraded	4.51E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Similarly, no infections (and thus no risk) were observed through assessment of the Liquid Waste Pathway from either ABSL-4 AHR or ABSL-4 necropsy as presented in Table 9.10.2-3. None of the 18 liquid waste events evaluated resulted in an observable risk, suggesting that ***the NBAF planned in-facility effluent decontamination systems offer risk mitigation in regards to working with large animals in BSL-4 containment.***

The majority of the solid waste pathway events (11 out of 16) regardless of originating location (ABSL-4 AHR or necropsy) resulted in no infection events (see Table 9.10.2-4). The five solid waste events that resulted in a risk value only occurred when the on-site incinerator failed – in all cases where the incinerator was functional, regardless of functioning redundant autoclaves or tissue autoclave, the incineration alone was sufficient to reduce the quantity of infectious material to levels below the infectious dose threshold eliminating any resulting infections. When the incinerator failed and the in-series autoclaves were functional (event L4AS2), the in-series autoclaves were sufficient at reducing the risk from red-bagged autoclaved waste. (It should be noted that this event is not applicable to carcass disposal). ***As long as either the incinerator (for carcass rendering solid waste disposal or red bag waste disposal) OR the in-series autoclaves are functional (applicable to red bag waste disposal only), the solid waste pathway does not appear to pose observable risk.*** Of the solid waste pathway events that had observable risk, the greatest risk was observed when the tissue autoclave from ABSL-4 necropsy was functioning, yet the incinerator failed. This risk is reflective of the large viral load and sheer mass of material considered in the disposal of infected carcasses (as compared to standard red-bag solid waste). It is also notable that the frequency of release or F_{Loss} for the 5 solid waste events with observable risk ranged from $2.0 \times 10^{-9} \text{ yr}^{-1}$ to $2.0 \times 10^{-19} \text{ yr}^{-1}$ or less than once every 500 million years.

Table 9.10.2-3: Frequency of Infection, Impact, and Risk by Liquid Waste Pathway (Sorted by NiV Risk, Low to High)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4AL1	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment works	2.77E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL2	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment fails	2.77E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL3	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment works	2.77E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL4	AHR	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment fails	2.77E-13	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL5	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment works	1.72E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL6	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment fails	1.72E-04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL7	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment works	1.72E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AL8	AHR	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment fails	1.72E-14	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL1	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment works	4.74E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL2	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank works, wastewater treatment fails	4.74E-04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL3	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment works	4.74E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL4	Necropsy	Liquid Waste	Source decontamination of drain pipes works, cook tank fails and performance indicator fails, wastewater treatment fails	4.74E-14	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL5	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment works	2.69E+00	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL6	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank works, wastewater treatment fails	2.69E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL7	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment works	2.69E-10	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NL8	Necropsy	Liquid Waste	Source decontamination of drain pipes fails, cook tank fails and performance indicator fails, wastewater treatment fails	2.69E-15	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Table 9.10.2-4: Frequency of Infection, Impact, and Risk by Solid Waste Pathway (Sorted by NiV Risk, Low to High)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4NST2	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave or performance indicator works, incinerator fails	2.00E-09	9.17E-13	8.25E-10	9.17E-13	8.25E-10	1.24E+06	3.85E+04	6.95E+03	2.13E+00	3.18E-05	8.13E-09
L4NSW4	Necropsy	Solid Waste (Red Bag)	One of two autoclaves fail, Incinerator fails	1.00E-13	1.47E-17	1.33E-14	1.47E-17	1.33E-14	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.12E-10	1.31E-13
L4AS6	AHR	Solid Waste (Red Bag)	Both autoclaves fail, Incinerator fails	2.94E-18	2.62E-21	2.36E-18	2.62E-21	2.36E-18	1.24E+06	3.85E+04	6.95E+03	2.13E+00	9.11E-14	2.33E-17
L4NSW6	Necropsy	Solid Waste (Red Bag)	Both autoclaves fail, Incinerator fails	5.01E-19	2.51E-22	2.26E-19	2.51E-22	2.26E-19	1.24E+06	3.85E+04	6.95E+03	2.13E+00	8.71E-15	2.22E-18
L4NST4	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave and performance indicator fails, incinerator fails	2.00E-19	1.00E-22	9.00E-20	1.00E-22	9.00E-20	1.24E+06	3.85E+04	6.95E+03	2.13E+00	3.47E-15	8.87E-19
L4AS1	AHR	Solid Waste (Red Bag)	Autoclave #1 works, Autoclave #2 works, Incinerator works	2.94E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS2	AHR	Solid Waste (Red Bag)	Autoclave #1 works, Autoclave #2 works, Incinerator fails	2.94E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS3	AHR	Solid Waste (Red Bag)	One of two autoclaves fail, Incinerator works	5.88E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS4	AHR	Solid Waste (Red Bag)	One of two autoclaves, Incinerator fails	5.88E-13	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4AS5	AHR	Solid Waste (Red Bag)	Both autoclaves fail, Incinerator works	2.94E-08	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NSW1	Necropsy	Solid Waste (Red Bag)	Autoclave #1 works, Autoclave #2 works, Incinerator works	5.01E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NSW2	Necropsy	Solid Waste (Red Bag)	Autoclave #1 works, Autoclave #2 works, Incinerator fails	5.01E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NSW3	Necropsy	Solid Waste (Red Bag)	One of two autoclaves fail, Incinerator works	1.00E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NSW5	Necropsy	Solid Waste (Red Bag)	Both autoclaves fail, Incinerator works	5.01E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NST1	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave or performance indicator works, incinerator works	2.00E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NST3	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave and performance indicator fails, incinerator works	2.00E-09	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

The transference pathway represented the greatest associated risk across all of the ABSL-4 release pathways considered.

The transference-injection pathway contained the highest ranked risk events for NiV and HeV observed across all 109 events evaluated (see Table 9.10.2-5, events L4NTI1, L4NTI3 and L4NTI2). The events demonstrating the highest risk values originated within the ABSL-4 necropsy room in which a researcher cut their PPE during a standard necropsy procedure resulting in a breach of the skin barrier with a (NiV or HeV) contaminated scalpel and did not receive the appropriate medical response (i.e., medical monitoring, reducing contact, or adhering to barrier practices to prevent subsequent transmission to other people). [Note that in these events the researcher did not either report the event or receive the proper medical response – both of which are in violation of standard protocols.] Three other transference-injection events also resulted in observable risk – events L4ATli1, L4ATli3 and L4ATli2. These events originated in the AHR during inoculation of study animals and resulted in lower observed risk values compared to the transference-injection events originating from the necropsy room. This observation is consistent with containment community SME feedback that indicated sharps handling errors during necropsy procedures were of concern.

For both pathogens, the transference-respiratory suit failures that lead to respiratory exposure of the researchers working within the AHR were among the highest risk events as evident by the risk value assigned to events L4ATRs3, L4ATRs5, L4ATRs4, L4ATRs6 and L4ATRs9 (Table 9.10.2-6). The observed risk in these events was attributed to degradation of the encapsulated suit respiratory protection (due to a tear/leak) coupled with exposure to potentially significant amounts of aerosolized pathogen being generated by the infected animals within the AHR. [Note that the observed risk for similar sequence of events in the necropsy room was significantly less.] In all of the transference-respiratory events evaluated (originating from the AHR or necropsy) where PPE function was nominal, no infection events were observed (thus no risk). ***These observations indicate that practice of and conformance to procedures to maintain, frequently evaluate, and verify respiratory PPE performance as well as minimize movements in AHRs to prevent suit tears may reduce the risk of respiratory exposures.***

Table 9.10.2-5 Frequency of Infection, Impact, and Risk by Transference Injection Pathway (Sorted by NiV Risk, Low to High)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4NTI3	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is not reported and no medical response	1.85E-01	8.29E-02	0.00E+00	9.21E-05	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.03E+05	6.41E-01
L4NTI2	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is reported and failed medical response	1.84E-01	8.25E-02	0.00E+00	9.17E-05	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.02E+05	6.37E-01
L4NTI1	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is reported and appropriate medical response	3.66E+01	1.82E-02	0.00E+00	1.82E-02	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	5.51E+02	5.51E+02
L4ATI3	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure not reported; no medical response	9.25E-07	4.16E-07	0.00E+00	4.62E-10	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.16E-01	3.21E-06
L4ATI2	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure reported and failed medical response	9.20E-07	4.14E-07	0.00E+00	4.60E-10	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.13E-01	3.20E-06
L4ATI1	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure reported and appropriate medical response	1.83E-04	9.15E-08	0.00E+00	9.15E-08	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	2.77E-03	2.77E-03
L4ATI0	AHR	Transference (Injection, Inoculation)	Sedation works or squeeze chute works or PPE works or no stabbing through skin. No inoculum injected.	1.48E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATI0	AHR	Transference (Injection)	Squeeze chute works or penning works or suit is not cut by animals or skin barrier is not broken. No laboratory injection	1.41E+04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATI1	AHR	Transference (Injection)	Squeeze chute failure, penning failure, rogue animal cuts, kicks, bites through PPE suit and through skin barrier. Injection exposure is reported and appropriate medical response	1.75E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATI2	AHR	Transference (Injection)	Squeeze chute failure, penning failure, rogue animal cuts, kicks, bites through PPE suit and through skin barrier. Injection exposure is reported and failed medical response	8.78E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATI3	AHR	Transference (Injection)	Squeeze chute failure, penning failure, rogue animal cuts, kicks, bites through PPE suit and through skin barrier. Injection exposure is not reported and no medical response	8.82E-06	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTI0	Necropsy	Transference (Injection)	Researcher does not cut through the PPE or does not cut through the skin barrier. No exposure.	1.48E+04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Table 9.10.2-6: Frequency of Infection, Impact, and Risk by Transference Respiratory Pathway (Sorted by NiV Risk, Low to High)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4ATRs5	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is not reported and no medical response	7.31E-02	8.35E-03	0.00E+00	9.28E-06	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.04E+04	6.45E-02
L4ATRs4	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and failed medical response	7.28E-02	8.31E-03	0.00E+00	9.24E-06	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.03E+04	6.42E-02
L4ATRs3	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and appropriate medical response	1.45E+01	1.84E-03	0.00E+00	1.84E-03	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	5.56E+01	5.56E+01
L4ATRs8	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is not reported and no medical response	3.67E-04	4.19E-05	0.00E+00	4.66E-08	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.20E+01	3.24E-04
L4ATRs7	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and failed medical response	3.65E-04	4.17E-05	0.00E+00	4.64E-08	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.17E+01	3.22E-04
L4ATRs11	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is not reported and no medical response	7.35E-05	8.40E-06	0.00E+00	9.33E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.04E+01	6.49E-05
L4ATRs10	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and failed medical response	7.31E-05	8.35E-06	0.00E+00	9.28E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.04E+01	6.45E-05
L4ATR3	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is not reported; no medical response	8.82E-06	3.94E-06	0.00E+00	4.38E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	4.89E+00	3.05E-05
L4ATR2	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is reported and failed medical response	8.78E-06	3.92E-06	0.00E+00	4.36E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	4.86E+00	3.03E-05
L4ATRs6	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and appropriate medical response	7.27E-02	9.23E-06	0.00E+00	9.23E-06	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	2.79E-01	2.79E-01
L4NTRs5	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is not reported and no medical response	5.00E-07	1.31E-07	0.00E+00	1.46E-10	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.63E-01	1.02E-06

Table 9.10.2-6: Frequency of Infection, Impact, and Risk by Transference Respiratory Pathway (Sorted by NiV Risk, Low to High)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4NTRs4	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and failed medical response	4.98E-07	1.31E-07	0.00E+00	1.45E-10	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.62E-01	1.01E-06
L4ATRs9	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and appropriate medical response	1.46E-02	1.85E-06	0.00E+00	1.85E-06	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	5.58E-02	5.58E-02
L4ATR1	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is reported and appropriate medical response	1.75E-03	8.68E-07	0.00E+00	8.68E-07	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	2.62E-02	2.62E-02
L4NTRs3	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and appropriate medical response	9.90E-05	2.89E-08	0.00E+00	2.89E-08	0.00E+00	3.02E+04	5.40E-01	3.02E+04	1.00E+00	8.74E-04	8.74E-04
L4ATRO	AHR	Transference (Respiratory)	Squeeze chute works or penning works or suit is not cut or hose is not entangled. No respiratory exposure	1.41E+04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATRs1	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is not torn during movement in ABSL-4 AHR.	2.91E+03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTRs1	Necropsy	Transference (Respiratory, Suit Failure)	Suit is tested before entry. No exposure	1.99E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4ATRs2	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is not torn during movement in ABSL-4 AHR.	1.46E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTRs2	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry and suit does not leak. No exposure	9.99E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

Several transference-contact pathway events were evaluated and the majority of these events (10 out of 14) resulted in no observable risk (see Table 9.10.2-7). Two transference-contact circumstances were considered along this pathway. The first contact pathway involves the transfer of infectious material to the surface of a researcher's hand (palm) during a necropsy event in which a breach in PPE occurred. (It was assumed in these contact events that the infectious material could result in an infection through unnoticed minor cuts/abrasions of the researcher's hand, or secondary transfer to researcher's mucous membranes if the material was not sufficiently removed via spot disinfection.) The second contact pathway involves the transfer of infectious material to a fomite (i.e., the outside of a sample container that is taken out of containment). Regarding these two types of transference-contact events, the only events that resulted in observable risk were those where the researcher either: 1) failed to recognize the exposure and thereby did not treat the contamination through proper disinfection at the site of the exposure (hand) such as in events L4NTCp3, L4NTCp4, and L4NTCp5; or 2) completely failed to process the sample container through the required decontamination steps for shipment of a sample out of the facility including a chemical shower, followed by the equivalent of three dunk tank disinfections (event L4NTCf8). The frequency associated with the failure to decontaminate the fomite (sample container) was extremely low (1.85×10^{-10}), or once every 5.4 billion years, indicating this is not likely a credible event. However, the risk observed when the contact occurred with the researcher's hand and no subsequent spot treatment with a chemical disinfectant was applied, as demonstrated by event number L4NTCp3, was significant, especially when working with NiV (risk value of 6.05×10^4 for NiV and 3.77×10^{-1} for HeV). ***These events indicate that immediate decontamination of potentially exposed skin using SOPs may effectively mitigate the risks of these exposures and that adequate and continued training of this practice should be enforced at the NBAF.***

Table 9.10.2-7: Frequency of Infection, Impact, and Risk by Transference Contact Pathway (Sorted by NiV Risk, High to Low)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Index Case Frequency (F_{Event})				Impact Ratio (C)				Risk	
					NiV		HeV		NiV		HeV		NiV	HeV
					Human	Animal	Human	Animal	Human	Animal	Human	Animal		
L4NTCp3	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. All body showers (2) are performed prior to leaving containment.	3.66E-01	4.88E-02	0.00E+00	5.42E-05	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	6.05E+04	3.77E-01
L4NTCp4	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. 1/2 body showers are performed prior to leaving containment.	3.68E-03	1.52E-03	0.00E+00	1.68E-06	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.88E+03	1.17E-02
L4NTCp5	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. 0/2 body showers are performed prior to leaving containment.	9.24E-06	4.12E-06	0.00E+00	4.58E-09	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	5.11E+00	3.19E-05
L4NTCf8	Necropsy	Transference (Contact, Fomite)	No chemical shower, 0/3 dunk tank disinfections	1.85E-10	8.31E-11	0.00E+00	9.24E-14	0.00E+00	1.24E+06	3.85E+04	6.95E+03	2.13E+00	1.03E-04	6.42E-10
L4NTCp0	Necropsy	Transference (Contact, Palm)	Researcher does not cut their PPE suit and there is no contact transference event	1.47E+04	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCp1	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is reported, there is the appropriate medical response. Due to the appropriate medical response and researcher awareness of the exposure, there is a chemical spot treatment and 2 body showers prior to leaving containment.	7.32E+01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCp2	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is reported, there is a failed medical response. Due to the researcher awareness of the exposure, there is a chemical spot treatment and 2 body showers prior to leaving containment	3.68E-01	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf1	Necropsy	Transference (Contact, Fomite)	Chemical shower, 3 dunk tank disinfections	1.46E+02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf2	Necropsy	Transference (Contact, Fomite)	Chemical shower, 2/3 dunk tank disinfections	2.20E+00	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf3	Necropsy	Transference (Contact, Fomite)	Chemical shower, 1/3 dunk tank disinfections	1.10E-02	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf4	Necropsy	Transference (Contact, Fomite)	Chemical shower, 0/3 dunk tank disinfections	1.85E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf5	Necropsy	Transference (Contact, Fomite)	No chemical shower, 3 dunk tank disinfections	1.46E-03	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf6	Necropsy	Transference (Contact, Fomite)	No chemical shower, 2/3 dunk tank disinfections	2.20E-05	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event
L4NTCf7	Necropsy	Transference (Contact, Fomite)	No chemical shower, 1/3 dunk tank disinfections	1.10E-07	No Inf. Event	No Inf. Event	No Inf. Event	No Inf. Event	--	--	--	--	No Infection Event	No Infection Event

In total, the top 10 highest ranked risk events across both NiV and HeV were observed across the following four specific transference pathways: transference-injection, transference-respiratory suit failure, transference-contact (palm), and transference-respiratory (associated with total loss of positive pressure). For both pathogens the lowest risk values were observed with events along the solid waste release pathway. No observable, credible risk was observed along the aerosol or liquid waste pathways.

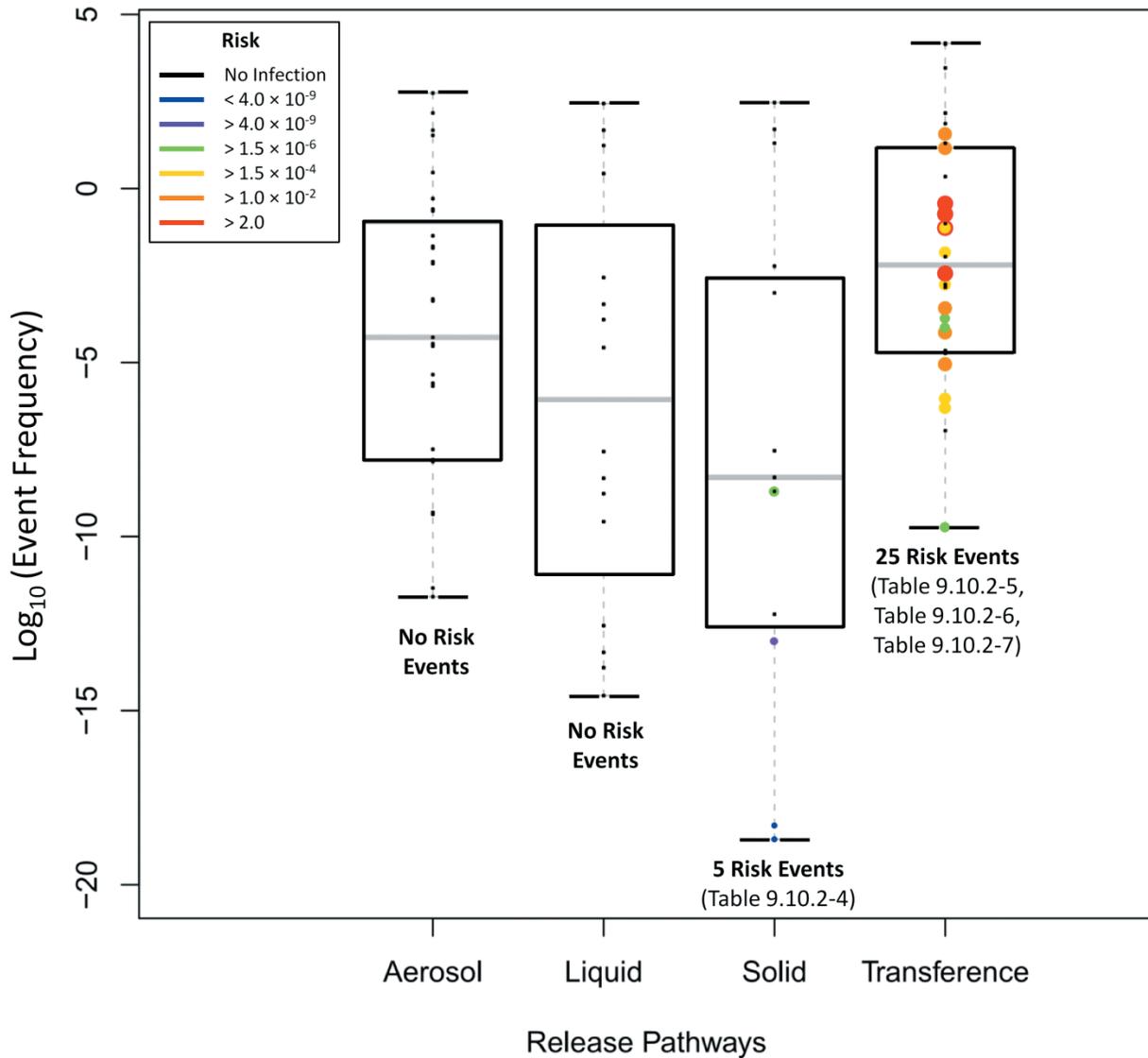


Figure 9.10.2-1: NiV Event Risk Summary by Release Pathway

Figures 9.10.2-1 and 9.10.2-2 represent the risk of each of the 107 events by pathway with associated event frequency and spread of the event frequency across the events (as shown by box plot range and whiskers). [Note that the two extremely low aerosol event frequencies (i.e., full HEPA failure) previously deemed as not credible, were eliminated from the range calculations in the box plots.] These composite figures visually represent all events and, at-a-glance, offer insight into which release pathways dominate the risk (for detail regarding specific data points, the corresponding tables are referenced). The colors of

the circles represent the risk associated with each event and the size of the circle is based on the value of the calculated risk per event (i.e., a larger circle represents an event with greater risk). The small black points represent events that had no observable risk.

In general, the trend of observable risk was consistent across the two pathogens evaluated; the data indicate that the greatest risk for both NiV and HeV activities in ABSL-4 is along transference pathway releases, followed by a few observable, although highly infrequent, events along the solid waste pathway, and no observable, credible risk along the liquid or aerosol pathways. NiV, with the increased potential for person-to-person transmission as compared to HeV, resulted in a greater overall impact (and thus greater risk), as shown in the risk shading differences presented in Figures 9.10.2-1 and 9.10.2-2. Furthermore, the impact ratio associated with human infection was significantly greater than that for animal infection due to the variant value of human life versus livestock, as described in Section 9.9.2.2. While the risk values were variable between the two pathogens, the general trends were sufficiently consistent such that risk mitigation measures (e.g., administrative controls based on procedures and staff training; and physical controls, which are derived from facility design parameters and installation of specified safety equipment) should reduce the frequency of fault events that led to the potential releases regardless of pathogen type.

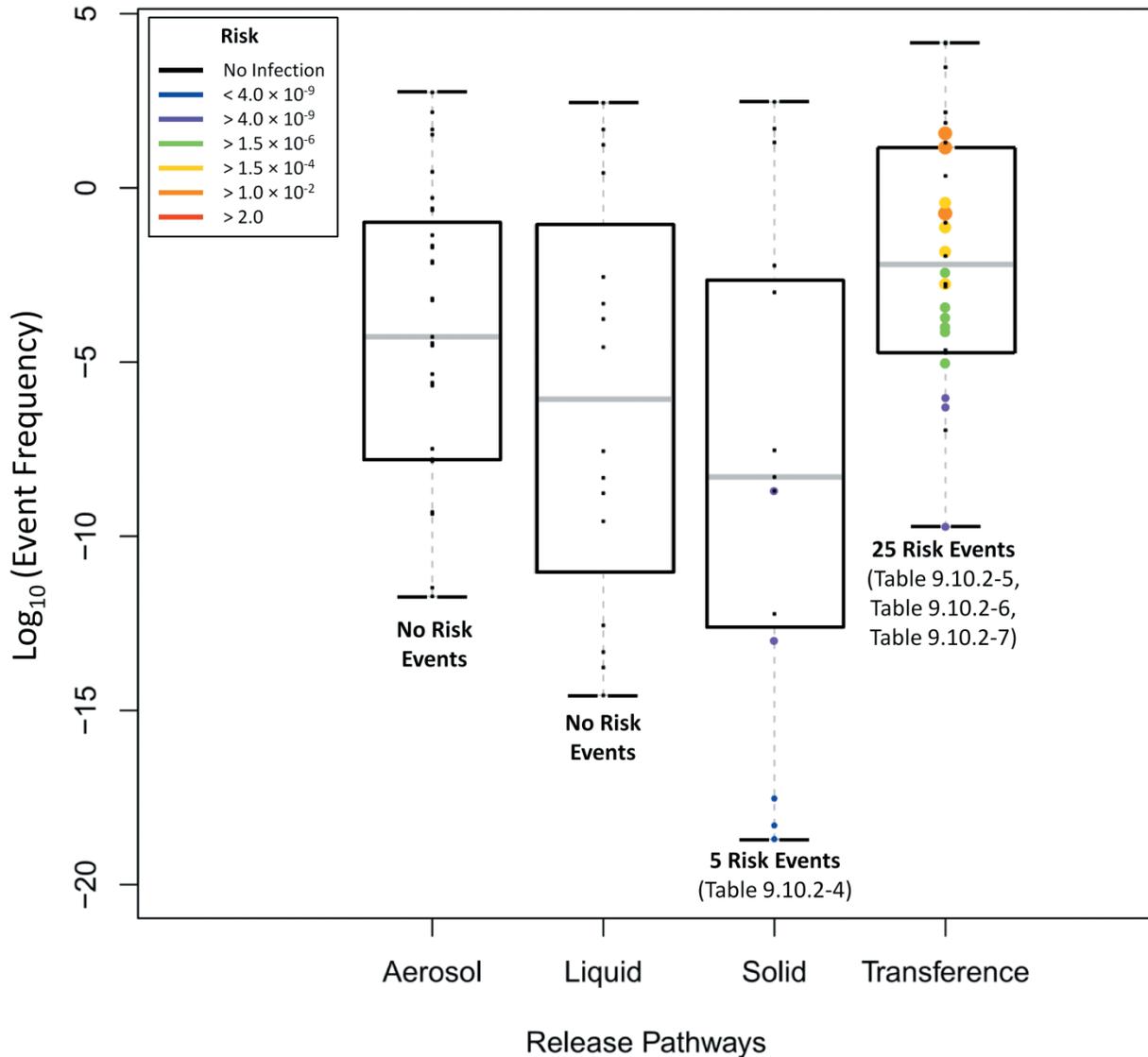


Figure 9.10.2-2: HeV ABSL-4 Event Risk Summary by Release Pathway

By far, the greatest risk is observed along the transference pathway, which relies less on design elements for success as it does on a trained, compliant staff, and well defined standard operating practices, plans and procedures. This observation is consistent with feedback from the biocontainment community, which suggested that human errors during necropsy and handling of infected animals posed the greatest threats to workers inside ABSL-4 containment. ***Through this ABSL-4 assessment, with the exception of five infrequent solid waste events, it appears that the 65% Design elements mitigate the risk of NiV or HeV release along the aerosol, solid, and liquid pathways from ABSL-4 containment.***

Table 9.10.2-8 presents all 30 of the evaluated ABSL-4 events that resulted in an observable risk (the two HEPA failure events were removed as they were deemed not credible to the extremely low event frequency). The events were sorted by event frequency, with the resulting return period for each event presented. The corresponding risk values for NiV and HeV are presented on the far right columns and were ranked (see numbers 1-30 in red text, 1 indicating the highest risk ranking; see previous tables in Section 9.10 for events ranked by risk). Recommendations were formed to address all of the 30 events that resulted in any risk value, even those with negligible risk. The vast majority of the risk observed in the ABSL-4 assessment could be attributed to human error. ***This observation highlights the importance for the NBAF (as it nears operation over the next eight years) to develop SOPs, plans, and practices with continued periodic training of staff to assess their continued compliance. The observable risk also indicates that proper training of staff (e.g., biosafety, biosecurity, biocontainment, security, etc.) through continuing education and refresher training to ensure the understanding and compliance with SOPs, plans, and practices will reduce the potential for the human errors attributed to the transference events and the subsequent impact of an initial laboratory acquired infection.*** Biocontainment SMEs suggested that the key to a properly functioning facility is the operating staff, emphasizing that personnel represent the first line in protecting the facility and maintaining containment.

The observable risk also indicates that ***proper training of staff against well-developed SOPs, which is reinforced through regular and continuing education/refresher training, and ensuring the understanding and compliance with those procedures/practices through monitoring (e.g., video, buddy system, audits, etc.) will reduce the potential for the human errors attributed to the transference events and the subsequent impact of an initial laboratory acquired infection (through education of proper exposure reporting and response procedures).*** The specific types of SOPs and training recommended, relevant to the specific events assessed in this body of work, include:

- Provide continuing education on necropsy skills and techniques that minimize sharps hazards;
- Perform and re-enforce training on minimization of movement practices and maintaining safe working distances from animals within the ABSL-4 AHRs to prevent suit tears;
- Perform and reinforce training on the importance of suit checks. Perform evaluation of suit performance and methods of suit maintenance in collaboration with international containment partners to identify and leverage the current state-of-the-practice in regards to their use and care;
- Develop, implement, and monitor conformance to SOPs that emphasize scrutiny of suit upon containment entry and exit to ensure any breaches are recognized so that appropriate mitigation, decontamination, and/or medical response may be initiated;
- Develop, monitor, and enforce adherence to training and SOPs on the control of animals in containment, including sedation practices, and squeeze chute and pen operation;
- Develop, monitor, and enforce adherence to SOPs on the maintenance and regular monitoring of autoclave and incinerator performance; and,

- Provide continuing education and training on proper decontamination procedures.

Events that resulted in an initial infection that were in turn elevated due to subsequent infection events in this large animal ABSL-4 assessment, may be mitigated through:

- Periodic training and continuing education of the NBAF staff on proper exposure reporting and medical response procedures; and
- Working with the medical and veterinary health organizations and facilities within or around the NBAF (such as Mercy Regional Health Center, University of Kansas Hospital, and local veterinarians) to establish capability and capacity to rapidly respond to NiV, HeV, or other zoonotic exposures such that proper detection, diagnosis, treatment, and other medical response procedures (such as contact precautions, etc.) are initiated as soon as possible should an exposure or infection occur (see Section 3, Best Practices, for a more detailed account of the local healthcare capacity near the NBAF).

Of the 30 events with observable risk, event-specific SOPs, training, and related recommendations are proposed in Table 9.10.2-8. The general recommendations designed to reduce human error and monitor system performance (described above) are applicable to all of the events with observable risk; however, these recommendations have not been duplicated in Table 9.10.2-8.

Table 9.10.2-8: Events with Associated Risk and Proposed Risk Mitigations (Sorted by Event Frequency)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Event Return Period (yr/event)	Risk		Risk Mitigation Recommendation
						Nipah	HeV	
L4NTI1	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is reported and appropriate medical response	36.6	0.027	5.51E+02 (7)	5.51E+02 (1)	Develop, train, and enforce adherence to SOPs on safe necropsy practices. Provide continuing education on necropsy skills and techniques that minimize sharps hazards. Develop, train, and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.).
L4ATRs3	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and appropriate medical response	14.5	0.069	5.56E+01 (8)	5.56E+01 (2)	Perform and re-enforce training on minimization of movement practices and maintaining safe working distances from animals within the ABSL-4 AHRs to prevent suit tears.
L4NTCp3	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. All body showers (2) are performed prior to leaving containment.	0.366	2.73	6.05E+04 (3)	3.77E-01 (5)	Develop, train, and enforce adherence to SOPs on safe necropsy practices. Provide continuing education on necropsy skills and techniques that minimize sharps hazards. Develop, train, and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.).
L4NTI3	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is not reported and no medical response	0.185	5.41	1.03E+05 (1)	6.41E-01 (3)	Develop, train, and enforce adherence to SOPs on safe necropsy practices. Provide continuing education on necropsy skills and techniques that minimize sharps hazards. Develop, train, and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.). Develop medical response capacity and capability at or near the NBAF to increase likelihood of proper occupational health monitoring and medical response when exposures occur.
L4NTI2	Necropsy	Transference (Injection)	Researcher cuts through PPE and through the skin barrier. Laboratory exposure is reported and failed medical response	0.184	5.44	1.02E+05 (2)	6.37E-01 (4)	
L4ATRs5	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is not reported and no medical response	0.0731	13.7	1.04E+04 (4)	6.45E-02 (7)	Perform and re-enforce training on minimization of movement practices and maintaining safe working distances from animals within the ABSL-4 AHRs to prevent suit tears. Develop, train, and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.). Develop medical response capacity and capability at or near the NBAF to increase likelihood of proper occupational health monitoring and medical response when exposures occur.
L4ATRs4	AHR	Transference (Respiratory, Suit Failure)	Suit is tested before entry and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and failed medical response	0.0728	13.7	1.03E+04 (5)	6.42E-02 (8)	
L4ATRs6	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and appropriate medical response	0.0727	13.8	2.79E-01 (18)	2.79E-01 (6)	
L4ATRs9	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and appropriate medical response	0.0146	68.7	5.58E-02 (21)	5.58E-02 (9)	

Table 9.10.2-8: Events with Associated Risk and Proposed Risk Mitigations (Sorted by Event Frequency)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Event Return Period (yr/event)	Risk		Risk Mitigation Recommendation
						Nipah	HeV	
L4NTCp4	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. 1/2 body showers are performed prior to leaving containment.	3.68×10^{-3}	272	1.88E+03 (6)	1.17E-02 (11)	Develop, train, and enforce adherence to SOPs on safe necropsy practices. Provide continuing education on necropsy skills and techniques that minimize sharps hazards. Develop, train, and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.)..
L4ATR1	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is reported and appropriate medical response	1.75×10^{-3}	573	2.62E-02 (22)	2.62E-02 (10)	Develop, train and enforce adherence to SOPs on the control of animals in containment, including squeeze chute and pen operation. Perform and re-enforce training on minimization of movement practices and maintaining safe working distances from animals within the ABSL-4 AHRs to prevent suit tears.
L4ATRs8	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is not reported and no medical response	3.67×10^{-4}	2,720	5.20E+01 (9)	3.24E-04 (14)	Develop, implement, monitor, and enforce adherence to SOPs that emphasize scrutiny of suit upon entry and exit to ensure any breaches are recognized so that appropriate mitigation, decontamination, and/or medical response may be initiated. Perform and re-enforce training on minimization of movement practices and maintaining safe working distances within the ABSL-4 AHRs to prevent suit tears. Develop, train and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.).
L4ATRs7	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, no suit leak, and suit is torn during movement in ABSL-4 AHR. Respiratory exposure is reported and failed medical response	3.65×10^{-4}	2,740	5.17E+01 (10)	3.22E-04 (15)	Develop medical response capacity, capability at or near the NBAF to increase likelihood of proper occupational health monitoring and medical response when exposures occur.
L4ATli1	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure reported and appropriate medical response	1.83×10^{-4}	5,460	2.77E-03 (23)	2.77E-03 (12)	Develop, train, and enforce adherence to SOPs on the control of animals in containment, including sedation practices and squeeze chute and pen operation. Perform and re-enforce training on minimization of movement practices and maintaining safe working distances from animals within the ABSL-4 AHRs to prevent worker displacement (and potential subsequent needle sticks). Provide continuing education on techniques that minimize sharps hazards.
L4NTRs3	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and appropriate medical response	9.90×10^{-5}	10,100	8.74E-04 (24)	8.74E-04 (13)	Develop, implement, monitor, and enforce adherence to SOPs that emphasize scrutiny of suit upon entry and exit to ensure any breaches are recognized so that appropriate mitigation, decontamination, and/or medical response may be initiated. Perform and re-enforce training on minimization of movement practices and maintaining safe working distances within the ABSL-4 AHRs to prevent suit tears. Develop, train and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.).
L4ATRs11	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is not reported and no medical response	7.35×10^{-5}	13,600	1.04E+01 (11)	6.49E-05 (16)	Develop medical response capacity, capability at or near the NBAF to increase likelihood of proper occupational health monitoring and medical response when exposures occur.
L4ATRs10	AHR	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and failed medical response	7.31×10^{-5}	13,700	1.04E+01 (12)	6.45E-05 (17)	

Table 9.10.2-8: Events with Associated Risk and Proposed Risk Mitigations (Sorted by Event Frequency)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Event Return Period (yr/event)	Risk		Risk Mitigation Recommendation
						Nipah	HeV	
L4NTCP5	Necropsy	Transference (Contact, Palm)	Researcher cuts through their PPE suit and there is a contact transference event. The exposure is not reported as the researcher is not aware of the exposure event. As there is no awareness, no chemical spot treatment is performed. 0/2 body showers are performed prior to leaving containment.	9.24×10^{-6}	108,000	5.11E+00 (13)	3.19E-05 (18)	Develop, train, and enforce adherence to SOPs on safe necropsy practices. Provide continuing education on necropsy skills and techniques that minimize sharps hazards. Develop, train, and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.).
L4ATR3	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is not reported; no medical response	8.82×10^{-6}	113,000	4.89E+00 (14)	3.05E-05 (19)	Develop, train, and enforce adherence to SOPs on the control of animals in containment, including squeeze chute and pen operation. Perform and re-enforce training on minimization of movement practices and maintaining safe working distances from animals within the ABSL-4 AHRs to prevent suit tears. Develop, implement, train, and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.).
L4ATR2	AHR	Transference (Respiratory)	Squeeze chute failure, penning failure, rogue animal causes severe tear in PPE suit, hose becomes entangled, positive pressure lost. Respiratory exposure is reported and failed medical response	8.78×10^{-6}	114,000	4.86E+00 (15)	3.03E-05 (20)	Develop medical response capacity and capability at or near the NBAF to increase likelihood of proper occupational health monitoring and medical response when exposures occur.
L4ATI3	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure not reported; no medical response	9.25×10^{-7}	1.08 million years	5.16E-01 (16)	3.21E-06 (21)	Develop, train, and, enforce adherence to SOPs on the control of animals in containment, including sedation practices and squeeze chute and pen operation. Perform and re-enforce training on minimization of movement practices and maintaining safe working distances from animals within the ABSL-4 AHRs to prevent worker displacement (and potential subsequent needle sticks). Provide continuing education on techniques that minimize sharps hazards.
L4ATI2	AHR	Transference (Injection, Inoculation)	Sedation failure, squeeze chute failure, stabbing event through PPE and through skin. Laboratory exposure reported and failed medical response	9.20×10^{-7}	1.09 million years	5.13E-01 (17)	3.20E-06 (22)	Develop, train, and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.). Develop medical response capacity and capability at or near the NBAF to increase likelihood of proper occupational health monitoring and medical response when exposures occur.
L4NTRs5	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is not reported and no medical response	5.00×10^{-7}	2.00 million years	1.63E-01 (19)	1.02E-06 (23)	Develop, implement, and enforce adherence to SOPs that emphasize scrutiny of suit upon entry and exit to ensure any breaches are recognized so that appropriate mitigation, decontamination, and/or medical response may be initiated. Develop, train, and enforce adherence to SOPs on recognition and reporting of exposures, and post-exposure procedures (such as medical monitoring, eliminating contact with susceptible species, reducing person to person transmission via PPE or contact precautions, etc.).
L4NTRs4	Necropsy	Transference (Respiratory, Suit Failure)	Suit is not tested before entry, suit leaks. Respiratory exposure is reported and failed medical response	4.98×10^{-7}	2.01 million years	1.62E-01 (20)	1.01E-06 (24)	Develop medical response capacity and capability at or near the NBAF to increase likelihood of proper occupational health monitoring and medical response when exposures occur.
L4NST2	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave or performance indicator works, incinerator fails	2.00×10^{-9}	50 million years	3.18E-05 (26)	8.13E-09 (25)	Develop, monitor, and enforce adherence to SOPs on the maintenance and regular monitoring of incinerator performance.

Table 9.10.2-8: Events with Associated Risk and Proposed Risk Mitigations (Sorted by Event Frequency)

Event ID	Originating Location	Pathway	Description	Frequency (F_{Loss}) (yr^{-1})	Event Return Period (yr/event)	Risk		Risk Mitigation Recommendation
						Nipah	HeV	
L4NTCf8	Necropsy	Transference (Contact, Fomite)	No chemical shower, 0/3 dunk tank disinfections	1.85×10^{-10}	5.4 billion years	1.03E-04 (25)	6.42E-10 (26)	Develop SOPs, train, and provide continuing education regarding proper decontamination procedures.
L4NSW4	Necropsy	Solid Waste (Red Bag)	One of two autoclaves fail, Incinerator fails	1.00×10^{-13}	9.97 trillion years	5.12E-10 (27)	1.31E-13 (27)	Develop, monitor, and enforce adherence to SOPs on the maintenance and regular monitoring of autoclave and incinerator performance.
L4AS6	AHR	Solid Waste	Both autoclaves fail, Incinerator fails	2.94×10^{-18}	3.4×10^{17} years	9.11E-14 (28)	2.33E-17 (28)	
L4NSW6	Necropsy	Solid Waste (Red Bag)	Both autoclaves fail, Incinerator fails	5.01×10^{-19}	2.0×10^{18} years	8.71E-15 (29)	2.22E-18 (29)	
L4NST4	Necropsy	Solid Waste (Tissue/Carcasses)	Tissue autoclave and performance indicator fails, incinerator fails	2.00×10^{-19}	5.0×10^{18} years	3.47E-15 (30)	8.87E-19 (30)	Develop, monitor, and enforce adherence to SOPs on the maintenance and regular monitoring of autoclave and incinerator performance.

In addition to the recommendations provided above, other sources of guidelines and practices should continue to be reviewed for applicability and relevant practices adapted for inclusion in the operations, preparedness, and/or response plans for the NBAF as it approaches operation over the next eight years. For example, zoonotic viruses necessitate appropriate working procedures and personal protective equipment in veterinary practice [Hanna, 2006]. Findings, such as the infection of veterinary workers during field examinations and autopsies, have led to publication of revised guidelines for veterinarians handling horses suspected of HeV infection. These guidelines, published through the Queensland Department of Primary Industries and Fisheries, provide clinical case definitions, recommended response measures, PPE guidance, and reporting procedures that may be leveraged. Furthermore, the Australian Animal Health Laboratory (AAHL), one of the only containment facilities in the world currently working with large animals within ABSL-4 containment (HeV infected horses), will provide all relevant ABSL-4 SOPs, incident response plans, biosafety plans, etc., so that relevant practices may be adapted for NBAF operations, maintenance, preparedness, and response planning.

Due to the complexity of zoonotic diseases and the associated impact of a release, it is recommended that training at the NBAF be developed around an integrated “one health” paradigm. Animal disease researchers and human (and zoonotic) disease researchers work in very similar environments, use similar lexicons, and apply many of the same basic biosafety practices. However, the research “cultures” are different, and early, integrated, and periodic training will help mitigate risks that may otherwise arise from these differences. It is also suggested that DHS and USDA arrange for temporary assignments that will put future NBAF staff members in different laboratory environments prior to their assignment at the NBAF.

These and other guidelines from the containment community should be periodically reviewed and leveraged to develop state-of-the-practice updates. As the NBAF is not slated to become operational until 2020, it is prudent to consider the recommendations presented herein as guidelines that should be adapted, modified, or improved as new relevant information become available regarding containment practices and procedures.

10. Conclusions and Recommendations

The Updated SSRA provides a current assessment of the risks associated with the operation of the NBAF at the selected Manhattan, Kansas location based on the latest design documents and other information available at the time of evaluation. In addition to incorporating input from DHS, USDA, and other sources, this update addresses findings and recommendations made by the NAS SSRA Committee. This iteration of the risk management process provides an updated quantitative assessment of the risks associated with FMDv research (Section 1-8) and an estimate of risks associated with zoonotic pathogen research on large animal models in BSL-4 laboratories (Section 9). Conclusions from these assessments are presented in Section 10.1; recommendations for DHS and other NBAF stakeholders are presented in Section 10.2. A summary of continuing risk management efforts and DHS responses to NAS SSRA Committee findings on the SSRA is provided in Section 10.3.

The Updated SSRA is part of the overall DHS risk management effort for the NBAF and is based on the 65% Design. This update satisfies Congressional requirements (Public Law 112–10, §1647), addresses feedback provided by the NAS SSRA Committee, incorporates additional data collected on the selected site (Manhattan, Kansas), uses the most up-to date modeling tools, and integrates updated design, operations, and accident response strategies into the assessment. DHS has completed the 50% and 65% Designs, thus satisfying the requirements of §1647(b)(1). The Updated SSRA satisfies the Congressional requirements for demonstrating how calculated risks have been significantly reduced by incorporating mitigations into the risk assessment and addressing shortcomings identified by the NAS SSRA Committee (§1647(b)(2), §1647(c)(1)) through the application of the following enhancements, and others, to the risk assessment process:

- Providing a more systematic approach to the assessment of potential accident events including the use of fault tree and event tree analyses;
- Characterizing uncertainties in calculated results based on standard deviations, unknowns, assumptions, and stochastic variability associated with inputs that are modeled in the assessment;
- Incorporating the use of a published tornado return period calculation methodology;
- Providing additional knowledge and data collected for the NBAF location (e.g., susceptible populations, outbreak control measure resources, etc.) that were used in the predictive epidemiological modeling; and
- Developing and using a methodology to estimate the cumulative risk of an FMD infection that would result from an accidental release of viable virus from the laboratory over the anticipated operating lifetime of the facility.

Other enhanced risk assessment methodologies used in the Updated SSRA comprise the use of updated epidemiological modeling and sensitivity analyses, higher-fidelity meteorological modeling, and advanced economic modeling of potential outbreaks.

In addition, this Updated SSRA satisfies §§1647(c)(2) and (3) by assessing the impact of surveillance, response, and mitigation plans, and providing an assessment of the overall risks associated with research involving large animal models in BSL-4 containment to assist the government in evaluation of the effectiveness of control measures and inform stakeholders on the feasibility of implementation.

10.1 Conclusions

The conclusions drawn from the quantitative evaluation of all FMDv events, including event risk rankings are presented in Section 10.1.1; cumulative risk over a one-year operating period at the NBAF, and cumulative risk over the expected 50-year operating lifetime of the facility are presented in Section 10.1.2. The conclusions derived from the BSL-4 assessment are summarized and a high level comparison to the observations from the FMDv assessment is provided in Section 10.1.3.

10.1.1 Conclusions and Risk Rankings for FMDv-Related Events

The estimated risk of FMDv-related accident events are determined based on the estimated event frequency (where an event is defined as a loss of containment of viable virus material that leads to an FMD infection) and the estimated economic consequences if an event were to occur. Event trees were developed for four pathways: aerosol, solid waste, liquid waste, and transference; and for four originating locations: BSL-Ag Animal Holding Rooms (AHRs), BSL-3Ag necropsy rooms, BSL-3E/BSL-3E “Special Procedure” rooms, and non-containment areas. In addition, two catastrophic events were considered: tornados and earthquakes. In total, 26 event trees comprising a total of 142 events were evaluated. This section presents a summary and interpretation of the risks across the events and release pathways that were considered in this Updated SSRA.

Nearly half (65/142) of the assessed FMDv events did not result in an outbreak because an insufficient quantity of viable pathogen was released from containment or an insufficient quantity of viable virus was delivered to a susceptible animal. Of the 77 events that resulted in a nonzero estimate of risk, only one generated an expected risk (the product of frequency and consequence) value greater than \$0.50M, and only five others generated a mean expected value that was greater than \$0.01M (see A8 for detailed risks associated with each event). The expected frequency of the FMDv infection events (F_{Event}), contingent upon a release, for all events resulting in a nonzero risk was never greater than 6×10^{-7} events per year (excluding catastrophic events). ***The relatively low risk observed across the various potential release events, originating locations, and pathways are reflective of the design, operational plans, and response practices that have been adopted or improved upon since the 15% Design and the 2010 SSRA.***

Virtually no risk was observed from the aerosol pathway when the event originated within containment. This finding is consistent with the large animal BSL-4 Assessment, which also indicated no credible risk

from the aerosol pathway when the release originated within the BSL-4 containment area. ***This suggests that the 65% Design, which has been upgraded to include redundant double (in-series) HEPA filtration, sufficiently mitigates the risk of release of infectious material via the aerosol pathway for events originating in containment.***

Risks associated with solid waste pathways were very low in all events, with solid waste aggregate risk values (summed across all events within a given solid waste tree) falling between 3.8×10^{-10} and 8.2×10^{-5} . These low risk values, as compared to other event trees considered in the Updated SSRA, reflect low probabilities of releases leading to infections. These low probabilities are the result of the efficacy of redundant and independent solid waste decontamination systems planned for the NBAF. ***The addition of redundant and independent solid waste decontamination systems in the 65% Design, including the addition of on-site incineration, has mitigated the risks of release of infectious material via the solid waste pathway from the NBAF.***

No risk of a liquid release resulting in an infection was observed in any area within the NBAF when the Effluent Decontamination System (EDS) cook tank was functional, regardless of whether there were failures in any other node of the waste disposal system (e.g., priming of the drains or wastewater pretreatment). In all liquid waste events with observable risk, the risks were less than \$0.01M. However, the economic impact of such an event, should it occur, is significant (approximately \$108B). ***The NBAF engineering control practice of including an independent and redundant verification indicator of cook tank performance prior to releasing liquid waste from the NBAF has mitigated the risk along this release pathway.***

Although the design and operational features of the NBAF incorporated in the 65% Design significantly reduced modeled risks, some risks are still present. Of the risk-generating events, two are along the aerosol pathway (these risks were limited to a loss originating outside of containment), 11 occurred along the solid waste pathway; 11 occurred along the liquid waste pathway, 51 occurred along the transference pathway, and two were due to catastrophic events.

The catastrophic earthquake event was found to pose the highest risk (approximately \$0.56M) of all of the events considered in this Updated SSRA. The relatively high risk value is driven by the return period of an earthquake event. The facility hardening that was performed to protect the containment areas from high wind events will likely enhance the earthquake performance of the laboratory and thereby increase the return period of an earthquake event that would cause containment failure. However, until a detailed assessment of the earthquake performance of the hardened containment area is performed, the modeled performance of the containment area is limited to the specified building code requirements. It is recognized that these modeling assumptions may have resulted in an overestimation of the extent of structural damage and thus the source term released and subsequent infections resulting from a catastrophic earthquake event but a detailed dynamic structural analysis was beyond the scope of this effort. ***Additional analysis on the structural and containment penetration seals for the NBAF is currently being performed to inform the risk assessment process and provide a more***

representative return period and risk calculation for the earthquake event. Note that the expected risk associated with a catastrophic tornado event is relatively low (in comparison to the earthquake event) at approximately \$0.002M, indicating that the tornado hardening improvements implemented since the 2010 SSRA have greatly reduced the risk associated with a tornado.

Transference events evaluated in this assessment represent the greatest fraction of all events resulting in risk. However, the transference event risks aggregated across all events are \$0.05M. The events that occurred most frequently and thus occupied the greatest transference risk space are those that occurred outside of containment (OT event trees that occurred between the Transshipping Facility and the Laboratory) or were due to a full failure or disregard of procedures and a resultant fomite transfer (event ATF3). Even though the economic impact was significant for transference events that resulted in an infection, the frequency of any individual transference event was estimated to be approximately once in 2 million years ($F_{Event} = 5.33 \times 10^{-7}$). **As concluded in the 2010 SSRA and in the large animal BSL-4 assessment presented in Section 9, thorough and continuously-reinforced training and a safety-oriented workforce are key to reducing accidents from transference events, which are attributable largely to human error.**

The only aerosol events that resulted in observable risk (events OA2 and OA3) were those that originated outside of containment. Because this type of release was modeled as occurring outside of the NBAF building (between the Transshipping Facility and the Laboratory Building) and the source term was not reduced by the filtration of the HEPA systems, these events had a significant impact relative to some of the other modeled events. **Although the overall risk of transshipping errors outside of containment leading to an aerosol release is relatively low (approximately \$0.02M), the consequence of one of these events (conditional on their occurrence) are among the highest consequence events (approximately \$108B). It is important to note that risks associated with receiving improperly packaged shipments containing infectious materials are not unique to the NBAF.**

10.1.2 Cumulative Risk Calculations for FMDv-Related Accidents

Cumulative risk estimates for the NBAF – for both the first year of operation and over the 50-year expected lifetime of the facility, are presented in this section. While the risk calculations do provide useful information for ranking risks, identifying vulnerabilities, prioritizing investments, and developing response strategies, the practice of numerically estimating risk over such a long period is not recommended (but required by Public Law 112–10, §1647), and care should be taken to avoid over-interpreting the cumulative risk estimate as an absolute number. Furthermore, the uncertainty associated with the estimates comprising the cumulative risk values are, in many cases, large relative to the estimated risks. The associated underlying uncertainties that contribute to the uncertainty in the cumulative risk values are detailed in Section 8.

With this caveat, the estimated probability that an accidental release of viable FMDv from the NBAF will occur and cause an infection was calculated for a single year (the first year) of NBAF operation and across the 50-year lifetime. For a single year of NBAF operation, when all events are considered

(including catastrophic events), the expected probability of at least one release resulting in an infection in a given year is 2.16×10^{-5} and the estimated range is approximately 3.07×10^{-11} to 4.23×10^{-4} . When catastrophic events are excluded, the probability of at least one release resulting in an infection in a given year is estimated to be between 3.07×10^{-11} and 2.33×10^{-5} with an expected probability of 1.52×10^{-6} . The cumulative risk over all events for one year was \$0.7M when all events were included and \$0.13M when the catastrophic events were excluded.

The 50-year cumulative probability estimate is 1.08×10^{-3} (ranging from 1.54×10^{-9} to 2.35×10^{-2}) when all events were included and 7.61×10^{-5} (ranging from 1.54×10^{-9} to 1.17×10^{-3}) when catastrophic events were excluded. In other words, when all events are considered, the probability of at least one release resulting in an infection over the 50-year NBAF operating lifetime is estimated to be less than 0.11%. When catastrophic events are excluded, the probability of at least one release resulting in an infection over the 50-year NBAF operating lifetime is estimated to be less than 0.008%. The cumulative risk over the 50-year operating lifetime of the NBAF was \$35M when all events were included and \$7M when the catastrophic events were omitted. The uncertainty (standard deviation) in the 50-year cumulative risk was found to be approximately \$15B, regardless of whether catastrophic events are included.

In summary, the practice of numerically estimating risk over such a long period is not recommended. With this caveat, ***the estimated probability that an accidental release of FMDv from the NBAF will occur and result in a subsequent outbreak during the NBAF's nominal 50-year operating life is less than 0.11%.***

10.1.3 Summary of Risks Associated with Infected Livestock in BSL-4 Containment

The Large Animal BSL-4 (ABSL-4) Assessment presented in Section 9 relied on a panel of domestic and international biocontainment Subject Matter Experts (SMEs), members of the NBAF Design Partnership, and risk assessment professionals to develop and analyze a set of events that represent the state-of-the-practice risks associated with handling (infected) livestock within BSL-4 containment. A total of 109 events that spanned potential loss of containment across the aerosol, liquid waste, solid waste, and transference pathways were described and the associated risks estimated. A summary of the risks observed in the ABSL-4 Assessment is provided herein; for the detailed ABSL-4 Assessment conclusions and recommendations, refer to Section 9.10.2.

In the ABSL-4 assessment, the greatest risk was identified along the transference pathway, which relies less on design elements and more on well-trained staff that comply with planned protocols, practices, and standard operating procedures (SOPs). The vast majority of the transference event risk observed in the ABSL-4 assessment was attributable to human error. This observation highlights the importance for any biocontainment laboratory, including the NBAF, to develop SOPs, plans, and practices and reinforce these practices with periodic staff training. The observable ABSL-4 risk also indicated that proper training of staff (e.g., biosafety, biosecurity, biocontainment, security, etc.) through continuing education and refresher training to ensure the understanding and compliance with

SOPs, plans, and practices will reduce the potential for the human errors attributed to the transference events and the subsequent impact of an initial laboratory acquired infection.

The ABSL-4 Assessment also concluded that, with the exception of a few improbable specific events, ***the NBAF 65% Design elements mitigate the risk of pathogen release along the aerosol, solid waste, and liquid waste pathways from ABSL-4.***

A list of the high-level conclusions generated from the ABSL-4 Assessment includes:

- The risk mitigation of redundant, dual-series HEPA filtration caissons in the NBAF 65% Design provided significant protection against release along this pathway from ABSL-4 AHRs and necropsy rooms. No credible risk was identified along the aerosol release pathway from ABSL-4 containment. This observation is consistent with that observed during the FMDv risk assessment for BSL-3Ag containment.
- None of the 18 liquid waste events evaluated resulted in an observable risk, implying that the NBAF planned in-facility effluent decontamination systems (in particular the cook tank) offer sufficient risk mitigation in regards to working with large animals in BSL-4 containment. This observation is consistent with that observed during the FMDv risk assessment for BSL-3Ag containment.
- As long as either the incinerator (for the solid fraction from the large tissue autoclaves or solid waste disposal) or the in-series autoclaves are functional, the solid waste pathway does not appear to pose observable risk. Of the solid waste pathway events that had observable risk, the greatest risk was observed when the tissue autoclave from ABSL-4 necropsy was functioning, yet the incinerator failed. This risk is reflective of the large viral load and sheer mass of material considered in the disposal of infected carcasses (as compared to non-carcass solid waste). It is also notable that the frequency of release or F_{Loss} for the five solid waste events with observable risk ranged from $2.0 \times 10^{-9} \text{ yr}^{-1}$ to $2.0 \times 10^{-19} \text{ yr}^{-1}$. This observation is consistent with the findings of the FMDv risk assessment.
- The transference pathway represented the greatest associated risk across all of the ABSL-4 release pathways considered. The transference-injection and transference-respiratory specific pathways represented the greatest associated risk across all of the ABSL-4 events. In total, the ten events with the greatest risk for both Nipah (NiV) and Hendra (HeV) were observed along the transference pathway due to exposures via injection (e.g., sharps/bites), inhalation (due to loss of respiratory protection positive pressure), and contact routes. This is consistent with the FMDv assessment that indicated that the majority of the events that led to observable risk were due to transference events.
- The estimated risk values were somewhat variable between the two primary pathogens used to estimate the risk of working with infected livestock in ABSL-4 containment (NiV and HeV). However, the general trends were sufficiently consistent such that risk mitigation measures (e.g., administrative controls based on procedures and staff training and physical controls, which are derived from facility design parameters and installation of specified safety equipment) should reduce the frequency of fault events that led to the potential releases regardless of pathogen type, including HeV, NiV, RVFv, or other emerging agents.

It is important to note that this is an estimate of ABSL-4 risk—many factors that could influence risk (including the economic impact) are not fully characterized for the modeled pathogens or other emerging pathogens. As more information on these pathogens becomes available, the conclusions and recommendations included herein should be reevaluated and reconsidered for relevance. This work does represent a reasonable advancement in the understanding of high-containment risks associated with working on livestock (and large animals) and, at a minimum, provides a starting point for future discussions and collaborations, and provides an extensive historical overview of the potential impacts of NiV and HeV outbreaks should a release occur.

10.2 Recommendations

Recommendations for consideration by DHS, USDA, and other stakeholders presented herein are intended to inform NBAF planning processes on design features, operations-related concepts, and response strategies that may help further reduce risks associated with animal and zoonotic pathogen research. Recommendations have been derived from the quantitative assessment of FMD-related research in BSL-3Ag and BSL-3E facilities (including the Special Procedure areas), and the assessment of zoonotic pathogen research in ABSL-4 facilities. The aggregated recommendations for design and construction, operational planning, and response strategies are presented in the following sections.

During the performance of the Updated SSRA, two design features were identified that provided the opportunity to significantly reduce the modeled accident frequencies. These features were presented to DHS along with preliminary estimates on the risk reduction that would be achieved by implementation of the interim design recommendations. DHS agreed to incorporate the design modifications in the 100% Design and the anticipated risk mitigation achieved from these modifications was incorporated in the current assessment. The accepted recommendations are described below:

- Redundant temperature sensors and an independent temperature monitoring method will be integrated with all cook tanks in the Effluent Decontamination Systems (EDSs) to increase the overall confidence that liquid waste is properly treated prior to its discharge.
- Redundant temperature sensors and an independent temperature monitoring method will be integrated with all tissue autoclaves (carcass and tissue disposal systems) to increase the overall confidence that waste tissue is properly treated prior to the removal of residuals from the system.

10.2.1 Design and Construction

From the risk assessment perspective, ***the NBAF 65% Design is a sound design that has no evident fundamental flaws or design features that would prohibit the implementation of the best and safest practices used in animal and zoonotic pathogen research facilities. However, additional design considerations that may enhance overall risk management efforts are submitted as recommendations (that have been accepted by DHS) below:***

10.2.1.1 Disinfection Fixtures

The development of design detail that includes the addition of dedicated disinfection fixtures in shower areas (e.g., water showers) would ensure that appropriate space is allocated for the necessary fixtures. Providing details and specification for fixture and utility requirements for the dunking process will facilitate procedure and protocol development and minimize the potential for procedural oversights or fixture improvisation. The transfer of items from higher containment levels to lower containment levels is a frequent event, and permanency of accommodating fixtures for the disinfection process is highly recommended by the Updated SSRA team.

10.2.1.2 Time Interlocked Shower Doors

The specifics of practices and procedures for personnel showers (when transiting through containment levels or from high- to low-titer areas) for the NBAF will be defined before the laboratory is operational and will continue to evolve with experience and as research activities change over time. However, for the foreseeable future, biosafety practices will include prescribed shower times. It is recommended that consideration be given to incorporating time-interlocked shower doors (with emergency egress) for the containment exit shower facilities—the shower facility at the exit of the BSL-3E area. A similar successful implementation in Denmark allows personnel to pass through the shower from the “clean” area to the “dirty” area and greatly enhances adherence to shower time protocols. The current NBAF design already incorporates interlock capabilities and the addition of time sequencing should require minimal adjustments. On exit from the dirty area, the shower exit door is nominally locked for the protocol-driven shower cycle time. (Emergency egress can be accomplished if necessary.)

10.2.1.3 Earthquake Performance Analysis

The facility hardening that was performed to protect the containment areas from high wind events will likely enhance the earthquake performance of the laboratory and thereby increase the return period of an earthquake event that would cause containment failure. However, since a structural analysis on the earthquake tolerance of the hardened containment area was outside the scope of this effort, a conservative approach was taken that may have overestimated the extent of structural damage (and thus the source term released) given an earthquake event. ***If the earthquake performance of the containment area is enhanced by the hardened structure, the risk of the loss of containment from an earthquake will be further reduced. DHS may choose to seek further collaboration with experts in earthquake structural design and tolerance analysis to refine and inform this risk further.***

10.2.1.4 Beneficial Reuse Considerations

Beneficial reuse practices are not being considered for the NBAF. If considered for any fraction of the containment waste stream, the practice should be methodically assessed for additional risk contributions. Results from these dedicated studies should be used to inform DHS and USDA biosafety officials, management, and responsible officials so that appropriate mitigation and control measures can be incorporated in the decision process (e.g., costs, risks, and benefits). Specifically, marginal risks from the reuse of solids (e.g., sludge, activated sludge, etc.) from the on-site wastewater pretreatment facility should be assessed before supporting infrastructure or operational plans are developed.

10.2.2 Operational Planning

With regard to operational planning, ***it is recommended that the operational planning cycle include emergency and incident response stakeholders and that plans (upon completion) be available for stakeholder review and contribution.***

As DHS and USDA develop and modify NBAF SOPs, plans, and practices, ***it is recommended that DHS and USDA provide periodic training on the developing SOPs, plans, and practices with current staff members to begin the adaptation and familiarization of potential new processes and identify opportunities for optimization of the developing documentation.*** DHS has performed similar practices for the transition of some U.S. Army Medical Research Institute of Infectious Diseases (USAMRIID) activities to the National Biodefense Analysis and Countermeasures Center (NBACC). Such training can be accomplished while engaging the workforce and enhancing worker satisfaction. Initial and continued training of NBAF staff in biosafety, biosecurity, biocontainment, and security practices will enhance understanding of and compliance with NBAF SOPs, plans, and practices that will ultimately reduce the potential for human errors that contributed to most of the observed transference event risks.

Accelerated staff training on emerging SOPs, plans, and practices will also reinforce and enhance current biosafety practices and facilitate the smooth transition from PIADC to the NBAF—similar to the USAMRIID to NBACC activities mentioned above. The specific types of SOPs and training recommended (based on conclusions from the FMDv and ABSL-4 assessments) include:

- Necropsy skills and techniques that minimize sharps hazards;
- Techniques on the optimization of movement and maintaining safe working distances from animals to minimize the potential for PPE damage and physical injury;
- Continuous PPE checks and maintenance;
- Best practices on working with livestock in containment, including sedation practices, and squeeze chute and pen operation;
- Decontamination procedures for workers and potential fomites; and
- Methods and procedures for proper exposure reporting and medical response procedures.

Releases that occurred outside of containment, whether through the aerosol pathway or through transference of material on persons or via fomites, provide a unique set of circumstances (e.g., failure of packaging materials and subsequent release of viable pathogen) that can be mitigated using a number of approaches. The following suggestions for mitigating the risks associated with receipt and handling of improperly packaged infectious pathogens should be considered:

- ***Develop practices and procedures that reduce handling of and exposure to potentially infectious packages outside of containment,*** such as using staff in the transshipping sample receipt area who are fully trained in the safe handling and containment of infectious materials; publishing

shipping guidelines and requirements, and requesting specified sample containers be used when sending samples to the NBAF; dedicating disposable clothing and footwear to the Transshipping Facility; and requiring clothing and footwear change, and complete shower-out (similar to that performed when exiting the BSL-3Ag AHRs) before exiting the Transshipping Facility after contact with sample containers.

10.2.3 Response Planning

Based on the risks observed in the Updated SSRA and the time commitment required to build new relationships and coordinate with existing stakeholders, ***it is recommended that DHS accelerate the response planning efforts beyond those identified in the “NBAF O&M Establishment Timeline” (Figure 1.1.7-1) to the extent practical, and to facilitate response planning efforts.*** The response planning efforts are motivated by FMD concerns that are not all related to NBAF and the planning effort will benefit many stakeholders.

In order to achieve the goals of an FMD response to (1) detect, control, and contain FMD in animals as quickly as possible; (2) eradicate FMD using strategies that seek to stabilize animal agriculture, the supply, and the economy while protecting public health; and (3) provide science- and risk-based approaches and systems to facilitate continuity of business for non-infected animals and non-contaminated animal products, one or more response strategies may need to be employed at any time during an outbreak. The strategies employed may vary by region, species, or other defining characteristic. In each case, the decision and application of a specific response strategy or strategies will be based on considering many criteria, and will require the coordination and involvement of numerous entities. In the event of FMD detection, USDA and the affected states and tribal nations will work together in a Unified Command, per NIMS, to detect, control, and contain FMD as expeditiously as possible. Detection of FMD in the U.S. will result in emergency intervention by state, tribal, and federal authorities.

Specifically, any response strategy or strategies regarding emergency vaccination need to be approved by the U.S. CVO prior to implementation, with agreement from the SAHO and the Unified Command Incident Commander. Choosing one vaccination strategy, multiple strategies, or modifying strategies as an outbreak unfolds is an important, but very complex decision process. Depending upon the circumstances and scale of the outbreak, a combination of one or more of the response strategies may be applied. ***It is recommended that a publicly-available vaccination response plan be provided early on to allow proper coordination and weigh-in of all stakeholders and, if possible, to evaluate, estimate, and/or discuss the effectiveness, benefits, or detriments of the various response strategies under consideration prior to implementation during an emergency event.***

To mitigate the risks to public and veterinary health identified in the ABSL-4 Assessment, ***it is recommended that initial response planning efforts comprise a high-level description of the process for working with the medical and veterinary health organizations and facilities within and around the NBAF (such as Mercy Regional Health Center, University of Kansas Hospital, local veterinarians, etc.)***

to establish the capability and capacity to rapidly respond to Nipah, Hendra, or other zoonotics such that proper detection, diagnosis, treatment, and other medical response (such as contact precautions, etc.) are initiated as soon as possible should an exposure or infection occur.

The sensitivity analysis and cost-benefit analysis performed during the quantitative FMDv epidemiological modeling indicated the following strategies were effective at reducing the extent of an outbreak and should be considered for inclusion to response planning efforts for the NBAF. Investments to achieve the predicted culling capacity are critical for FMD outbreak mitigation, and further investments to improve culling capacity were beneficial no matter how large the outbreak was or where it initiated. It is suggested that the NBAF response plans outline an approach to, at a minimum, achieve the predicted culling capacity in Kansas and the surrounding states.

Investments to reduce the degree of direct and indirect contact between infected and susceptible farms after an outbreak were beneficial in reducing the extent of outbreaks. It is suggested that NBAF response plans include and define approaches and methods to be used to reduce direct and indirect contact between infected farms and susceptible farms during an outbreak of FMD.

Despite the fact that early detection of an outbreak can greatly mitigate its effects, current technologies related to air samplers, sentinel herds, and active surveillance were of limited value because these systems were unlikely to signal that an outbreak has occurred or will occur given the specific releases modeled from the NBAF. However, the advancement of related surveillance technologies and associated implementation strategies may significantly change this observation. It is suggested that DHS, USDA, and other stakeholders continue to invest in surveillance technologies that provide more benefit than current systems. The epidemiological assessment indicated that producer education campaigns that incentivize producers to observe animals for suspicious signs, enable them to recognize the signs of FMD as suspicious, and encourage them to call a veterinarian when the signs are first observed, could significantly reduce the impact of an outbreak. ***It is recommended that NBAF response plans include and define the goals, approach, and program of instruction for a producer education campaign (or similar instruction effort as described above) for the state of Kansas and the NBAF region.***

10.2.4 Recommendations Summary Table

The Updated SSRA recommendations for consideration by DHS and USDA are summarized in Table 10.2.5-1.

Table 10.2.5-1: Updated SSRA Recommendations Summary

No.	Description	Status
1	Add permanent disinfection fixtures to the design in shower (water) areas between containment levels.	Accepted
2	Incorporate time-interlocked doors in shower area between the BSL-3E containment area and non-containment.	Accepted
3	Assess the enhanced earthquake performance that may be derived from the structural hardening and containment penetration specifications added for the high-wind and tornado design mitigations for the benefit of future risk assessments.	Accepted
4	Perform additional analyses, as needed, prior to incorporating beneficial reuse into designs and plans.	Accepted
5	Continue to include outside emergency and incident response stakeholders in the operational planning cycle and distribute plans (upon completion) for review and additional contributions.	Accepted
6	Begin periodic training on newly developed and evolving NBAF SOPs, plans, and practices.	Accepted
7	Develop practices and procedures that reduce handling of and exposure to potentially infectious packages outside of containment.	Accepted
8	Accelerate response planning efforts while including emergency and incident response stakeholders (Recommendation 5) and appropriate interested entities.	Accepted
9	To the extent possible, make vaccination response plans publicly available.	Accepted
10	Publish a high-level description of the cooperative arrangements and roles of public and veterinary health providers.	Accepted
11	Develop and implement a producer education program for livestock producers in the NBAF region.	Accepted

10.3 Continuing Risk Management and Advancements Following the 2010 SSRA

DHS is committed to the development and implementation of continuing risk management practices. The continuing practices will be described in a DHS plan that is currently under development. The plan is based on a continuous improvement model as illustrated in Figure 10.3-1. Each risk assessment iteration is used to inform the NBAF program, which may then adjust plans as needed to accommodate identified risks. Enhanced fidelity for conceptual facility models are then used with improved modeling tools and newly collected data to model the risk mitigation achieved by the adjusted plans. Results from the updated modeling are used to assess the adjusted risks and again inform the program. Implementation of this model will allow DHS and other stakeholders to ensure that resources are being used to most effectively address identified risks and identify new risks that may arise from other design changes or updated plans.

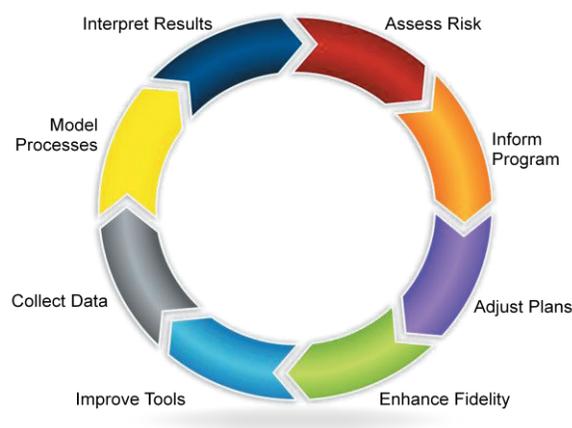


Figure 10.3-1: Iterative Risk Model

10.3.1 Implementation of 2010 SSRA Recommendations

The 2010 SSRA provided 17 specific recommendations for the mitigation of risks for the NBAF in the areas of design and engineering, operations planning, and response strategies. DHS and USDA have implemented or are in the process of implementing or addressing all 17 of these recommendations. These implemented changes are reflected in the Updated SSRA. Specifically, DHS has incorporated all design recommendations into the 65% Design. DHS continues to work with USDA to formulate operating strategies to address the operations planning recommendations, and has made progress on the collaboration processes required to coordinate federal, state, and local responders on response planning strategies. A summary of the SSRA recommendations and the DHS responses is presented in Table 10.3-1.

Table 10.3-1: Summary of 2010 SSRA Recommendations and DHS Responses

No.	Recommendation	DHS Response
1	DHS should initiate the development of NBAF staff training programs as soon as is practically possible. The control of fomites, vectors, carriers, and laboratory acquired infections is one of the most important elements of risk control for the facility.	DHS continues to work with USDA to formulate operating strategies for the NBAF. DHS has established a Research and Transition Working Group; has continued stakeholder engagements to ensure full understanding by local and regional community of the NBAF mission; and has established baseline biosafety guidelines for incorporation into design basis and standard operating procedures.
2	DHS should convene professionals from the design team and other subject matter experts to explore all of the options available to the NBAF for carcass disposal systems. This group should make a final recommendation to DHS before the schematic design evolves to the next level.	DHS held special meetings and used additional expertise to assess all carcass disposal technologies and identify the best system for the NBAF. The 65% Design uses redundant rendering systems (autoclaves) inside containment coupled with medical waste incinerators outside containment.
3	DHS should strictly limit access to the NBAF laboratory areas and minimize the potential for unauthorized visitors. When access to the containment block is required (e.g., FADD students), strict escort protocols must be followed and visitors must be provided with ingress/egress training and/or supervision.	DHS continues to work with USDA to formulate operating strategies for the NBAF. DHS has established a Research and Transition Working Group; has continued stakeholder engagements to ensure full understanding by local and regional community of the NBAF mission; and has established baseline biosafety guidelines for incorporation into design basis and standard operating procedures.
4	The NBAF Biosafety Officer is responsible for developing respiratory protection guidelines with specific regard to staff and visiting researchers who work in a BSL-3Ag environment with large animals infected with non-zoonotic pathogens. The appropriate guidelines for evaluating respiratory protection should be prepared prior to completing the facility design.	NBAF current plans include a respiratory protection strategy that requires personnel to use respiratory protection when potentially exposed to FMDv aerosols.

Table 10.3-1: Summary of 2010 SSRA Recommendations and DHS Responses

No.	Recommendation	DHS Response
5	Non-operational containment integrity (static containment) should be maintained for up to an F2 event. This recommendation also applies to portions of the Central Utility Plant (CUP) that provide essential services to the laboratory facility while in “shut down” mode after a tornado strike. In addition, the design team should perform a technical assessment to determine if the F2 working loads would provide F3 static containment. If not, the design team should assess the marginal costs of satisfying F3 requirements for static containment and DHS should evaluate the cost-benefit analysis before finalizing the facility design.	DHS has used a 200 mph wind speed design basis with additional factors of safety that result in a facility design that can withstand wind speeds of 228 mph and maintain static containment. (This is similar to the design-basis storm used by the Nuclear Regulatory Commission (NRC) in Regulatory Guide 1.76 (230 mph). The NBAF Design also provided for protection against tornado missiles. Thus, the 65% Design exceeds the requirements recommended in the SSRA.
6	DHS should provide additional expertise to the design team to include an engineering organization that has extensive design experience in high-wind event mitigation practices. This additional resource would assist DHS in setting the most appropriate design specifications and reviewing the developments of the NBAF design as it evolves.	DHS engaged a team of experts in the field of high-wind event mitigation and engineering to develop the schematic design and construction plan presented in the 65% Design regarding hardening the NBAF against a high-wind strike.
7	DHS should consider adding a requirement to install an on-site underground sanitary sewage waste retention system. This system should be able to accommodate at least one day’s worth of liquid effluent and incorporate the ability to be sanitized and/or bypassed as needed.	DHS has added an underground sanitary retention tank and on-site sewage treatment facility to the NBAF. The decision to include an on-site wastewater treatment facility was not driven directly by this recommendation. However, the flow-down of additional wastewater requirements from federal regulations and the addition of the more appropriate carcass disposal technology necessitate the on-site facility.
8	DHS should develop and implement a plan for identifying resources with local and regional entities to enhance and exercise Foreign Animal Disease (FAD) Emergency Response Plans.	DHS has begun the collaboration process with federal, state, and local responders and drafted the approach to develop the response plans. Additionally, DHS has begun discussions with USDA and other agencies to review response and mitigation policies associated with NBAF construction and operations.
9	DHS should resolve details regarding the final disposition of solid waste removed from the high-containment areas.	NBAF on-site incineration of all solid waste will be performed prior to solid waste disposal.

Table 10.3-1: Summary of 2010 SSRA Recommendations and DHS Responses

No.	Recommendation	DHS Response
10	DHS should evaluate additional solid waste disposal options for non-containment waste located in close proximity to the NBAF. A dedicated site for disposition with controllable access and scavenger exclusion features would minimize this risk.	The landfill used by Riley County will use best practices to control access and minimize intrusions.
11	DHS should consider adding an NBAF requirement to identify an emergency supplier for potable water (mobile provider) or install an on-site potable water supply reservoir.	DHS added 60,000 gallons of storage capacity for potable water. In addition, the city has a 12-hour reserve of potable water provided by an existing 2-million gallon water supply.
12	DHS should accommodate the permanent addition of a laboratory mock-up facility. The recommendation is to provide an on-site location for the mock-up so that it can become a permanent non-operational fixture that may facilitate training and operational readiness exercises.	DHS will build temporary mock-ups to test containment penetration systems and structural components. DHS is working with other organizations to provide familiarization and training for new or visiting staff.
13	The NBAF should incorporate basic design features to facilitate the safe and humane movement of animals through the facility.	NBAF has adopted best practices design elements such as rounded corners, adjustable penning, hoist systems, lighting considerations, and other features that will help maintain animal temperament and minimize animal agitation.
14	Documentation and publications that describe NBAF activities and pathogens should identify the current capabilities associated with research, diagnostics, and training demonstrations.	DHS has begun the collaboration process with federal, state, and local responders and drafted the approach to develop the response plans. Additionally, DHS has begun discussions with USDA and other agencies to review response and mitigation policies associated with NBAF construction and operations.
15	The NBAF should develop a proactive maintenance program that includes preventative and predictive maintenance procedures.	DHS continues to work with USDA to formulate operating strategies for the NBAF. DHS has established a Research and Transition Working Group; has continued stakeholder engagements to ensure full understanding by local and regional community of the NBAF mission; and has established baseline biosafety guidelines for incorporation into design basis and standard operating procedures.

Table 10.3-1: Summary of 2010 SSRA Recommendations and DHS Responses

No.	Recommendation	DHS Response
16	DHS should consider developing site-specific natural disaster and enhanced disease surveillance and response plans for inclusion in NBAF’s operating procedures. Disease surveillance plans for local and regional facilities should also be developed in conjunction with public and private sectors.	DHS has begun the collaboration process with federal, state, and local responders and drafted the approach to develop the response plans. Additionally, DHS has begun discussions with USDA and other agencies to review response and mitigation policies associated with NBAF construction and operations.
17	DHS should implement all personnel screening requirements from the Employee Access program as well as security requirements currently in use at PIADC, and consider adding personnel security requirements recommended by the Working Group on “Strengthening Laboratory Biosecurity in the United States” established by Executive Order 13386 on 9 January 2009, and the report “Responsible Research with Biological Select Agents and Toxins,” prepared by the Committee on Laboratory Security and Personnel Reliability Assurance Systems for Laboratories Conducting Research on Biological Select Agents and Toxins of the National Research Council.	DHS continues to work with USDA to formulate operating strategies for the NBAF. DHS has established a Research and Transition Working Group; has continued stakeholder engagements to ensure full understanding by local and regional community of the NBAF mission; and has established baseline biosafety guidelines for incorporation into design basis and standard operating procedures.

10.3.2 NBAF Design Evolution

DHS and USDA program representatives and the NBAF Design Partnership began the site-specific design process in June 2009. The project team has worked together for the purpose of creating a design that maximizes the safety and security aspects of the NBAF. As indicated above and illustrated in Table 10.3-1, DHS has proactively addressed all 17 of the 2010 SSRA recommendations regarding design considerations. In addition to addressing these recommendations, ***the NBAF 65% Design complies with or exceeds all modern biocontainment design principles, standards, and applicable biocontainment facility codes and requirements—specifically with regard to redundancy recommendations on room exhaust air filtration.*** Advancements from the 15% Design to the 65% Design include, but are not limited to, the following features:

10.3.2.1 Redundant HEPA Caissons and Autoscan Capability

The NAS SSRA Committee expressed concern about the lack of complete redundant capacity for the double (series) HEPA laboratory exhaust air filtration from areas with an elevated risk for aerosolized pathogens. In the 65% Design, redundancy for all elevated risk areas is provided (2N for smaller rooms and N+1 for larger rooms). The addition of built-in HEPA autoscan functionality will enhance the ability to monitor HEPA performance.

10.3.2.2 Carcass Disposal

Recommendation #2 from the 2010 SSRA was to identify a different carcass disposal technology to potentially replace the carcass incineration method. After considerable study and deliberation, DHS and the NBAF Design Partnership, in consultation with other experts, selected another proven carcass disposal technology that addressed the concerns noted in the 2010 SSRA. The selected technology (large tissue autoclave) is capable of processing and dehydrating carcasses and other waste materials without some of the integration complications inherent to incinerators. The identification and incorporation of this technology satisfies SSRA Recommendation #2.

10.3.2.3 On-Site Wastewater Pretreatment

The 2010 SSRA recommended that DHS consider adding an on-site sanitary sewage waste retention system to accommodate the accumulation of sewage during a denial of service without causing undue risk to the experiments or the environment (SSRA Recommendation #7). Subsequent developments (e.g., upcoming regulatory requirements and the selection of a different carcass disposal technology) drove the NBAF Design Partnership and DHS to add an on-site wastewater pretreatment facility as described above. Additional storage capacity for disinfected liquid effluent and the addition of this new on-site wastewater pretreatment system satisfies the intent of SSRA Recommendation #7.

10.3.2.4 Potable Water

The SSRA also recommended that the NBAF have access to emergency potable water supplies to accommodate safe laboratory and containment operations (and shutdown) in the event of temporary denial of routine service (SSRA Recommendation #11). DHS and the NBAF Design Partnership have added 60,000 gallons of storage capacity and have made arrangements with the municipality to provide a 12-hour reserve of potable water if the need arises to address this recommendation.

10.3.2.5 Tornado Hardening

The 2010 SSRA presented two recommendations (SSRA Recommendations #5 and #6) related to enhancing the NBAF's ability to survive a direct strike by a tornado without containment loss. DHS and the NBAF Design Partnership developed a plan that provides a nearly equivalent level of protection to that required by the Nuclear Regulatory Commission (NRC) for U.S. nuclear power plants. This high standard was selected because there are no prevailing standards for biocontainment laboratories. Current design standards for biocontainment facilities, such as the *Biosafety in Microbiological and Biomedical Laboratories* (BMBL) 5th Edition, do not identify specific requirements for facility hardening for high-wind events [USDHHS/CDCP, 2007]. DHS, however, directed the NBAF Design Partnership to establish appropriate design criteria to provide high confidence that the facility will maintain containment during and after a credible high-wind event. The NBAF comprises a tornado-hardened zone (Figure 2.4.5-1) that would protect the BSL-3E, BSL-3Ag, and BSL-4 laboratories from loss of containment resulting from a tornado strike with winds of 228 mph. Section 8 of the 65% Design provides full details on the analysis used to establish the new design requirements. Section 5 provides an assessment of credible high-wind events and the potential loss of pathogenic materials resulting from such events.

10.3.3 DHS/USDA Operational and Response Planning

Since publication of the 2010 SSRA, DHS has initiated or continued the following activities to further advance operational and response planning:

- Continued to engage the Plum Island Animal Disease Center (PIADC) to leverage 60 years of operating experience, knowledge, and planning documents;
- Leveraged and applied information from a highly successful CDC/USDA inspection of the National Biodefense and Countermeasures Center (NBACC) laboratory to support planning efforts;
- Engaged and continues to engage with local and regional emergency responders to initiate Memorandums of Understanding (MOUs) for needed response capabilities;
- Established the Research and Transition Working Group to begin formulating training requirements;
- Continued stakeholder engagements to ensure full understanding by local and regional community of the NBAF mission; and
- Established appropriate baseline biosafety guidelines for incorporation into design basis and standard operating procedures.

DHS has also started the development of the initial operating capability (IOC) of the NBAF in preparation for the migration of personnel, equipment, and operations from the PIADC facility. In collaboration with USDA, DHS is in the beginning stages of developing the NBAF Emergency Response Plan (ERP). The NBAF ERP will provide guidance and direction to assure an integrated and coordinated response to emergency situations at the NBAF. The ERP will include the delineated steps and actions needed for mitigation, preparedness, response, and recovery and will provide guidance and direction to assure an integrated and coordinated response to emergencies at the NBAF.

While DHS has started the development of operational and response plans, it has been purposefully slow to publish protocols, practices, and strategies. With laboratory commissioning and operations still several (7-8) years away, there is adequate time to develop, review, and inculcate scientific users, personnel, and response stakeholders without the risk of prematurely developing plans that may not be relevant when the facility is finally constructed. As research priorities and technology advance, it is important to have practices and procedures that represent the best available at the time of commissioning and operation. In addition, there may be some concerns about the enhancement of strategic risks related to public disclosure of sensitive information on U.S. countermeasure programs. However, as described above, the collaborative process is underway.

10.3.4 Response to NAS SSRA Committee Findings

DHS and the Updated SSRA have addressed the NAS SSRA Committee Findings that are summarized in Table 10.3.4-1. AppendixB1 provides the detailed comments received from the NAS SSRA Committee and references the section(s) where each comment is specifically addressed in the Updated SSRA.

Table 10.3.4-1: NAS SSRA Committee Findings Summary and DHS/Updated SSRA Response

Finding	Description	DHS Response
1	The 2010 SSRA lacks evidence to support the conclusion that the risk of release that results in infection is very low relative to the risk of infection introduced from an external source.	The 2010 SSRA did not attempt to quantify the risk of FMD infection from an external source. A risk-ranking and cumulative risk assessment are included in the Updated SSRA.
2	The 2010 SSRA overlooks some critical issues, both site-specific and non-site-specific, that could significantly elevate the risk of accidental release and spread of pathogens.	The Updated SSRA includes additional livestock data and infrastructure data from the surrounding area that have been collected and used in the assessment.
3	The 2010 SSRA has several methodological flaws related to dispersion modeling, tornado assessment, and epidemiological modeling. Thus, the committee believes that questions remain about the validity of the overall risk estimates.	Additional fidelity has been added to the meteorological modeling and local observations data have been included in the assessment. Sensitivity analyses were performed for the modeled conditions and discussion on the sensitivity is included in the report. Specifically with regard to NAADSM inputs, the epidemiological modeling performed in the Updated SSRA uses inputs and settings developed in conjunction with nationally recognized NAADSM experts and users. All of the input data, assumptions, and settings used in NAADSM are incorporated in the Updated SSRA documentation.
4	The committee agrees with the 2010 SSRA's conclusion that for FMDv, long-distance plume transport will likely be less important than the near-site exposure of cattle.	Near-site exposure is modeled in the Updated SSRA and illustrates the impact of transportation hubs and local premises with susceptible species.

Table 10.3.4-1: NAS SSRA Committee Findings Summary and DHS/Updated SSRA Response

Finding	Description	DHS Response
5	Substantial gaps in knowledge make predicting the course of an FMD outbreak very difficult, which led to weaknesses in the 2010 SSRA.	Additional knowledge and data were collected such that relevant advancements in FMDv research and knowledge have been reflected in the Updated SSRA. The Updated SSRA Team recognizes that there are scientific gaps in knowledge about FMDv (and other pathogens of interest such as Nipah and Hendra). However, as in any discipline, in order to inform decisions, the best available data were brought to bear, uncertainty was characterized and represented, risk were characterized, and recommendations were made accordingly.
6	Although the economic modeling was conducted with appropriate methods, the epidemiological estimates used as inputs to the 2010 SSRA were flawed.	Additional infrastructure reviews were performed and subject matter experts were engaged and interviewed to address the NAS SSRA Committee’s concerns. More realistic and representative initial culling rates were developed for the Updated SSRA and were incorporated in the modeling.
7	The committee agrees with the 2010 SSRA’s conclusion that early detection and rapid response can limit the impact of an FMDv release from the NBAF, but is concerned that the SSRA does not describe how the NBAF could rapidly detect such a release.	The risk assessment team is in full agreement with the NAS SSRA Committee’s observation on the importance of early detection and rapid response. DHS has initiated efforts to develop or leverage technologies that will be beneficial for surveillance and response strategies. The Updated SSRA provides additional information on the concept.
8	The 2010 SSRA lacks a comprehensive mitigation strategy developed with stakeholder input for addressing major issues related to pathogen release. The mitigation strategies that are provided do not realistically demonstrate current or foreseen capacity for how federal, state, and local authorities would effectively respond to and control a pathogen release.	The 2010 SSRA and the Updated SSRA were not intended to provide the comprehensive mitigation strategies. DHS (and others) are developing such strategies and have made significant progress since the performance of the 2010 SSRA. Information and data were collected from USDA experts on federal response strategies and these data were used in the Updated SSRA.

Table 10.3.4-1: NAS SSRA Committee Findings Summary and DHS/Updated SSRA Response

Finding	Description	DHS Response
9	The Committee agrees with the 2010 SSRA's conclusion that human error will be the most likely cause of an accidental pathogen release, and fomite carriage is the most likely way that a pathogen would escape the facility's outer biocontainment and biosecurity envelope.	Human error is a significant contribution to the potential for an accidental pathogen release. The Updated SSRA demonstrates that mitigation of fomites is an important consideration in the facility design and operational plans.
10	The committee agrees with the 2010 SSRA's conclusion that investment in biosafety and biosecurity engineering and the training of personnel and responders can reduce the risks, but is concerned about current design plans that potentially compromise safety measures.	The 65% Design is fully compliant with the recommendations and guidelines in the most recent version (Fifth Edition) of <i>Biosafety in Microbiological and Biomedical Laboratories</i> (BMBL) [USDHHS/CDCP, 2007]. Comprehensive design reviews have been conducted by an experienced team, including partners from international laboratories.
11	The 2010 SSRA's qualitative risk assessment of work with BSL-4 pathogens in large animals was inadequate.	An updated assessment of risks associated with working in a BSL-4 environment with livestock was performed. The conclusions and recommendations derived from this study are presented in the body of this report.

Acknowledgements

The Updated SSRA comprised a broad collaborative team that combined the experience, talents, and effort of a variety of domestic and international experts. Expertise was provided by individuals and consultants from private industry; academia; and international, national, state and local government entities, selected for their detailed knowledge of Department of Homeland Security (DHS) and United States Department of Agriculture (USDA) foreign animal disease programs or specific technical expertise. Below is a list of the individuals whose combined expertise and efforts performed the Updated SSRA and produced this Final Report. Some of these contributors were asked only to provide input and comments for subsections of the Updated SSRA. In such cases the reviewers and experts provided valuable input and suggestions and made substantive contributions to the Updated SSRA, but they were not asked to endorse the product in its entirety.

Contractors

This section lists the individuals who were compensated for their contributions to the Updated SSRA including the Prime Contractor, Signature Science, LLC's, key personnel and key personnel from subcontractors Gryphon Scientific, LLC, STAR Institute and SES Inc. This section also lists consultants who were paid under agreement with Signature Science, LLC or a subcontractor.

Prime Contractor, Signature Science, LLC

Adam L. Hamilton, P.E., M.S., C.H.S.

Program Manager

Engineering, Biosafety, Program Management

Dana R. Kadavy, Ph.D., PMP

Program Principal Investigator

Microbiology, Biosafety, Biosecurity

Sara C. Szmania, M.B.A., PMP, CQA

Deputy Program Manager

Microbiology, Public Health, Management

Molly Isbell, Ph.D., PMP, CQE

Task Lead Risk Calculations

Risk Analytics, Statistics

Myles W. Gardner, Ph.D.

Task Lead Event Descriptions

Analytical Chemistry

Kathy Tray

Program Administrator

Administration

Stephanie Normand, Ph.D., PMP

BSL4 Assessment Support

Medical and Veterinary Entomology

Elaine Stotts

SSRA Final Report Production

Administration

Michelle Gomez
SSRA Final Report Production
Administration

Aubrey Devine
SSRA Final Report Production
Administration

Robyn Guerrero
Fault Tree Development
Chemistry

Subcontractor, Gryphon Scientific, LLC

Rocco Casagrande, Ph.D.
Principal Investigator
Biology, Agricultural Threats, Modeling

Alexander Josephs
Data Collection, Modeling

Margaret Rush, Ph.D.
Project Manager
Biology, Epidemiological Modeling

Ashley Keller
Data Collection, Modeling

Mark Kazmierczak, Ph.D.
Transference Modeling
Biology, Data Collection, Modeling

Elizabeth Kramer
Data Collection, Modeling

Neelima Yeddanapudi, M.S.
Epidemiological Modeling
Data Collection, Modeling

Kimberly Legrow
Administration

Marib Akanda
Data Collection, Modeling

Jillian McVae
Data Collection, Modeling

Jessica Austin, M.S.
Data Collection, Modeling

Kerry Morrison
Data Collection, Modeling

Elizabeth Barnes
Data Collection, Modeling

Mark Mussante
Cost Benefit Analysis
Data Collection, Modeling

Vidya Eswaran
Data Collection

Jay Orr
Data Collection, Modeling

Russel Fielding
Data Collection, Modeling

Kyle Steinhouse
Data Collection, Modeling

Priyanka Gokhale
Data Collection

Matthew Whiting
Modeling

Ellie Graeden, Ph.D.
Data Collection, Modeling

Subcontractor, STAR

Paul Bieringer, Ph.D.

Plume Modeling

Tornado Climatology

George Bieberbach, M.S.

Plume Modeling

T&D Modeling, Climatology

Jeff Copeland, Ph.D.

Plume Modeling

Climatology

Scott Longmore, M.S.

Plume Modeling

T&D Modeling, Climatology

Scott Swerdlin, M.S.

Senior Management

Kelly Hellman

Financial and Security Officer

Ryan Cabell

Software and Engineering Support

Jonathan Hurst

Software Engineering Support

John Exby

IT Support

Courtney Gomez

Administrative Support

Carey Reynolds

Office Manager

Subcontractor, SES, Inc.

Frank Bryant, M.S., President

Data Collection

Eric Hess, M.S.

Data Collection

Patrick Splichal, M.S.

Data Collection

Amber Wilson, M.S.

Data Collection

Matt Lawrence

Data Collection

Bryan Deimeke, M.S.

Data Collection

Aaron Ball

Data Collection

Compensated (Consultant or Subcontractor) Subject Matter Experts

Mark A. Hopper, P.E., M.S.

Broaddus & Associates

Sanitary Sewer Assessment

*Sanitary Sewers, Containment Facilities
Development*

Gerrod W. Kilpatrick, P.E., M.S.

Broaddus & Associates

Sanitary Sewer Recommendations

Sanitary Sewers

James Bowers, M.S.

Kona Science Consulting

Plume Modeling

T & D Modeling SME

Steven Hanna, Ph.D.

Harvard School of Public Health

Plume Modeling

T & D Modeling, Source Terms

R. Ian Sykes, Ph.D.

Sage Management

Plume Modeling

T & D Modeling

Daran Rife, M.S.

NCAR

Plume Modeling

Climate downscaling, SOM

David S. Alburty

AlburtyLab, Inc.

Plume Modeling

Aerosol science

Dustin Pendell, Ph.D.

Colorado State University

Economic Modeling

Agricultural Economics

Jayson Lusk, Ph.D.

Oklahoma State University

Economic Modeling

Agricultural Economics

John Bilotta

O'Connor, Bilotta & Associates, LLC

Public Relations

Mary-Liz Lichtenfels

O'Connor, Bilotta & Associates, LLC

Public Relations

Holly Gaff, Ph.D.

Old Dominion University

Epidemiology

Disease Modeling

Michael Ward, Ph.D.

University of Sydney

Epidemiology

Disease Modeling

Robin Cosgrove

Zephyr Environmental Corporation

Technical Editing

Jeanne Yturri

Zephyr Environmental Corporation

Technical Editing

Steven Bolin, DVM, Ph.D.

Michigan State University

Containment Practices

Veterinary Virology

Cindy Wilson

Zephyr Environmental Corporation

Technical Editing

Jennifer L. Lyon, Ph.D., ELS

Associate Director, Center for Nano- and

Molecular Science and Technology

University of Texas at Austin

Technical Editing

Jon Crane, A.I.A.

CUH2A, HDR

Containment Practices

Science facility design

Keith Coble, Ph.D.
Mississippi State University
Economic Modeling
Agricultural Economics

Thomas L. Marsh, Ph.D.
Washington State University
Economic Modeling
Agricultural Economics

Paul Kitching, B.Sc., B.Vet.Med., M.Sc., Ph.D.,
M.R.C.V.S.
Chief Provincial Veterinary Officer, British
Columbia, Canada
Containment Practices
Foreign Animal Disease

Robert Ellis, Ph.D., DAVCM, CBSP
Colorado State University
Containment Practices
Microbiology, Biosecurity

John Clements, Ph.D.
Tulane University
Containment Practices
Microbiology

CJ Peters, M.D.
UTMB at Galveston
Containment Practices
Tropical Viruses

Dennis Perrotta, Ph.D.
TAMU Health Science Center
Containment Practices
Epidemiology

Kimothy Smith, DVM, Ph.D.
Operational Surveyors
Containment Practices
Epidemiology

Terrance M. Wilson, DVM, Ph.D.
ACVP – Private Consultant
Foreign Animal Disease

Uncompensated Contributors

Many SMEs from national, state, and local government institutions and entities lent their time and energy to the Updated SSRA without compensation from the Prime or Subcontractors. These experts contributed in event development, interviews, peer review, panel discussions, and data collection.

Non-U.S. Government Expertise

Scott Rusk
Director, Pat Roberts Hall
Biosecurity Research Institute

Lance Luftman
Facility Security Manager
Biosecurity Research Institute

Jerry Jaax, DVM
Associate V.P. for Research Compliance
University Veterinarian
Kansas State University

Darren Pascoe
Head, Quality Assurance; Institute Risk Manager
Institute for Animal Health (IAH), Pirbright, UK

David Shadwell
Site Engineer

Jason Tearle
Biorisk Advisor to the IAH Development
Programme
Institute for Animal Health (IAH), Pirbright, UK

Jef Hammond, Ph.D.
Head, World Reference Laboratory for FMD
Institute for Animal Health (IAH), Pirbright, UK

Lee Caines
Head of Security
Institute for Animal Health (IAH), Pirbright, UK

Steven Copping
Head of Compliance, Regulatory Affairs & Risk
Institute for Animal Health (IAH), Pirbright, UK

Patti Gillespie
Biorisk Manager
Public Health Agency of Canada

John Copps, DVM
Deputy Director
National Centre for Foreign Animal Diseases
Canadian Food Inspection Agency

Kelly Keith
Senior Communications Officer
Public Health Agency of Canada

Les Wittmeier
Manager, Technical Services
Public Health Agency of Canada

Martyn Jeggo, B.Vet.Med., M.Sc., Ph.D., M.R.C.V.S.
Director
Australian Animal Health Laboratory,
Geelong, Australia

Uwe Mueller-Doblies, Ph.D.
Head of Biosecurity
Institute for Animal Health (IAH), Pirbright, UK

Thomas Ksiazek, DVM, Ph.D.
Professor, Pathology
University of Texas Medical Branch

Michael Johnson, Ph.D.
Head of Pirbright Laboratory
Institute for Animal Health

Greg Smith, Ph.D.
Microbiological Security Manager
Commonwealth Scientific and Industrial Research
Organization

Stefan Wagener, Ph.D., C.B.S.P.
Scientific Director, Biorisk Management
National Microbiology Laboratory
Public Health Agency of Canada

Catherine Robertson, M.Sc.
Head, Safety and Environmental Services,
Public Health Agency of Canada

United States Government Experts

James V. Johnson, M.S.
Director
DHS, S&T, ONL

James Helt, Ph.D.
Operations Branch Chief
DHS, S&T, ONL

Larry Barrett, DVM, M.S., DACVPM
Center Director, PIADC
DHS, S&T, ONL

Joanne Jones-Meehan, Ph.D.
Biosurety Officer
DHS, S&T, ONL

L. Eugene Cole, II, R.A.
COTR, NBAF Design & Construction Contract
DHS, S&T, ONL

Michael Gallagher
Contractor Acquisition Specialist, Emergency
Management and Diagnostics
Veterinary Services
USDA, APHIS

Moon Paik
National Animal Health Emergency Response
Corps Advisor, Emergency Management and
Diagnostics
Veterinary Services
USDA, APHIS

Rodney White
Supervisory Logistics Specialist, Emergency
Management and Diagnostics
Veterinary Services
USDA, APHIS

Thomas Mettenleiter, Ph.D.
Freidrich-Loeffler Institute
Federal Research Institute for Animal Health

Mustafa S. Altinaker, Ph.D.
Director and Research Professor
National Center for Computational Hydroscience
and Engineering
University of Mississippi

Steve Bennett, Ph.D.
Assistant Director, Risk Analytics
DHS, NPPD

Bruce Harper, Ph.D.
Director of Science, PIADC
DHS, S&T, ONL

Michelle M. Colby, DVM, M.S.
Agricultural Defense Branch Chief
DHS, S&T, Chem Bio Division

Julie S. Brewer, M.S.
Construction Branch Chief
DHS, S&T, ONL
NBAF PM

Renee Hickson
Contracting Officer
DHS/FLETC

William R. White, BVSc., M.P.H.
Lead Veterinarian, PIADC
DHS

Elizabeth Lautner, DVM, M.S.
Director, National Veterinary Services Laboratories
USDA, APHIS

Daisy Witherspoon
Veterinary Services
USDA, APHIS

Jane Rooney, DVM
Veterinary Services
USDA, APHIS

Sharon Fisher
Chief of Staff, Emergency Management and
Diagnostics
Veterinary Services
USDA, APHIS

Joseph Kozlovac, M.S., RBP, CBSP
Biological Safety Officer
USDA, ARS

Cyril Gerard Gay, DVM, Ph.D.
Senior National Program Leader
USDA, ARS

Charles Wenderoth
Facility Engineer, PIADC
DHS

Tammy Beckham, DVM, Ph.D.
Director
National Center for Foreign Animal Disease and
Zoonotic Disease Defense

Christopher Broder, Ph.D.
Director
Uniformed Services University of the Health
Sciences

Danny T. Hager
Procurement Executive
DHS/FLETC

Robert E. Driggers, M.S.
Contracting Officer
DHS/FLETC

Nicki Pesik, M.D.
Associate Director for Biosecurity;
Epidemiology Team Lead;
Bacterial Zoonoses Branch
National Center for Emerging and Zoonotic
Diseases (NCEZID) (proposed)
Centers for Disease Control and Prevention

Stuart T. Nichol, Ph.D.,
Chief, Special Pathogens Branch,
Division of Viral and Rickettsial Diseases,
NCEZID (proposed)
Centers for Disease Control and Prevention

Jonathan T. Zack, DVM
Director, Preparedness & Incident Coordination,
Emergency Management and Diagnostics
USDA, APHIS

José R. Díez, DVM
Associate Deputy Administrator, Emergency
Management and Diagnostics
Veterinary Services
USDA, APHIS

James Palmieri
Security Manager, PIADC
DHS

Luis L. Rodriguez, DVM, Ph.D.
Research Leader, PIADC
USDA, ARS

Marvin J. Grubman, Ph.D.
Supervisory Research Chemist, PIADC
USDA, ARS

Thomas Sawicki
Biological Safety Officer, PIADC
USDA, ARS, NAA

Michael Robertson
AAAS S&T Policy Fellow
DHS, Chem Bio Division, S&T

John Balog
Biosafety Program Manager
USDA, APHIS

Steven Kappes, Ph.D.
Deputy Administrator, Animal Production and
Protection
USDA, ARS

Greg Pompelli, Ph.D.
Acting Associate Administrator
USDA, Economic Research Service

Natasha L. Hawkins
Senior Risk Analyst
Office of Risk Management and Analysis
DHS, NPPD

Randall L. Crom, DVM
Senior Staff Veterinarian
National Center for Animal Health Emergency
Management
USDA, APHIS

Kimberly Forde-Folle, DVM, M.S.
Veterinary Epidemiologist
USDA, APHIS

Mark E. Teachman, DVM
Director
National Center for Animal Health Emergency
Management
USDA, APHIS

Pierre E. Rollin, M.D.
Special Pathogens Branch
Centers for Disease Control and Prevention

Ken Linthicum, Ph.D.
Center Director
Center for Medical, Agricultural & Veterinary
Entomology
USDA ARS

Debra Elkins
Section Chief, Risk Assessments and Analysis
Office of Risk Management and Analysis
DHS, NPPD

Fernando Torres-Velez, Ph.D., DVM
Head of Diagnostic Services Section
NVSL Foreign Animal Disease Diagnostic
Laboratory, USDA APHIS

Anne Marie Zaudtke
SETA Support Contractor
DHS, S&T, Chem Bio Division

Sharla Rausch
Acting Deputy Director
DHS, S&T, ONL

Timothy Barr
NBAF Site Manager
DHS, S&T, ONL

NBAF Design Partners

Dan Watch, A.I.A.
Perkins + Will
Project Executive

Michael Moreland, LEED AP
Perkins + Will
Project Manager
Steve Freson, A.I.A.
Flad Architects
Lead Vivarium Planner

Chris Kronser, A.I.A., RA, NCARB, LEED AP
Flad Architects
Large Animal Architect

Paul Langevin, P.Eng.
Senior Vice President
Merrick Canada ULC
Director of Laboratory Design

Chris Kiley, P.E.
Merrick & Company
Senior Mechanical Engineer

Ken Meschke, P.E.
Affiliated Engineers, Inc.
Project Manager

David Duthu, P.E.
CCRD Partners
Project Manager

Jennifer Gaudioso, Ph.D.
Sandia National Laboratories
Biosecurity

Booz Allen Hamilton (DHS S&T SETA)

Tony Bonanno, M.S.
Planner

Naeem Brewington
Architect, Program Support

Douglas Smith, Jr., M.S.
Architect

Persons Interviewed for Baseline Data Collection, Emergency Response & Planning

Arkansas

Joslyn Burleson
Program Coordinator
Arkansas Dept. of Environmental Quality
Water Division Permits Branch

California

Kent Fowler, DVM
Animal Health Branch Chief
California Dept. of Food and Agriculture

Tammy Hernandez
California Dept. of Food and Agriculture

Nicole Elbert
Livestock Inspector
California Dept. of Food and Agriculture, Animal
Health Branch

Colorado

Billy W. Bennett, DVM
Director, Homeland Security
Colorado Commissioners Office, Colorado Dept. of
Agriculture

Keith Roehr, DVM
State Veterinarian
Colorado Dept. of Agriculture

Erin Kress
Colorado Dept. of Public Health & Environment
Environmental Agriculture Program

Nick Striegel, DVM, M.P.H.
Assistant State Veterinarian
Colorado Dept. of Agriculture

Florida

Mary Smith
Environmental Consultant
Florida Dept. of Environmental Protection

Illinois

Janet Christer
FOIA Coordinator
Illinois Bureau of Water

Linda Rhodes
Illinois Dept. of Agriculture

Indiana

Denise Derrer
Public Information Director
Indiana State Board of Animal Health

Randall Tauer
Agricultural Liaison
Indiana Dept. of Environmental Management

Iowa

Claire Hruby
Geologist
Iowa Dept. of Natural Resources

Randy Wheeler, DVM
Assistant State Veterinarian and
Iowa Veterinary Rapid Response Team Coordinator
Iowa Dept. of Agriculture and Land Stewardship

David Schmitt, DVM
State Veterinarian
Iowa Dept. of Agriculture and Land Stewardship

Janet Bowers
Iowa Import Clerk
Iowa Depart. of Agriculture and Land Stewardship

Kansas

Mary Lou Marino, Ph.D.
Development Director
Office of Research and Sponsored Programs,
Kansas State University

Angee Morgan
Deputy Director
Kansas Division of Emergency Management
(KDEM)

Brad Moeller
Hazard Mitigation Planner
KDEM

Bill Brown, DVM
Kansas Livestock Commissioner, Elect

Bill Bryant, DVM
State Veterinarian
Kansas Animal Health Dept

Brandt Haehn
Planning & Mitigation Branch Chief
KDEM

Bruce Brazzle
Fire Supervisor
Pottawatomie County Emergency Mgmt.

Julie Miller, R.N.
Clinical Coordinator
Emergency Dept.
Mercy Regional Health Center, Manhattan
Karen Domer
Administrative Specialist
Kansas Animal Health Dept.

Kyle Voth
Inspector
Manhattan Fire Dept.

Larry Couchman, R.N., M.I.C.T.
Director
Emergency Services & Riley County EMS
Mercy Regional Health Center, Manhattan

Dr. Asad Mohmand, M.D.
Infection Disease Specialist
Mercy Regional Health Center
Manhattan, Kansas

Laurie Harrison
Coordinator
Riley County Emergency Mgmt

Lloyd B. Fox, Ph.D.
Big Game Program Coordinator
Kansas Dept. of Wildlife and Parks

Maj. Dave Young
Kansas National Guard (detailed to KDEM)
Evaluation and Education
Eisenhower Center for Homeland Security
Research

Marty Vanier, DVM
Director of Operations
National Agriculture Biosecurity Center
Kansas State University

Michael McNulty
Operations Director
Bureau of Public Health Preparedness
KDHE

Mindee Reece
Director
Center for Public Health Preparedness
KDHE

Scott French
Assistant Chief
Manhattan Fire Dept.

Steven Broccolo
Coordinator, Emergency Management
Kansas State University

Steven Galitzer, Ph.D.
Director
Dept of Environmental Health and Safety,
Kansas State University

Swapan Saha, Ph.D.
Environmental Scientist
KDEM

Theresa Crubel, R.N.
Director, Occupational Health Services
Mercy Regional Health Center,
Manhattan, Kansas

Vivian Nutsch, R.N.
Infection Control Nurse
Mercy Regional Health Center, Manhattan, Kansas

Gary Brinker
Director
Docking Institute of Public Affairs
Fort Hays State University

Chris Trudo
Emergency Manager
Pottawatomie County Emergency Mgmt.

Brett Zollinger, Ph.D.
Senior Policy Fellow
Docking Institute of Public Affairs
Fort Hays State University

Craig Beardsley
Program Administrator
National Agricultural Biosecurity Center
Kansas State University

Steven J. Galitzer
Director
Dept. of Environmental Health & Safety
Kansas State University

Danny Woodworth
Director
Plant Engineering, Safety, and Security
Mercy Regional Health Center, Manhattan

David Vogt, DVM
Area Veterinarian-in-Charge
USDA-APHIS

Don Francis
Deputy Chief
Manhattan, Kansas Fire Dept.

James Laurino, M.D.
Medical Director, Occupational Health Services
Mercy Regional Health Center,
Manhattan, Kansas

Mike Heideman
Communications and Training Specialist
KDHE, Bureau of Public Health Preparedness

Captain Rob Ladner
Regional Law Enforcement Supervisor (Topeka)
Kansas Dept. of Wildlife and Parks

Shane Hesting
Wildlife Disease Coordinator
Kansas Dept. of Wildlife and Parks

Rick McKee
Senior Vice President
Kansas Livestock Association

Sam Dameron
Chief Training Officer
Manhattan Fire Dept.

Marty Vanier, DVM
Director of Operations
National Agricultural Biosecurity Center
Kansas State University

R.W. Trewyn, Ph.D.
Vice President for Research
Kansas State University

George Teagarden
Livestock Commissioner
Kansas Animal Health Dept.

Ingrid C. Garrison
Environmental Health Officer and State Public
Health Veterinarian
KDHE

Patrick R. Collins
Director, Emergency Management and Fire Chief
Riley County Emergency Management

Matt Peek
Kansas Dept. of Wildlife and Parks

Clayton Hughesman
Executive Director
Feedlot Division
Kansas Livestock Association

Ryan Almes
Fire Marshall
Manhattan Fire Dept.

Sandy Johnson
Homeland Security Specialist
Office of the Secretary
Kansas Dept of Agriculture

Stephen Higgs Ph.D. F.R.E.S.,
Associate Vice President for Research,
Research Director, Biosecurity Research Institute
(BRI),
Peine Professor of Biosecurity,
Professor, Diagnostic Medicine & Pathobiology,
Kansas State University.

Kentucky

Morgan P. Elliston
Freedom of Information Coordinator
Kentucky Division of Water

Sue K. Billings, DVM, MSPH
Deputy State Veterinarian
Office of the State Veterinarian
Kentucky Dept. of Agriculture

Robert Stout, DVM
Executive Director
Office of the State Veterinarian
Kentucky Dept. of Agriculture

Michigan

Chris Sinicropi
Administration Section Secretary
Michigan Dept. of Natural Resources
Water Bureau

Marcia Weld
Dept. Analyst
Michigan Dept. of Agriculture
Animal Industry Division

Minnesota

Tamara D. Dahl, MPCA
Data Specialist, Pollution Control
Minnesota Pollution Control Agency

Stacey Schwabenlander, DVM, M.P.H.
Minnesota Board of Animal Health

Beth Thompson, JD, DVM
Senior Veterinarian
Minnesota Board of Animal Health

Missouri

Linda Hickham, DVM
Missouri Dept of Agriculture
Division of Animal Health

Sarah Wilkinson
Senior Office Support Assistant
Missouri Dept. of Agriculture
Division of Animal Health

Sherwet Witherington
Agri-Security Manager
Missouri Dept. of Agriculture
Division of Animal Health

Taylor Woods, DVM
State Veterinarian
Missouri Dept. of Agriculture
Division of Animal Health

Tony Dohmen
Environmental Specialist
Missouri Dept. of Natural Resources

Ohio

Charles King, MD
Professor of International Health
Case Western Reserve University
Center for Global Health and Diseases

Oklahoma

Becky Brewer-Walker, DVM
State Veterinarian
Oklahoma Dept. of Agriculture
Food and Forestry

Elizabeth Tennery
Assistant General Counsel
Oklahoma Dept. of Agriculture/Food and Forestry

Debbie Cunningham, DVM
Staff Veterinarian
Oklahoma Dept. of Agriculture
Food and Forestry

Jon Bernstein
Environmental Specialist
Ohio Environmental Protection Agency
Division of Surface Water

Nebraska

Daniel C. Hiller
Supervisor, Planning Dept.
Nebraska Emergency Management Agency

Dennis A. Hughes, DVM
Nebraska Dept. of Agriculture
Bureau of Animal Industry

Rachel Ahrens
Staff Assistant
Nebraska Dept of Environmental Quality

North Carolina

Bruce Shankle
Manager
Livestock Section, NCDA & CS
Marketing Division

Keith Larick
Animal Feeding Operations Unit Supervisor
North Carolina Division of Water Quality

Tom Ray, DVM, M.P.H.
Director, Animal Health Programs, Livestock
NCDA&CS, Veterinary Division

South Dakota

Kent R. Woodmansey, P.E.
Natural Resources Engineering Director
Surface Water Quality Program

Todd Tedrow, DVM
Animal Industry Board Veterinarian
South Dakota Animal Industry Board

Lacey Poile
Records Supervisor
South Dakota Animal Industry Board

Texas

Jim Hay
Open Records Coordinator
Texas Commission on Environmental Quality
(TCEQ)
Open Records & Reporting Services

Barbara Hallmark
Program Supervisor
Program Records Dept.
Texas Animal Health Commission

Wisconsin

Cindy Adamson
USDA
National Agricultural Statistics Service
Wisconsin Field Office

Persons that Provided Additional Input for Modeling

Aaron Reeves
Research Associate
Animal Population Health Institute
Dept. of Clinical Sciences
Colorado State University

John Sterman
Director, MIT Systems Dynamics Group
Sloan School of Management
Massachusetts Institute of Technology

Neil Harvey
Research Associate
Department of Computing and Information Science
University of Guelph

Mike Sanderson, DVM, MS, DACT, DACVPM
Professor, Production Medicine
College of Veterinary Medicine
Kansas State University

Mo Salman, DVM, MPVM, Ph.D, DACVPM, F.A.C.E.
Professor of Veterinary Epidemiology
Departments of Clinical Sciences and Environmental
and Radiological Health Sciences
Colorado State University

Sangeeta Rao, BVSc, MVSc, PhD
Research Scientist
Animal Population Health Institute
Colorado State University

Bibliography

- Abdalla, A., Beare, S., Cao, L., Garner, G. and Heaney, A. (2005). "Foot and Mouth Disease: Evaluating Alternatives for Controlling a Possible Outbreak in Australia," *ABARE eReport* 05.6., ABARE, Canberra.
- Abraham, Gordon, Le Blanc Smith, Peter Michael and McCabe, Phillip (1999). "HEPA Filter Replacement Experience in a Biological Laboratory," *Journal of the American Biological Safety Association*, 3(4), 134-142,
- Aggarwal, N., Zhang, Z., Cox, S., Statham, R., Alexandersen, S., Kitching, R. P. and Barnett, P. V. (2002). "Experimental studies with foot-and-mouth disease virus, strain O, responsible for the 2001 epidemic in the United Kingdom," *Vaccine*. 2002/06/12, 20 (19-20), 2508-2515, DOI: S0264410X02001780 [pii], 0264-410X (Print) 0264-410X (Linking), Retrieved: Jun 7, <http://www.ncbi.nlm.nih.gov/pubmed/12057606>.
- Aida, N., et al. (2008). "Population analysis of *Aedes albopictus* (Skuse) (Diptera: Culicidae) under uncontrolled laboratory conditions," *Tropical Biomedicine*. 25 (2), 117-125, http://www.msptm.org/files/117_-_125_Nur_Aida.pdf.
- Alexandersen, S., and Donaldson, A.I. (2002). "Further studies to quantify the dose of natural aerosols of foot-and-mouth disease virus for pigs," *Epidemiology and Infection*. 128 (2), 313-323, <http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=102581>.
- Alexandersen, S., et al. (2002). "Natural aerosol transmission of foot-and-mouth disease virus to pigs: minimal infectious dose for strain 01 Lausanne," *Epidemiol Infect.* 128, 301-312, <http://www.ncbi.nlm.nih.gov/pubmed/12002549>.
- Alexandersen, S., et al. (2002). "Quantities of infectious virus and viral RNA recovered from sheep and cattle experimentally infected with foot-and-mouth disease virus O UK 2001," *Journal of General Virology*. 83, 1915-1923.
- Alexandersen, S., et al., (2003). "The Pathogenesis and Diagnosis of Foot-and-Mouth Disease," *J. Comp. Path.* 129, 1-36.
- Alvarez, L. G., Webb, C. R. and Holmes, M. A. (2011). "A novel field-based approach to validate the use of network models for disease spread between dairy herds," *Epidemiology and Infection*, 139(12), 1863-1874, DOI:10.1017/s0950268811000070,
- Amass, Sandra F., Mason, Peter W., Pacheco, Juan M., Miller, Cheryl A., Ramirez, Antonio, Clark, L. Kirk, Ragland, Darryl, Schneider, Jessica L. and Kenyon, Simon J. (2004). "Procedures for preventing transmission of foot-and-mouth disease virus (O/TAW/97) by people," *Veterinary Microbiology*, 103(3-4), 143-149, <http://www.sciencedirect.com/science/article/pii/S0378113504003190>.

- Amassa, Sandra F, Masonb, Peter W., Pachecob, Juan M., Millerc, Cheryl A., Antonio Ramirezd, Clarka, L. Kirk, Raglanda, Darryl, Schneidera, Jessica L. and Kenyona, Simon J. (2004). "Procedures for preventing transmission of foot-and-mouth disease virus (O/TAW/97) by people," *Veterinary Microbiology*, 103, 143-149,
- American Society of Agricultural Engineers (2003). "Manure Production and Characteristics," ASAE. D384 (1 FEB03).
- (2005). "Manure Production and Characteristics."
- Amlot, Richard, et al. (2010). "Comparative Analysis of Showering Protocols for Mass-Casualty Decontamination," *Prehospital and Disaster Medicine*,
- Anderson, I. (2008, March 11). "Foot and Mouth Review: 2007, A Review and Lessons Learned," <http://archive.cabinetoffice.gov.uk/fmdreview/>.
- Ansari, S. A., et al. (1988). "Rotavirus survival on human hands and transfer of infectious virus to animate and nonporous inanimate surfaces," *J. Clin. Microbiol.* 26, 1513-1518.
- Ansari, Shamim A., et al. (1989). "In Vivo Protocol for Testing Efficacy of Hand-Washing Agents against Viruses and Bacteria: Experiments with Rotavirus and Escherichia coli," *Applied and Environmental Microbiology*. Dec, 3113-3118.
- Ansari SA, Springthorpe VS, et al (1991). "Potential role of hands in the spread of respiratory viral infections: studies with human parainfluenza virus 3 and rhinovirus 14. ," *Journal of Clinical Microbiology*. 29, 2115-2119.
- Arunkumar, R., et al. (2004). "Evaluation of Mass Emission Rates Down Stream of HEPA Filters as a Function of Source Terms and Selected Failure Modes," *WM '04 Conference*. February 29-March 4, 2004, Tucson, AZ, WM-4279.
- AUSVETPLAN (2006). "Australian Veterinary Emergency Plan (AUSVETPLAN), Edition 3, Disease Strategy Foot-and-Mouth Disease (VERSION 3.1)," Primary Industries Ministerial Council, Canberra, ACT.
- Ayliffe, G.A.J., et al. (1990). "Hygienic Hand Disinfection Tests in Three Laboratories," *J. Hosp. Infect.* 16, 141-149.
- Bachrach, H. (1968). "Foot-and-Mouth Disease," *Annual Review of Microbiology*. 201-244.
- Bardell, D. (1989). "Hand-to-hand transmission of herpes simplex virus type 1," *Microbios* 59, 93-100.
- Barnett, P. V. and Carabin, H. (2002). "A review of emergency foot-and-mouth disease (FMD) vaccines," *Vaccine*. 2002/02/23, 20 (11-12), 1505-1514, DOI: S0264410X01005035 [pii], 0264-410X (Print) 0264-410X (Linking), Retrieved: Feb 22, <http://www.ncbi.nlm.nih.gov/pubmed/11858856>.

- Barnett, P. V., Keel, P., Reid, S., Armstrong, R. M., Statham, R. J., Voyce, C., Aggarwal, N. and Cox, S. J. (2004). "Evidence that high potency foot-and-mouth disease vaccine inhibits local virus replication and prevents the 'carrier' state in sheep," *Vaccine*. 2004/03/09, 22 (9-10), 1221-1232, DOI: 10.1016/j.vaccine.2003.09.024 S0264410X03006984 [pii], 0264-410X (Print) 0264-410X (Linking), Retrieved: Mar 12, <http://www.ncbi.nlm.nih.gov/pubmed/15003651>.
- Barnett, P. V., Pullen, L., Williams, L. and Doel, T. R. (1996). "International bank for foot-and-mouth disease vaccine: assessment of Montanide ISA 25 and ISA 206, two commercially available oil adjuvants," *Vaccine*. 1996/09/01, 14 (13), 1187-1198, DOI: S0264410X96000552 [pii], 0264-410X (Print) 0264-410X (Linking), Retrieved: Sep, <http://www.ncbi.nlm.nih.gov/pubmed/8961504>.
- Baxt, B. and Mason, P. W. (1995). "Foot-and-mouth disease virus undergoes restricted replication in macrophage cell cultures following Fc receptor-mediated adsorption," *Virology*, 207(2), 503-509, <http://www.ncbi.nlm.nih.gov/pubmed/7886954>.
- Bean, B., Moore, B. M., Sterner, B., Peterson, L. R., Gerding, D. N. and Balfour, H. H., Jr. (1982). "Survival of influenza viruses on environmental surfaces," *Journal of Infectious Diseases*. 1982/07/01, 146 (1), 47-51, 0022-1899 (Print) 0022-1899 (Linking), Retrieved: Jul, <http://www.ncbi.nlm.nih.gov/pubmed/6282993>.
- Bellamy, K., Alcock, R., Babb, J. R., Davies, J. G. and Ayliffe, G. A. (1993). "A test for the assessment of 'hygienic' hand disinfection using rotavirus," *J Hosp Infect*. 1993/07/01, 24 (3), 201-210, DOI: 0195-6701(93)90049-6 [pii], 0195-6701 (Print) 0195-6701 (Linking), Retrieved: Jul, <http://www.ncbi.nlm.nih.gov/pubmed/8104210>.
- Berhane, Yohannes, Berry, Jody D., Ranadheera, Charlene, Marszal, Peter, Nicolas, Brigitte, Yuan, Xin, Czub, Markus and Weingartl, Hana (2006). "Production and characterization of monoclonal antibodies against binary ethylenimine inactivated Nipah virus," *Journal of Virological Methods*, 132(1-2), 59-68, <http://www.sciencedirect.com/science/article/pii/S0166093405002879>.
- Berhane, Y., Weingartl, H. M., Lopez, J., Neufeld, J., Czub, S., Embury-Hyatt, C., Goolia, M., Copps, J. and Czub, M. (2008). "Bacterial Infections in Pigs Experimentally Infected with Nipah Virus," *Transboundary and Emerging Diseases*, 55(3-4), 165-174, <http://onlinelibrary.wiley.com.ezproxy.lib.utexas.edu/doi/10.1111/j.1865-1682.2008.01021.x/abstract>.
- Best, M., Springthorpe, V.S., Sattar, S.A., & Bact, D. (1994 abstract accessed online 20 December 2011). "Feasibility of a combined carrier test for disinfectants: studies with a mixture of five types of microorganisms," *American Journal of Infection Control*. Vol. 22 (Issue 3), pp. 152-162, <http://www.sciencedirect.com/science/article/pii/S0196655394900043>.
- Bidawid S, Farber JM et al (2000). "Contamination of foods by food handlers: experiments on hepatitis A virus transfer to food and its interruption," *Applied and Environmental Microbiology* 66, 2759-2763.
- Billings, Sue, DVM (2010, April 22). "KYdatNBAF," Office of the State Veterinarian, Kentucky Department of Agriculture, Personal correspondence.

- Blackwell, J. H., McKercher, P. D., Kosikowski, F. V., Carmichael, L. E. and Gorewit, R. C. (1982). "Concentration of foot-and-mouth disease virus in milk of cows infected under simulated field conditions," *Journal of Dairy Science*, 65(8), 1624-1631, <http://www.ncbi.nlm.nih.gov/pubmed/6292275>.
- Blake, A., Sinclair, M.T. and Sugiyarto, G., (2002). "The Economy-Wide Effects of Foot and Mouth Disease in the UK Economy," Cristel DeHaan Tourism and Travel Institute, Nottingham Business School, <http://www.nottingham.ac.uk/ttri/>.
- Blayney, D.P. (2005). "Disease-Related Trade Restrictions Shaped Animal Product Markets in 2004 and Stamp Imprints on 2005 Forecasts," USDA, Economic Research Service (August 2005), LDP-M-133-101.
- Bossart, K.N., Bingham, J., & Middleton, D. (2007). "Targeted Strategies for Henipavirus Therapeutics," *The Open Virology Journal*. Vol. 1, pp. 14-25.
- Bossart, K.N., Geisbert, T.W., Heinz, F., Zhongyu, Z., Feldman, F., Geisbert, J.B., Yan, L., Feng, Y., Brining, D., Scott, D., Wang, Y., Dimitrov, A.S., Callison, J., Chan, Y., Hickey, A.C., Dimitrov, D.S., Broder, C.C., & Rockx, B. (2011). "A Neutralizing Human Monoclonal Antibody Protects African Green Monkeys from Hendra Virus Challenge," *Science Translational Medicine*. Vol. 3 (Issue 105), pp. 1-8.
- Bouma, A., Dekker A et al (2004). "No foot-and-mouth disease virus transmission between individually housed calves," *Vet Microbiol* 98, 29-36.
- Brocchi, E., Bergmann, I. E., Dekker, A., Paton, D. J., Sammin, D. J., Greiner, M., Grazioli, S., De Simone, F., Yadin, H., Haas, B., Bulut, N., Malirat, V., Neitzert, E., Goris, N., Parida, S., Sorensen, K. and De Clercq, K. (2006). "Comparative evaluation of six ELISAs for the detection of antibodies to the non-structural proteins of foot-and-mouth disease virus," *Vaccine*. 2006/06/07, 24 (47-48), 6966-6979, DOI: S0264-410X(06)00500-7 [pii] 10.1016/j.vaccine.2006.04.050, 0264-410X (Print) 0264-410X (Linking), Retrieved: Nov 17, <http://www.ncbi.nlm.nih.gov/pubmed/16753241>.
- Broyles, J. M., O'Connell, K. P., and Korniewicz, D. M. (2002). "PCR-Based Method for Detecting Viral Penetration of Medical Exam Gloves," *J Clin Microbiol* 40, 2725-2728.
- Burrows, R. (1966). "The infectivity assay of foot-and-mouth disease virus in pigs," *J Hyg (Lond)*. 64, 419-429.
- Burrows, R. (1968). "The persistence of foot-and mouth disease virus in sheep," *The Journal of Hygiene*, 66(4), 633-640, <http://www.ncbi.nlm.nih.gov/pubmed/4303955>.
- Burrows R, Mann JA et al (1981). "The pathogenesis of natural and simulated natural foot-and-mouth disease infection in cattle," *J Comp Pathol* 91, 599-609.
- Burton, C.S., Stoeckenius, J.P. and Nordin, J.P. (1983). "The Temporal Representativeness of Short-Term Meteorological Data Sets: Implications for Air Quality Impact Assessments," (Docket No. A-80-46, II-G-11), Systems Applications Inc.

- Cadwallader, L.C. (1998, September). "Selected Component Failure Rate Values From Fusion Safety Assessment Tasks," Lockheed Martin, INEEL/EXT-98-00892.
- Cagnolati, V., Tempia, S. and Abdi, A. M. (2006). "Economic Impact of Rift Valley Fever on the Somali Livestock Industry and a novel surveillance approach in nomadic pastoral Systems," *Proceedings of the 11th International Symposium on Veterinary Epidemiology and Economics*.
- California Water Boards (2009). "Annual Performance Report - Fiscal Year 2008-09," Retrieved: June 9, 2010,
http://www.waterboards.ca.gov/about_us/performance_report/plan_assess/1241_sso_sewage_spills.shtml.
- Campbell, C. H. (1969). "Virulence, adsorbability, and antigenicity of foot-and-mouth disease virus selected by adsorption with homogenized mouse kidney," *Archiv Für Die Gesamte Virusforschung*, 26(3), 238-248, <http://www.ncbi.nlm.nih.gov/pubmed/4306368>.
- Carpenter, T. E., Christiansen, L. E., Dickey, B. F., Thunes, C. and Hullinger, P. J. (2007). "Potential impact of an introduction of foot-and-mouth disease into the California State Fair," *Journal of the American Veterinary Medical Association*. 2007/10/17, 231 (8), 1231-1235, DOI: 10.2460/javma.231.8.1231, 0003-1488 (Print) 0003-1488 (Linking), Retrieved: Oct 15.
- Carpenter, T. E., O'Brien, J. M., Hagerman, A. D. and McCarl, B. A. (2011). "Epidemic and economic impacts of delayed detection of foot-and-mouth disease: a case study of a simulated outbreak in California," *Journal of veterinary diagnostic investigation: official publication of the American Association of Veterinary Laboratory Diagnosticians, Inc.* 2011/01/11, 23 (1), 26-33, 1943-4936 (Electronic) 1040-6387 (Linking), Retrieved: Jan.
- Carrillo, C., Lu, Z., Borca, M. V., Vagnozzi, A., Kutish, G. F. and Rock, D. L. (2007). "Genetic and Phenotypic Variation of Foot-and-Mouth Disease Virus during Serial Passages in a Natural Host," *Journal of Virology*, 81(20), 11341-11351,
- Carroll, J. (2011). "Vice President Quality Assurance & Regulatory Affairs for Fluid Milk, Dairy Farmers of America".
- Casagrande, R. (2000). "Biological Terrorism Targeted at Agriculture: the threat to US national security," *The Nonproliferation Review*. Fall/Winter.
- Cassano, J.J., Uotila, P. and Lynch, A. (2006). "Changes in synoptic weather patterns in the polar regions in the twentieth and twenty-first centuries, Part 1: Arctic," *Int. J. Climatol.* 26, 1027-1049.
- CDC (2007). "Hendra Virus Disease and Nipah Virus Encephalitis," National Center for Infectious Diseases, Special Pathogens Branch,
<http://www.cdc.gov/ncidod/dvrd/spb/mnpages/dispages/nipah.htm>, 25 October 2011.
- CDM/BG Team (2009, March). "Sanitary Sewer Collection System Master Plan Update," City of Manhattan, Public Works Department,
<http://ci.manhattan.ks.us/DocumentView.aspx?DID=6200>.

- Chadha M., et al. (2006). "Nipah virus-associated encephalitis outbreak, Siliguri, India.," *Emerg Infect Dis*, 12, 125-240,
- Chen, L. and Gasteiger, J. (1997). "Knowledge discovery in reaction databases: landscaping organic reactions by a self organizing map," *J. Am. Chem. Soc.* 119, 4033-4042.
- Chen, Y. S. and Vaughn, J. M. (1990). "Inactivation of human and simian rotaviruses by chlorine dioxide," *Applied and Environmental Microbiology*, 56(5), 1363-1366, <http://aem.asm.org/content/56/5/1363.abstract>.
- Chua, K B (2003). "Nipah virus outbreak in Malaysia," *Journal of Clinical Virology*. 26(3), 265-275.
- Chua, K. B., Lam, S. K., Goh, K. J., Hooi, P. S., Ksiazek, T. G., Kamarulzaman, A., Olson, J. and Tan, C. T. (2001). "The Presence of Nipah Virus in Respiratory Secretions and Urine of Patients during an Outbreak of Nipah Virus Encephalitis in Malaysia," *Journal of Infection*, 42(1), 40-43, <http://www.sciencedirect.com/science/article/pii/S0163445300907825>.
- City of Manhattan (2011). Population, <http://www.city-data.com/city/Manhattan-Kansas.html>.
- Coffey, B., J. Mintert, S. Fox, T. Schroeder, L. Valentin (2005). "The Economic Impact of BSE on the U.S. Beef Industry: Product Value Losses, Regulatory Costs, and Consumer Reactions, MF-2678," Kansas State University Agricultural Experiment Station and Cooperative Service.
- Cohen, Hubal, et al. (2005). "Characterizing residue transfer efficiencies using a fluorescent imaging technique," *J Expo Anal Environ Epidemiol*. 15, 261-270.
- Cohen, Hubal, et al. (2007). "Comparing Surface Residue Transfer Efficiencies to Hands using Polar and Nonpolar Fluorescent Tracers," *Environ. Sci. Technol*. 42, 934-939.
- Conrad, J.M., P.S. Gibson, and M. Peek (2006, July 23-26). "Historical and Current Status of Elk in Kansas," *Prairie Invaders: Proceedings of the North American Prairie Conference*. 307-312, Joseph T. Springer and Elaine C. Springer, University of Nebraska at Kearney.
- Constantine, D.G. (2003). "Geographic Translocation of Bats: Known and Potential Problems," *Emerging Infectious Diseases*. Vol. 9 (No. 1), pp. 17-21.
- Cooper, S. M., Scott, H. M., de la Garza, G. R., Deck, A. L. and Cathey, J. C. (2010). "Distribution and interspecies contact of feral Swine and cattle on rangeland in South Texas: implications for disease transmission," *J Wildl Dis*. 2010/01/22, 46 (1), 152-164, DOI: 46/1/152 [pii], 1943-3700 (Electronic) 0090-3558 (Linking), Retrieved: Jan, <http://www.ncbi.nlm.nih.gov/pubmed/20090028>.
- Cottral, G. E., Patty, R. E., Gailiunas, P. and Scott, F. W. (1966). "Relationship of foot-and-mouth disease virus plaque size on cell cultures to infectivity for cattle by intramuscular inoculation," *Archives of Virology*, 18(3), 276-293,

- Cox, S. J., Aggarwal, N., Statham, R. J. and Barnett, P. V. (2003). "Longevity of antibody and cytokine responses following vaccination with high potency emergency FMD vaccines," *Vaccine*. 2003/03/05, 21 (13-14), 1336-1347, DOI: S0264410X02006916 [pii], 0264-410X (Print) 0264-410X (Linking), Retrieved: Mar 28, <http://www.ncbi.nlm.nih.gov/pubmed/12615428>.
- Cox, S. J. and Barnett, P. V. (2009). "Experimental evaluation of foot-and-mouth disease vaccines for emergency use in ruminants and pigs: a review," *Vet Res*. 2008/12/02, 40 (3), 13, DOI: 10.1051/vetres:2008051 v08306 [pii], 0928-4249 (Print) 0928-4249 (Linking), Retrieved: May-Jun, <http://www.ncbi.nlm.nih.gov/pubmed/19040829>.
- Cox, S. J., Carr, B. V., Parida, S., Hamblin, P. A., Prentice, H., Charleston, B., Paton, D. J. and Barnett, P. V. (2010). "Longevity of protection in cattle following immunisation with emergency FMD A22 serotype vaccine from the UK strategic reserve," *Vaccine*. 2010/01/09, 28 (11), 2318-2322, DOI: S0264-410X(09)01982-3 [pii] 10.1016/j.vaccine.2009.12.065, 1873-2518 (Electronic) 0264-410X (Linking), Retrieved: Mar 8, <http://www.ncbi.nlm.nih.gov/pubmed/20056183>.
- Cummings, Kristin J., Cox-Ganser, Jean, Riggs, Margaret A., Edwards, Nicole and Kreiss, Kathleen (2007). "Respirator Donning in Post-Hurricane New Orleans," *Emerging Infectious Diseases*, 13(5), 700-707,
- Cunliffe, H. R. (1962). "Antibody Response in a Group of Swine After Infection with Foot-and-Mouth Disease Virus," *Can J Comp Med Vet Sci*. 1962/08/01, 26 (8), 182-185, 0316-5957 (Print) 0316-5957 (Linking), Retrieved: Aug, <http://www.ncbi.nlm.nih.gov/pubmed/17649387>.
- Cunliffe, H. R. and Graves, J. H. (1963). "Formalin-Treated Foot-and-Mouth Disease Virus: Comparison of Two Adjuvants in Cattle," *Can J Comp Med Vet Sci*. 1963/08/01, 27 (8), 193-197, 0316-5957 (Print) 0316-5957 (Linking), Retrieved: Aug, <http://www.ncbi.nlm.nih.gov/pubmed/17649456>.
- Daszak, P., Plowright, R.K. and Epstein, J.H., Pulliams, J., Rahman, S.A., Field, H.E., Jamaluddin, A., Sharifah, S.H., Smith, C.S., Olival, K.J., Luby, S., Halpin, K., Hyatt, A.D., Cunningham, A.A., & the Henipavirus Ecology Research Group (HERG), Inc., New York, (2006). "The emergence of Nipah and Hendra virus: pathogen dynamics across a wildlife-livestock-human continuum," *Disease ecology: community structure and pathogen dynamics*, pp. 186-201.
- de Leeuw, PW, J.G. van Bakkum, J.W. Tiessink (1978). "Excretion of foot-and-mouth disease virus in oesophageal-pharyngeal fluid and milk of cattle after intranasal infection," *J Hyg (Lond)*, 81, 415-425,
- Dee, D. P., S. M. Uppala, et al. (2011). "The ERA-Interim reanalysis: configuration and performance of the data assimilation system," *Quarterly Journal of the Royal Meteorological Society* 137(656), 553-597,
- Defang, Gabriel N., Khetawat, Dimple, Broder, Christopher C. and Quinnan Jr, Gerald V. (2010). "Induction of neutralizing antibodies to Hendra and Nipah glycoproteins using a Venezuelan equine encephalitis virus in vivo expression system," *Vaccine*. 29 (2), 212-220, 0264-410X, <http://www.sciencedirect.com/science/article/pii/S0264410X10015549>.

- DEFRA (2009, December). "Contingency Plan for Exotic Diseases of Animals," *DEFRA's Framework Response Plan for Exotic Animal Diseases - DEFRA's Overview for Emergency Preparedness for Exotic Diseases of Animals (Version 4)*. London, UK.
- Dekker, A. (1998). "Inactivation of foot-and-mouth disease virus by heat, formaldehyde, ethylene oxide and γ radiation," *Veterinary Record*. 143, 168-169.
- Derrer, Denise (2010, May 7). "Imports 2007 thru 2009 per request from Derrer," *Personal correspondence*. Indiana State Board of Animal Health.
- Desta, M. G. (2007). "The Regulatory Framework for Trade in IGAD Livestock Products," IGAD LPI Working Paper No. 07 - 08.
- DHS (2008). *National Bio and Agro-Defense Facility Final Environmental Impact Statement*. Retrieved: 2010, May 12, http://www.dhs.gov/files/labs/gc_1187734676776.shtm.
- DHS (2010). *Site-Specific Biosafety and Biosecurity Mitigation Risk Assessment*. NBAF, Science and Technology Directorate, 417.
- DHS (2010, May). "User Group #1 Presentation, Waste Flow Diagrams," DHS and USDA.
- DHS Risk Steering Committee (2010, September). *DHS Risk Lexicon*.
- Disney, W. T., Green, J. W., Forsythe, K. W., Wiemers, J. F. and Weber, S. (2001). "Benefit-cost analysis of animal identification for disease prevention and control," *Rev Sci Tech*. 2001/09/13, 20 (2), 385-405, 0253-1933 (Print) 0253-1933 (Linking), Retrieved: Aug, <http://www.ncbi.nlm.nih.gov/pubmed/11552703>.
- Dodds, R. D., Guy, P. J., Peacock, A. M., Duffy, S. R., Barker, S. G. and Thomas, M. H. (1988). "Surgical glove perforation," *The British Journal of Surgery*, 75(10), 966-968, <http://www.ncbi.nlm.nih.gov/pubmed/3219543>.
- Doel, T. R., Williams, L. and Barnett, P. V. (1994). "Emergency vaccination against foot-and-mouth disease: rate of development of immunity and its implications for the carrier state," *Vaccine*. 1994/05/01, 12 (7), 592-600, 0264-410X (Print) 0264-410X (Linking), Retrieved: May, <http://www.ncbi.nlm.nih.gov/pubmed/8085375>.
- Donaldson, A. (1986). "Aerobiology of foot-and-mouth disease (FMD): an outline and recent advances," *Rev Sci Tech Off Epiz* 5. 315-321.
- Donaldson A.I., Herniman K.A., Parker J., Sellers R.F. (1970). "Further investigations on the airborne excretion of foot-and-mouth disease virus," *J Hyg (Lond)*. 68, 557-564.
- Donaldson, A. I., C. F. Gibson, et al. (1987). "Infection of cattle by airborne foot-and-mouth disease virus: minimal doses with O1 and SAT 2 strains," *Research in veterinary science* 43, 339-346.
- Donaldson, A.I. (1997). "Risks of spreading foot and mouth disease through milk and dairy products," *Revue Scientifique et Technique de l'Office International des Epizooties*. 16, 117-124.

- Donaldson, A. I., Alexandersen, S., Sorensen, J. H. and Mikkelsen, T. (2001). "Relative risks of the uncontrollable (airborne) spread of FMD by different species," *Vet Rec.* 2001/06/02, 148 (19), 602-604, 0042-4900 (Print) 0042-4900 (Linking), Retrieved: May 12, <http://www.ncbi.nlm.nih.gov/pubmed/11386448>.
- Donaldson, A.I. and Alexanderson, S. (2002). "Predicting the spread of foot and mouth disease by airborne virus," *Revue scientifique et technique (International Office of Epizootics)*. 21 (3), 569-575.
- Donaldson, A. I. and Kitching, R. P. (1989). "Transmission of foot-and-mouth disease by vaccinated cattle following natural challenge," *Res Vet Sci.* 1989/01/01, 46 (1), 9-14, 0034-5288 (Print) 0034-5288 (Linking), Retrieved: Jan, <http://www.ncbi.nlm.nih.gov/pubmed/2537993>.
- Donaldson, C. (1973). "Atmospheric turbulence and the dispersal of atmospheric pollutants". *AMS Workshop on Micrometeorology*, American Meteorological Society.
- (2007). "DuPont™ TYVEK® / DuPont™ TYCHEM Technical Handbook."
- Dvorak, Glenda (2008). "Disinfection 101," www.cfsph.iastate.edu.
- Eaton, Bryan T., Broder, Christopher C., Middleton, Deborah and Wang, Lin-Fa (2006). "Hendra and Nipah viruses: different and dangerous," *Nature Reviews. Microbiology*. 4 (1), 23-35, 1740-1526, <http://www.ncbi.nlm.nih.gov/pubmed/16357858>.
- Eaton, B.T., C.C. Broder, D. Middleton and Wang, L. (2005). "Hendra and Nipah viruses: different and dangerous," *Nature Reviews Microbiology*, Vol. 4, pp. 23-35,
- Elbakidze, L., et al. (2009). "Economics Analysis of Mitigation Strategies for FMD Introduction in Highly Concentrated Animal Feeding Regions," *Applied Economic Perspectives and Policy*. 31 (4), 931-950.
- Environmental Protection Agency (2005). "Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revision," *Vol. 70, No. 216*.
- EPA (2011). "Regulatory Definitions of Large CAFOs, Medium CAFO, and Small CAFOs," Environmental Protection Agency, National Pollutant Discharge Elimination System http://www.epa.gov/npdes/pubs/sector_table.pdf.
- E-Z Pack Manufacturing (2011). "Specifications," *Hercules Commercial Front Loader*,
- FCSHWM (Florida Center for Solid and Hazardous Waste Management) (2003). *Litter from Solid Waste Collection Trucks*, Report #03-04,
- Fellowes, O. N. and Suttmoller, P. (1970). "Foot-and-mouth disease virus: biological characteristics of virus from bovine carriers," *Archives of Virology*, 30(2), 173-180,

- FEMA (2003, February 18). "Tornado Background," *FEMA News Release*.
<http://www.fema.gov/news/newsrelease.fema?id=2549>.
- Field, H., Schaaf, K., Kung, N., Simon, C., Waltisbuhl, D., Hobery, H., Moore, F., Middleton, D., Crook, A., Smith, G., Daniels, P., Glanville, R. & Lovell, D. (2010). "Hendra Virus Outbreak with Novel Clinical Features, Australia," *Emerging Infectious Disease*. Vol. 16 (No. 2), pp. 338-340.
- Finney, D.J. (1952). "Probit Analysis: A Statistical Treatment of the Sigmoid Response Curve," 2nd edition Cambridge University Press.
- Forde-Folle, Kim (2011). "Correspondence concerning USDA NAADSM parameters". M. Rush. Washington DC.
- Fowler, Kent, DVM (2010, May 6). "Jan-Dec 2009_CA_Cattle&Swine," *Personal correspondence*. California Department of Food and Agriculture.
- Fox, L. (2005, July). "Deer Check Stations, 2004: Performance Report, Statewide Wildlife Research and Surveys," Kansas Department of Wildlife and Parks.
- Fox, Loyd (2011). "Interview with Kansas Department of Wildlife and Parks". S. I. Matt Lawrence.
- Freidberg, A.N., M.N. Worthy, B. Lee, M.R. Holbrook (2010). "Combined chloroquine and ribavirin treatment does not prevent death in a hamster model of Nipah and Hendra virus infection," *Journal of General Virology*, 91, 765-772,
- French, N.P. and Kelly, L, et al (2002). " Dose-response relationships for foot and mouth disease in cattle and sheep," *Epidemiol Infect* 128, 325-332.
- Gailiunas, P., G.E. Cottral (1966). "Presence and persistence of foot-and-mouth disease virus in bovine skin," *Journal of Bacteriology*, 91(6), 2333-2338,
<http://www.ncbi.nlm.nih.gov/pubmed/4287587>.
- Gailiunas, P. and Cottral, G.E. et al (1969). "Survival of foot-and-mouth disease virus on meat packaging materials," *Proceedings, annual meeting of the United States Animal Health Association*. 73, 425-436.
- Garner, Dale (2011). "Interview on wildlife with Iowa Department of Natural Resources," Personal communication received by Matt Lawrence.
- Garner, MG and Cannon, RM (1995). "Potential for windborne spread of foot-and-mouth disease virus in Australia," *Bureau of Resources Sciences, Australia*. Volume 98.
- Geisbert, Thomas W., Daddario-DiCaprio, Kathleen M., Hickey, Andrew C., Smith, Mark A., Chan, Yee-Peng, Wang, Lin-Fa, Mattapallil, Joseph J., Geisbert, Joan B., Bossart, Katharine N. and Broder, Christopher C. (2010). "Development of an Acute and Highly Pathogenic Nonhuman Primate Model of Nipah Virus Infection," *PLoS One*, 5(5), e10690-e10690,
<http://dx.doi.org/10.1371/journal.pone.0010690>.

- Georges-Courbot, M. C., Contamin, H., Faure, C., Loth, P., Baize, S., Leyssen, P., Neyts, J. and Deubel, V. (2006). "Poly(I)-Poly(C12U) but Not Ribavirin Prevents Death in a Hamster Model of Nipah Virus Infection," *Antimicrob. Agents Chemother.*, 50(5), 1768-1772, <http://aac.asm.org/cgi/content/abstract/50/5/1768>.
- Gesch, D., Oimoen, M., Greenlee, S., Nelson, C., Steuck, M. and Tyler, D. (2002). "The National Elevation Dataset," *Photogrammetric Engineering and Remote Sensing*. 68 (1), 5-11.
- Gloster, J., et al. (2007). "Foot-and-mouth disease - quantification and size distribution of airborne particles emitted by healthy and infected pigs," *The Veterinary Journal*. 174 (1), 42-53, DOI: 10.1016/j.tvjl.2006.05.020.
- Gloster, John, et al. (2008). "Foot-and-mouth disease: Measurements of aerosol emission from pigs as a function of virus strain and initial dose," *The Veterinary Journal*. 177, 374-380.
- Goh, K.J., C.T. Tan, Chew, N.K., Tan, P.S.K., Kamarulzaman, A., Sarji, S.A., Wong, K.T., Abdullah, B.J.J., Chua, K.B. and Lam, S.T. (2000). "Clinical Features of Nipah Virus Encephalitis among Pig Farmers in Malaysia," *The New England Journal of Medicine*, Vol. 342(No. 17), pp. 1229-1235,
- Graham, et al. (2008). "A Guide to Emergency Quarantine and Isolation Controls of Roads in Rural Areas," National Cooperative Highway Research Program.
- Graves, John H., McVicar, John W., Suttmoller, Paul, Trautman, Rodes and Wagner, Gerald G. (1971). "Latent Viral Infection in Transmission of Foot-and-Mouth Disease by Contact between Infected and Susceptible Cattle," *the Journal of Infectious Diseases*, 124(3), 270-276, <http://www.jstor.org/stable/30108451>.
- Green, Francis H.Y., Yoshida, Ken (1990). "Characteristics of Aerosols Generated During Autopsy Procedures and Their Potential Role as Carriers of Infectious Agents," *Applied Occupational and Environmental Hygiene*. 5:12, 853-858.
- Greene, W.H. (2007). "NLOGIT Version 4.0 Reference Guide," Plainview, NY: Econometric Software.
- Grubman, M. J., Zellner, M. and Wagner, J. (1987). "Antigenic comparison of the polypeptides of foot-and-mouth disease virus serotypes and other picornaviruses," *Virology*, 158(1), 133-140, <http://www.ncbi.nlm.nih.gov/pubmed/2437694>.
- Guillaume, V., et al. (2009). "Acute Hendra virus infection: Analysis of the pathogenesis and passive antibody protection in the hamster model," *Virology*. 387, 459-465.
- Guillaume, V., Contamin, H., Loth, P., Georges-Courbot, M. C., Lefevre, A., Marianneau, P., Chua, K. B., Lam, S. K., Buckland, R., Deubel, V. and Wild, T. F. (2004). "Nipah Virus: Vaccination and Passive Protection Studies in a Hamster Model," *J. Virol.*, 78(2), 834-840, <http://jvi.asm.org/cgi/content/abstract/78/2/834>.
- Guillaume, V., Contamin, H., Loth, P., Grosjean, I., Courbot, M. C. Georges, Deubel, V., Buckland, R. and Wild, T. F. (2006). "Antibody Prophylaxis and Therapy against Nipah Virus Infection in Hamsters," *J. Virol.*, 80(4), 1972-1978, <http://jvi.asm.org/cgi/content/abstract/80/4/1972>.

- Guillaume, Vanessa, Lefevre, Annabelle, Faure, Caroline, Marianneau, Philippe, Buckland, Robin, Lam, Sai Kit, Wild, T. Fabian and Deubel, Vincent (2004). "Specific detection of Nipah virus using real-time RT-PCR (TaqMan)," *Journal of Virological Methods*, 120(2), 229-237, <http://www.sciencedirect.com/science/article/pii/S0166093404001569>.
- Gurley, E.S., et al. (2007). "Infection Control and Hospital Epidemiology," *Chicago Journals*,. Published on behalf of The Society of Healthcare Epidemiology of America, Vol. 28, No.6 (June), 740-742.
- Gwaltney, J. M., Jr., Moskalski, P. B. and Hendley, J. O. (1978). "Hand-to-hand transmission of rhinovirus colds," *Annals of Internal Medicine*, 88(4), 463-467, <http://www.ncbi.nlm.nih.gov/pubmed/205151>.
- Hackett, E.T., Jr. (2001). "Effect of Pinholes on Sterile Barrier Properties," Presented at HealthPak, March 2001, in St. Petersburg, Florida, http://www2.dupont.com/Medical_Packaging/en_US/assets/downloads/mar2001healthpak.pdf.
- Hahn, W., Perry, J., and Southard, L. (2009). "Comparing Two Sources of Retail Meat Price Data, ERR-88," U.S. Dept. of Agri., Econ. Res. Serv.
- Hall, C. B., Douglas, R. G., Jr. and Geiman, J. M. (1980). "Possible transmission by fomites of respiratory syncytial virus," *Journal of Infectious Diseases*, 141(1), 98-102, <http://www.ncbi.nlm.nih.gov/pubmed/7365274>.
- Halpin, K., et al., (2011). "Pteropid Bats are Confirmed as the Reservoir Hosts of Henipaviruses: A Comprehensive Experimental Study of Virus Transmission," *Am J Trop Med Hyg*, 85(5), 946-951,
- Hanna, J.N., et al. (2006). "Hendra virus infection in a veterinarian," *MJA* 2006. 185;562-564.
- Harit, A.K., et al. (2006). "Nipah/Hendra virus outbreak in Siliguri, West Bengal, India in 2001," *Indian J. Med Res* 123. (April 2006), 553-560.
- Heady, E. O., Sonka, S. (1974). "Farm Size, Rural-Community Income, and Consumer Welfare," *American Journal of Agricultural Economics*. 56 ((3)), 534-542.
- Health and Safety Executive (2007 September). *Final report on potential breaches of biosecurity at the Pirbright site 2007*.
- Heckert, R.A., et al. (1997). "Efficacy of Vaporized Hydrogen Peroxide against Exotic Animal Viruses," *Applied and Environmental Microbiology*. Oct. 1997 Vol. 63 No.10, 3916-3918.
- Henderson W.M., and Brooksby J.B. (1948). "The survival of foot-and-mouth disease virus in meat and offal," *J Hyg (Lond)*. 46, 394-402.
- Hensher, D.A, Rose, J.M. and Green, W.G. (2005). "Applied Choice Analysis: A Primer," Cambridge University Press.

- Hewitson, B.C. and Crane, R.G. (2002). "Self-organizing maps: applications to synoptic climatology," *Clim. Res.* 22, 13-26.
- Highfield, L. D., Ward, M. P., Laffan, S. W., Norby, B. and Wagner, G. G. (2010). "The impact of potential mitigation strategies on the predicted spread of foot and mouth disease in white-tailed deer in south Texas," *Prev Vet Med.* 2010/02/26, 94 (3-4), 282-288, DOI: S0167-5877(10)00032-2 [pii] 10.1016/j.prevetmed.2010.01.015, 1873-1716 (Electronic) 0167-5877 (Linking), Retrieved: May 1, <http://www.ncbi.nlm.nih.gov/pubmed/20181400>.
- Hill, J. (2011). "The Use of Captive Bolt Technology for the Humane Destruction of Hogs," *Agriculture and Rural Development, Food Safety and Animal Health Division, Government of Alberta*.
- Hollis, L. (2011). "Interview with Kansas State University Professor A. Wilson, SES, Inc."
- Homaira, N. (2010, October). "Cluster of Nipah Virus Infection, Kushtia District, Bangladesh, 2007," *Epidemiol. Infect.* Volume 5 (10 e13570), 138, 1630-1636.
- Hoogenboezem, W., et al. (2001). "Cryptosporidium and Giardia: Occurrence in sewage, manure and surface water," *RIWA/RIVM/RIZA-Report*. Amsterdam, The Netherlands.
- House, Carol, et al. (1990). "Inactivation of viral agents in bovine serum by gamma irradiation," *Can J. Microbiol.* 36, 737-740.
- House, J. A. and Yedloutschnig, R. J. (1982). "Sensitivity of seven different types of cell cultures to three serotypes of foot-and-mouth disease virus," *Canadian Journal of Comparative Medicine*, 46(2), 186-189,
- Hughes, G.J., R.P. Kitching, M.E. Woolhouse (2002a). "Dose-dependent responses of sheep inoculated intranasally with a type O foot-and-mouth disease virus.," *J Comp Pathol* (127), 22-29.
- Hughes GJ, V. Mioulet, Haydon DT and Kitching RP, Donaldson AI, Woolhouse ME (2002b). "Serial passage of foot-and-mouth disease virus in sheep reveals declining levels of viraemia over time," *J Gen Virol* 83, 1907-1914.
- Hyde, J. L., Blackwell, J. H. and Callis, J. J. (1975). "Effect of pasteurization and evaporation on foot-and-mouth disease virus in whole milk from infected cows," *Canadian Journal of Comparative Medicine*, 39(3), 305-309,
- IAH (2008, July). *The economic and social impact of the Institute for Animal Health's work on Foot and Mouth Disease*,
- lehle, C., Razafitrimo, G., Razainirina, J., Andriaholinirina, N., Goodman, S.M., Faure, C., Georges-Courbot, M., Rousset, D., & Reynes, J. (2007). "Henipavirus and Tioman Virus Antibodies in Pteropodid Bats, Madagascar," *Emerging Infectious Disease*. Vol. 12 (No. 1), pp.159-161.
- ILC Dover (2002). "Protection Factor Test Results - ILC Dover Chemtursion Model 3525,"

- International Organization for Standardization (ISO) (2009). "Risk management-Principles and guidelines," *International Standard, ISO 31000*. First edition 2009-11-15, Reference number ISO 31000:32009(E).
- Irving, Louise, Smith, F. A. (1981 Jan). "One-Year Survey of Enteroviruses, Adenoviruses, and Reoviruses Isolated from Effluent at an Activated-Sludge Purification Plant," *Applied and Environmental Microbiology*. Vol 41, No. 1, 51-59.
- Irwin, E.G., A.M. Issermann, A.M. M. Kilkenny, and M.D. Partridge (2007). "A Century of Research on Rural Development and Regional Issues," *American Journal of Agricultural Economics* 89, 582-595.
- Jennings, L. C., Dick, E. C., Mink, K. A., Wartgow, C. D. and Inhorn, S. L. (1988). "Near disappearance of rhinovirus along a fomite transmission chain," *Journal of Infectious Diseases*. 1988/10/01, 158 (4), 888-892, 0022-1899 (Print) 0022-1899 (Linking), Retrieved: Oct, <http://www.ncbi.nlm.nih.gov/pubmed/2844923>.
- Johnson, John (2011). "Kansas Feral Swine Control Program, April 2011 Quarterly Update," United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services.
- Joutsiniemi, S.L., Kaski, S. and Larsen, T.A. (1995). "Self-organizing map in recognition of topographic patterns of EEG spectra," *IEEE Trans. Biomed. Eng.* 42, 1062-1068.
- Julian, T. R., Leckie, J. O., Boehm, A. B. (2010). "Virus transfer between fingerpads and fomites," *Journal of Applied Microbiology*. 109, 1868-1874.
- Julian, T.R. and Canales, R.A., et al. (2009). "A model of exposure to rotavirus from nondietary ingestion iterated by simulated intermittent contacts," *Risk Analysis*. 29, 617-632.
- Just, R.E., D. L. Hueth, and A. Schmitz (2004). "The Welfare Economics of Public Policy: A Practical Evaluation to Project and Policy Evaluation," Edward Elgar.
- Kalnay, E, Kanamitsu, M, Kirtler, R, Collins, W, D, Deaven, L, Gandin, M, Iredell, Saha, S, White, G, Woollen, J, Zhu, Y, Chelliah, M, Ebisuzaki, W, Higgins, W, Janowiak, J, Mo, KC, Ropelewski, C, Wang, J, Leetma, A, Reynolds, R, Jenne, R and D, Joseph (1996). "The NCEP/NCAR 40-year reanalysis project," *Bulletin of the American Meteorological Society*. 77, 437-471.
- Kampf, G. and Kramer, A. (2004). "Epidemiologic background of hand hygiene and evaluation of the most important agents for scrubs and rubs," *Clinical Microbiology Reviews*. 2004/10/19, 17 (4), 863-893, table of contents, DOI: 10.1128/CMR.17.4.863-893.2004, 0893-8512 (Print) 0893-8512 (Linking), Retrieved: Oct, <http://www.ncbi.nlm.nih.gov/pubmed/15489352>.
- Kansas Department of Wildlife and Parks (2010). "Correspondence regarding KS Deer Survey Data," Extracted from the figure in Slide 8.
- Kansas State Online (Accessed November 2011). "Equine in Kansas - Overview," *Kansas State University Animal Sciences & Industry; Kansas Horse Council*. <http://www.asi.ksu.edu/p.aspx?tabid=43>; <http://www.kansashorsecouncil.com/index.html>.

- Kaski, S., Kangas, J. and Kohonen, T. (1998). "Bibliography of Self-Organizing Map (SOM) papers: 1981 – 1997," *Neural Comput. Surv.* 1, 102-350.
- Kay-Sin, TAN, et al. (1999). "Epidemiological aspects of Nipah virus infection," *Neuro. J. Southeast Asia.* 1999:4, 77-81.
- Kelly, T.C., et al. (2003, December 8-9). "The Office of Science and Technology Policy Blue Ribbon Panel on The Threat of Biological Terrorism Directed Against Livestock," *Conference Proceedings.* <http://www.whitehouse.gov/files/documents/ostp/NSTC%20Reports/2003%20Livestock%20Blue%20Ribbon.pdf>.
- Kennedy, J., Bek, J., Griffin, D. (2000 accessed online 20 December 2011). "Selection and Use of Disinfectants," *NebGuide*. Published by the University of Nebraska-Lincoln Extension, Animal Diseases (F-8), <http://www.triton-vet.com/uso%20y%20seleccion%20desinfectantes.pdf>
- Kenny, M.T. and Sabel, F.L (1968). "Particle size distribution of *Serratia marcescens* aerosols created during common laboratory procedures and simulated laboratory accidents," *Appl Microbiol.* 16, 1146-1150,
- Kingsbury, N. (2008). "DHS Lacks Evidence to Conclude That Foot-and-Mouth Disease Research Can Be Done Safely on the U.S. Mainland," Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, House of Representatives, U.S. Government Accountability Office, GAO-08-821T.
- Kingsbury, N., et al. (2009). "Biological Research: Observations on DHS's Analyses Concerning Whether FMD Research Can Be Done as Safely on the Mainland as on Plum Island," (GAO-09-747), Report to Congressional Committees, <http://www.gao.gov/new.items/d09747.pdf>.
- Kitching, R. P. (2002). "Clinical variation in foot and mouth disease: cattle," *Revue scientifique et technique (International Office of Epizootics)*. 21 (3), 499-504, 0253-1933, <http://www.ncbi.nlm.nih.gov/pubmed/12523690>.
- Klein, R. C., Party, E., and Gershey, E. L. (1990). "Virus penetration of examination gloves," *BioTechniques*. 9, 196-199.
- Knobben, B. A. S., et al. (2007). "Transfer of bacteria between biomaterials surfaces in the operating room-An experimental study," *Journal of Biomedical Materials Research*. Part A 80A, 790-799.
- Knudsen, R. C., Card, D. M. and Hoffman, W. W. (1986). "Protection of guinea pigs against local and systemic foot-and-mouth disease after administration of synthetic lipid amine (Avridine) liposomes," *Antiviral Research*, 6(2), 123-133, <http://www.sciencedirect.com/science/article/pii/016635428690032X>.
- Knudsen, R. C., Groocock, C. M. and Andersen, A. A. (1979). "Immunity to foot-and-mouth disease virus in guinea pigs: clinical and immune responses," *Infection and Immunity*, 24(3), 787-787,

- Kohonen, T. (1982). "Self-organized information of topologically correct feature maps," *Biol. Cyber.* 43, 59-69.
- Kohonen, T., Hynninen, J., et al. (1996). "The Self-Organizing Map Program Package (SOM_PAK)," Espoo, Finland, Helsinki University of Technology, Laboratory of Computer and Information Science.
- Kohonen, T. (1998). "The self-organizing map," *Neurocomputing.* 21, 1-6.
- Kohonen, T. (2001). *Self-Organizing Maps, 3rd Edition.* (3rd Edition), 521, Springer, 3540679219.
- Korniewicz, Denise M., Garzon, Laurel, Seltzer, Judy and Feinleib, Manning (2004). "Failure rates in nonlatex surgical gloves," *American Journal of Infection Control*, 32(5), 268-273, <http://www.sciencedirect.com/science/article/pii/S019665530400358X>.
- Korniewicz, D. M et.al. (1990). "Leakage of virus through used vinyl and latex examination gloves," *J. Clin. Microbiol.* . 28, 787-788.
- Kowalski, W.J., et al. (1999). "Filtration of Airborne Microorganisms: Modeling and Prediction," *ASHRAE Trans.* 105, 4-17.
- Ksiazek, Thomas G., Rota, Paul A. and Rollin, Pierre E. (2011). "A review of Nipah and Hendra viruses with an historical aside," *Virus Research*, (0), <http://www.sciencedirect.com/science/article/pii/S0168170211003790>.
- K-State (2011). Enrollment, Registrar's Office.
- Kuchler, F., and Ababayehu, T. (2006). "Did Bse Announcements Reduce Beef Purchases?," *Economic Research Report 7251.* United States Department of Agriculture, Economic Research Service.
- Lam, S.K., Chau, K.B. (2002). "Nipah virus encephalitis outbreak in Malaysia," *Clinical Infectious Diseases.* 34(suppl 2), S48-51.
- Landsberg, H. E. and Jacobs, W. (1951). "Applied Climatology," *Compendium of Meteorology*, T. F. Malone. Boston, MA, American Meteorological Society: 976-992.,
- Le Blanc Smith, Peter M., et al. (2002). "Biological Testing of a Laboratory Pathological Waste Incinerator," *Applied Biosafety.* 7(2), 52-63.
- Lee, S. H., Jong, M. H., Huang, T. S., Lin, Y. L., Wong, M. L., Liu, C. I. and Chang, T. J. (2009). "Pathology and viral distributions of the porcophilic foot-and-mouth disease virus strain (O/Taiwan/97) in experimentally infected pigs," *Transboundary and Emerging Diseases*, 56(5), 189-201, <http://www.ncbi.nlm.nih.gov/pubmed/19432640>.
- Leontief, W. W. (1936). "Quantitative Input and Output Relations in the Economic Systems of the United States," *The Review of Economics and Statistics.* 18 (3), 105–125.
- Lewellen, W.S. (1977). "Use of invariant modeling." *Handbook of Turbulence*, pp. 237-280.

- Lewis, Raymond G., PE (2002). "Practical Guide to Autoclave Validation," *Pharmaceutical Engineering*. July/August.
- Li D, Bai XW, Sun P and Fu YF, Xie BX, Lu ZJ, Chen YL, Cao WJ, Liu ZX (2010). "Effect of the route of foot-and-mouth disease virus infection of piglets on the course of disease," *Acta Virol*. 54, 311-313.
- Li, Mingyi, Embury-Hyatt, Carissa and Weingartl, Hana M. (2010). "Experimental inoculation study indicates swine as a potential host for Hendra virus," *Vet Res*, 41(3),
- Lingaas, E., Fagernes, M. (2009). "Development of a method to measure bacterial transfer from hands," *Journal of Hospital Infection*. 72, 43-49.
- Little, C., and Doeksen, G. (1968). "Measurement of Leakage by Use of an Input-Output Model," *American Journal of Agricultural Economics*. 50 (4), 921-934.
- Liu, Y., Weisberg, R. H. and Mooers, C. N. K. (2006). "Performance evaluation of the self-organizing map for feature extraction," *Journal of Geophysical Research*. 111 (C5), 1-14, DOI: 10.1029/2005jc003117, Retrieved: 05-25, <http://www.agu.org/journals/jc/jc0605/2005JC003117/2005JC003117.pdf>.
- Lodder, W.J., de Roda Husman, A.M. (2005 March). "Presence of Noroviruses and Other Enteric Viruses in Sewage and Surface Waters in The Netherlands," *Appl Environ Microbiol*. 71(3), 1453-1461.
- Loeffler, F., P. Frosch (1897-1898). *Reports of the Commission for the Investigation of foot and mouth disease at the Institute for Infectious Diseases in Berlin*, Zbl.. Bakt. I(Orig 1897; 22/1898; 23), 257-259/371-391,
- Loftkin, J.M., et al. (1996). "Evaluation of cattle insecticide treatments on attraction, mortality, and fecundity of mosquitoes," *Journal of the American Mosquito Control Association*. 12 (1), 17-22.
- Luby, S.P., et.al. (2009). "Transmission of Human Infection with Nipah Virus," *Clinical Infectious Diseases*. 49:1743-8, <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2784122/>.
- Madhanmohan, M., Nagendrakumar, S. B., Narasu, M. L. and Srinivasan, V. A. (2010). "Effect of FMD vaccine antigen payload on protection, sub-clinical infection and persistence following needle challenge in sheep," *Comp Immunol Microbiol Infect Dis*. 2009/11/10, 33 (6), e7-13, DOI: S0147-9571(09)00053-8 [pii] 10.1016/j.cimid.2009.10.001, 1878-1667 (Electronic), 0147-9571 (Linking), Retrieved: Dec, <http://www.ncbi.nlm.nih.gov/pubmed/19896714>.
- Mahy, B. W. J. (2005). "Global Epidemiology and Prospects for Control of Foot-and-Mouth Disease," *Foot-and-Mouth Disease Virus*. 137.
- Maisner, A., Neufeld, J. and Weingartl, H. (2009). "Organ-and endotheliotropism of Nipah virus infections in vivo and in vitro," *Thromb Haemost*, 102, 1014-1023,
- Mak, J. (1989). "The Economic Contribution of Travel to State Economies," *Journal of Travel Research*. 28, 3-5.

- Maramorosch, K. (1961). "For Determination of the conversion of TCID50 to PFU," *Advances in Virus Research*. The Plaque Assay of Animal Viruses, Chapter 8 p. 351, <http://books.google.com/books?id=-AT-SK60Py0C&lpq=PA319&ots=ja4uhVNE91&dq=fmdv%20%22one%20ID50%22&lr&pg=PA351#v=onepage&q&f=false>
- Mardones, F. (2010). "Parameterization of the duration of infection stages of serotype O foot-and-mouth disease virus: an analytical review and meta-analysis with application to simulation models," *Journal of Veterinary Research*. 41 (4), 45, DOI: 10.1051/vetres/2010017.
- Marsh, T.L., T. C. Schroeder, and J. Mintert (2004). "Impacts of Meat Product Recalls on Consumer Demand in the USA," *Applied Economics*. 36, 897-909.
- Martinsen, J. S. (1970). "The Effect of Diethylaminoethyl Dextran and Agar Overlay pH on Plaque Formation by Two Plaque-size Variants of Foot-and-Mouth Disease Virus," *Canadian Journal of Comparative Medicine*, 34(1), 13-19,
- Mathieu, Cyrille, Pohl, Christine, Szecsi, Judit, Trajkovic-Bodenec, Selena, Devergnas, Severine, Raoul, Herve, Cosset, Francois-Loic, Gerlier, Denis, Wild, T. Fabian and Horvat, Branka (2011). "Nipah Virus Uses Leukocytes for Efficient Dissemination within a Host," *J. Virol.*, 85(15), 7863-7871, <http://jvi.asm.org/cgi/content/abstract/85/15/7863>.
- Mbithi, J. N., Springthorpe, V. S., Boulet, J. R. and Sattar, S. A. (1992). "Survival of hepatitis A virus on human hands and its transfer on contact with animate and inanimate surfaces," *Journal of Clinical Microbiology*, 30(4), 757-763, <http://www.ncbi.nlm.nih.gov/pubmed/1315331>.
- Mbithi, J. N., Springthorpe, V. S. and Sattar, S. A. (1993). "Comparative in vivo efficiencies of hand-washing agents against hepatitis A virus (HM-175) and poliovirus type 1 (Sabin)," *Appl Environ Microbiol*, 59(10), 3463-3469, <http://www.ncbi.nlm.nih.gov/pubmed/8250567>.
- McCull, K. A., Westbury, H. A., Kitching, R. P. and Lewis, V. M. (1995). "The persistence of foot-and-mouth disease virus on wool," *Aust Vet J*. 1995/08/01, 72 (8), 286-292, 0005-0423 (Print) 0005-0423 (Linking), Retrieved: Aug, <http://www.ncbi.nlm.nih.gov/pubmed/8579558>.
- McCullough, M., Marsh, T.L. and Huffaker, R. (2010). "Reconstructing Market Reactions to Consumption Harms," Working paper, School of Economic Sciences, Washington State University.
- McDowell, Margaret A., et al. (2008). "Anthropometric Reference Data for Children and Adults: United States, 2003-2006,," *National Health Statistics Reports*. No. 10, USDHHS/CDC.
- McEachern, Jennifer A., Bingham, John, Cramer, Gary, Green, Diane J., Hancock, Tim J., Middleton, Deborah, Feng, Yan-Ru, Broder, Christopher C., Wang, Lin-Fa and Bossart, Katharine N. (2008). "A recombinant subunit vaccine formulation protects against lethal Nipah virus challenge in cats," *Vaccine*. 26 (31), 3842-3852, 0264-410X, <http://www.sciencedirect.com/science/article/pii/S0264410X08005720>.

- McVicar, J.W., Eisner, R.J. (1983, April 19). "Aerosol exposure of cattle to foot-and-mouth disease virus," *The Journal of Hygiene*. 91, 319-328, Cambridge University Press, Retrieved: January 27, 2010, <http://www.jstor.org/pss/3862908>.
- McVicar, J. W. and Suttmoller, P. (1976). "Growth of foot-and-mouth disease virus in the upper respiratory tract of non-immunized, vaccinated, and recovered cattle after intranasal inoculation," *J Hyg (Lond)*. 1976/06/01, 76 (3), 467-481, 0022-1724 (Print), 0022-1724 (Linking), Retrieved: Jun, <http://www.ncbi.nlm.nih.gov/pubmed/180177>.
- McVicar, J. W., Suttmoller, P. and Andersen, A. A. (1974). "Foot-and-mouth disease virus: plaque reduction neutralization test," *Archives of Virology*, 44(2), 168-172,
- Melius, Carl, Robertson, Alex and Hullinger, Pam (2006). "Developing Livestock Facility Type Information from USDA Agricultural Census Data for use in Epidemiological and Economic Models," Department of Homeland Security, Lawrence Livermore National Laboratory, UCRL-TR-226008.
- Middleton, D. J., Morrissy, C. J., van der Heide, B. M., Russell, G. M., Braun, M. A., Westbury, H. A., Halpin, K. and Daniels, P. W. (2007). "Experimental Nipah virus infection in pteropid bats (*Pteropus poliocephalus*)," *Journal of Comparative Pathology*, 136(4), 266-272, <http://www.ncbi.nlm.nih.gov/pubmed/17498518>.
- Middleton, D. J., Westbury, H. A., Morrissy, C. J., van der Heide, B. M., Russell, G. M., Braun, M. A. and Hyatt, A. D. (2002). "Experimental Nipah virus infection in pigs and cats," *Journal of Comparative Pathology*, 126(2-3), 124-136, <http://www.ncbi.nlm.nih.gov/pubmed/11945001>.
- Mohamed, F., Swafford, S., Petrowski, H., Bracht, A., Schmit, B., Fabian, A., Pacheco, J. M., Hartwig, E., Berninger, M., Carrillo, C., Mayr, G., Moran, K., Kavanaugh, D., Leibrecht, H., White, W. and Metwally, S. (2011). "Foot-and-mouth disease in feral swine: susceptibility and transmission," *Transbound Emerg Dis*, 58(4), 358-371, DOI:10.1111/j.1865-1682.2011.01213.x, <http://www.ncbi.nlm.nih.gov/pubmed/21418546>.
- Monaghan, Andrew J., Rife, Daran L., Pinto, James O., Davis, Christopher A. and Hannan, John R. (2010). "Global Precipitation Extremes Associated with Diurnally Varying Low-Level Jets". *Journal of Climate*. 23, pp. 5065-5084.
- Montgomery, J.M., et al. (2008). "Risk Factors for Nipah Virus Encephalitis in Bangladesh," *Emerging Infectious Diseases* Vol.14, No.10, October 2008.
- Moonen, P., Jacobs, L., Crienen, A. and Dekker, A. (2004). "Detection of carriers of foot-and-mouth disease virus among vaccinated cattle," *Vet Microbiol*, 103(3-4), 151-160, DOI:S0378-1135(04)00261-5 [pii], 10.1016/j.vetmic.2004.07.005, <http://www.ncbi.nlm.nih.gov/pubmed/15504586>.
- Mounts, A.W., et al. (2001). "A cohort study of health care workers to assess nosocomial transmissibility of Nipah virus, Malaysia," *J Infectious Diseases* 2001:183(810-813),

- Mungall, Bruce A., Middleton, Deborah, Crameri, Gary, Bingham, John, Halpin, Kim, Russell, Gail, Green, Diane, McEachern, Jennifer, Pritchard, L. Ian, Eaton, Bryan T., Wang, Lin-Fa, Bossart, Katharine N. and Broder, Christopher C. (2006). "Feline Model of Acute Nipah Virus Infection and Protection with a Soluble Glycoprotein-Based Subunit Vaccine," *Journal of Virology*. 80 (24), 12293-12302, <http://jvi.asm.org/content/80/24/12293.abstract>.
- NAADSM Development Team (2011) NAADSM version number 3.2.18. Free program distributed via the Internet at <http://www.naadsm.org>.
- NABC/KSU (2004). "Carcass Disposal: A Comprehensive Review," Chapters 4 and 6, <http://hdl.handle.net/2097/662>.
- National Center for Atmospheric Research (2010). "The Joint Effects Model Global Climate Database," 27.
- National Climatic Data Center (2001). "Climates of the States," *Climatology of the United States* No. 60, Climate of Kansas, http://hurricane.ncdc.noaa.gov/climatenormals/clim60/states/Clim_KS_01.pdf.
- National Climatic Data Center (2010). "Comparative Climatic Data," <http://ols.nndc.noaa.gov/plolstore/plsql/olstore.prodspecific?prodnum=C00095-PUB-A0001>.
- National Climatic Data Center (2010). "Quality Controlled Local Climatological Data (Manhattan Regional Airport Hourly ASOS Observations)," (January 30, 2010), <http://www.ncdc.noaa.gov/oa/ncdc.html>
- National Geospatial-Intelligence Agency "U.S. Military Specification Digital Terrain Elevation Data (DTED)".
- NDP (2010). *Update to Proposed Tissue Disposal System*. June.
- NDP (2011, 19 August). "50% Construction Documents," *Basis of Design*. DHS NBAF.
- Nelson, F.J., and Schertz, L.P. (1996). "Provisions of the Federal Agriculture Improvement and Reform Act of 1996," *USDA, Economic Research Service*. AIB729, <http://www.ers.usda.gov/publications/aib729/>.
- Nelson, J. R., et al. (1999). "A whole-glove method for the evaluation of surgical gloves as barriers to viruses," *American Journal of Contact Dermatitis* 10, 183-189.
- Nogueira, L., T. L. Marsh, P.R. Tozer and D. Peel (2011). "Foot-and-Mouth Disease and the Mexican Cattle Industry," *Agricultural Economics*. 42 (supplement), p:33-44.
- NRC 1.76 (2007). "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants," *Regulatory Guide 1.76*,

- NRC (2010). "Evaluation of a Site-Specific Risk Assessment for the Department of Homeland Security's Planned National Bio- and Agro-Defense Facility in Manhattan, Kansas: Preliminary Letter Report," *The National Academies Press*,
- NVS Countermeasures Working Group (2007). "National Veterinary Stockpile Countermeasures Working Group Report Foot-and-Mouth Disease," USDA Agricultural Research Service.
- O'Connell, K. P., et al. (2004). "Testing for viral penetration of non-latex surgical and examination gloves: a comparison of three methods," *Clin. Microbiol. Infect.* 10, 322-326.
- O'Shea, T.J., Bogan, M.A., and Ellison, L.E. (2003). "Monitoring Trends in Bat Population of the United States and Territories: Status of the Science and Recommendations for the Future," *US Geological Survey, University of Nebraska - Lincoln*.
- Odde, Ken (2011). "Interview with KSU Animal Science Department Head". A. Wilson, SES, Inc.
- O'Donnell, Vivian, LaRocco, Michael, Duque, Hernando and Baxt, Barry (2005). "Analysis of Foot-and-Mouth Disease Virus Internalization Events in Cultured Cells," *Journal of Virology*, 79(13), 8506-8518,
- O'Donnell, V. K., Pacheco, J. M., Henry, T. M. and Mason, P. W. (2001). "Subcellular distribution of the foot-and-mouth disease virus 3A protein in cells infected with viruses encoding wild-type and bovine-attenuated forms of 3A," *Virology*, 287(1), 151-162, <http://www.ncbi.nlm.nih.gov/pubmed/11504550>.
- OIE (2009). "OIE Terrestrial Manual," <http://www.oie.int/en/international-standard-setting/terrestrial-manual/>.
- OIE (2010). "Animal Diseases Data: Rift Valley Fever; Contagious Bovine Pleuropneumonia; Nipah; Japanese Encephalitis; Classical Swine Fever; Foot and Mouth Disease," Retrieved: May 12, 2010, http://www.oie.int/eng/maladies/en_technical_diseasecards.htm.
- OIE (2010). "Manual of Diagnostic Tests and Vaccines for Terrestrial Animals 2010," Retrieved: 2 Feb 2012, <http://www.cabi.org/ahpc/default.aspx?site=160&page=3323>.
- Ojajärvi, J. (1981). "The Importance of Soap Selection for Routine Hand Hygiene in Hospital," *J. Hyg. Cambridge*. 86, 275-283.
- Olsen, Robin J., Lynch, Patricia, Coyle, Marie B., Cummings, Jeanne, Bokete, Teresa and Stamm, Walter E. (1993). "Examination Gloves as Barriers to Hand Contamination in Clinical Practice," *JAMA: The Journal of the American Medical Association*, 270(3), 350-353, <http://jama.ama-assn.org/content/270/3/350.abstract>.
- Orsel, K., de Jong, M. C., Bouma, A., Stegeman, J. A. and Dekker, A. (2007). "The effect of vaccination on foot and mouth disease virus transmission among dairy cows," *Vaccine*. 2006/09/05, 25 (2), 327-335, DOI: S0264-410X(06)00901-7 [pii], 10.1016/j.vaccine.2006.07.030, 0264-410X (Print), 0264-410X (Linking), Retrieved: Jan 4, <http://www.ncbi.nlm.nih.gov/pubmed/16949184>.

- Orsel, K., Dekker, A., Bouma, A., Stegeman, J. A. and de Jong, M. C. (2005). "Vaccination against foot and mouth disease reduces virus transmission in groups of calves," *Vaccine*. 2005/07/09, 23 (41), 4887-4894, DOI: S0264-410X(05)00534-7 [pii], 10.1016/j.vaccine.2005.05.014, 0264-410X (Print), 0264-410X (Linking), Retrieved: Sep 30, <http://www.ncbi.nlm.nih.gov/pubmed/16002192>.
- Paarlberg, P.L., J.G. Lee, and A.H. Seitzinger (2003 April). "Measuring Welfare Impacts of an FMD Outbreak in the United States," *Journal of Agricultural and Applied Economics*. 35 (1), 53-65.
- Paarlberg, P.L., et al. (2008, May). "Economic Impacts of Foreign Animal Disease," *USDA, Economic Research Service*. ERR-57, <http://www.ers.usda.gov/publications/err57/>
- Paarlberg, P.L., Hillberg, S.A., Lee, J.G., Mathews Jr., K.H. (2009). "Supply reductions, export restrictions, and expectations for hog returns in a potential classical swine fever outbreak in the United States," *J Swine Health Prod* 17 (3), 155-162.
- Palakal, M.J., Murthy, U., Chittajallu, S.K and Wong, D. (1995). "Tonotopic representation of auditory responses using self-organizing maps," *Math Comput Model*. 22, 7-21.
- Pallister, J., Middleton, D., Broder, C. C. and Wang, L. F. (2011). "Henipavirus Vaccine Development," *J Bioterr Biodef S*. 1, 2-2.
- Pallister, Jackie, Middleton, Deborah, Wang, Lin-Fa, Klein, Reuben, Haining, Jessica, Robinson, Rachel, Yamada, Manabu, White, John, Payne, Jean, Feng, Yan-Ru, Chan, Yee-Peng and Broder, Christopher C. (2011). "A recombinant Hendra virus G glycoprotein-based subunit vaccine protects ferrets from lethal Hendra virus challenge," *Vaccine*. 29 (34), 5623-5630, 0264-410X, <http://www.sciencedirect.com/science/article/pii/S0264410X11008796>.
- Pancic, F., Carpentier, D. C. and Came, P. E. (1980). "Role of infectious secretions in the transmission of rhinovirus," *Journal of Clinical Microbiology*. 1980/10/01, 12 (4), 567-571, 0095-1137 (Print) 0095-1137 (Linking), Retrieved: Oct, <http://www.ncbi.nlm.nih.gov/pubmed/6252242>.
- Parida, S., Mahapatra, M., Kumar, S., Das, S. C., Baron, M. D., Anderson, J. and Barrett, T. (2007). "Rescue of a chimeric rinderpest virus with the nucleocapsid protein derived from peste-des-petits-ruminants virus: use as a marker vaccine," *J Gen Virol*. 2007/06/08, 88 (Pt 7), 2019-2027, DOI: 88/7/2019 [pii], 10.1099/vir.0.82913-0, 0022-1317 (Print), 0022-1317 (Linking), Retrieved: Jul, <http://www.ncbi.nlm.nih.gov/pubmed/17554036>.
- Parker, J. (1971). "Presence and Inactivation of Foot-and-Mouth Disease Virus in Animal Faeces," *The Veterinary Record*. 88 (659-662).
- Patil, P., Bayry, J., Ramakrishna, C., Hugar, B. , Misra, L. and Prabhudas, K. (2002). "Immune Responses of Sheep to Quadravalent Double Emulsion Foot-and-Mouth Disease Vaccines: Rate ofDevelopment Immunity and Variations among Other Ruminants.," *Journal of Clinical Microbiology*. 40 (11), 4367-4371.
- Peel, M. C., Finlayson, B. L. and McMahon, T. A. (2007). "Updated world map of the Köppen-Geiger climate classification," *Hydrology and Earth System Sciences*. 11, 1633-1644.

- Pelzer, Jeremy (2011). "Nebraska's wild pig population concerns Wyoming state veterinarian," *Wyoming Star-Tribune (Trib.com)*.
- Pendell, D.L. (2006). "Value of Animal Traceability Systems in Managing a Foot and Mouth Disease Outbreak in Southwest Kansas," Graduate Dissertation, Kansas State University, <http://hdl.handle.net/2097/199>
- Pendell, D.L., et al. (2007). "The Economic Impacts of a Foot-And-Mouth Disease Outbreak: A Regional Analysis," *Journal of Agricultural and Applied Economics*. 39 (Oct.), 13-33, <http://purl.umn.edu/37093>.
- Piggott, N., Marsh, T.L. (2004, February). "Does Food Safety Information Impact U.S. Meat Demand?," *American Journal of Agricultural Economics*, Vol. 86(No. 1), pp. 154-174,
- Playford, E.G., et al. (2010, February). "Human Hendra Virus Encephalitis Associated with Equine Outbreak, Australia, 2008," *Emerging Infectious Diseases*. Vol.16, No.2, <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2957996/>.
- Plowright, R.K., et al. (2011, April). "Urban habituation, ecological connectivity and epidemic dampening: the emergence of Hendra virus from flying foxes (*Pteropus* spp.)," *Proceedings of the Royal Society B.*, <http://rspb.royalsocietypublishing.org/content/early/2011/05/06/rspb.2011.0522.short?rss=1>.
- Plum Island Safety Committee (1979). *Final Committee Report: Exploratory Analysis - FMD Outbreak in Animal Supply*. Fax to USDA.
- Polatnick, Jerome (1967). "Chemically Characterized Media for Study of Foot-and-Mouth Disease Virus in Baby Hamster Kidney Cells," *Applied Microbiology*, 15(2), 228-232,
- Polatnick, Jerome and Bachrach, Howard L. (1978). "Effect of Zinc and Other Chemical Agents on Foot-and-Mouth Disease Virus Replication," *Antimicrobial Agents and Chemotherapy*, 13(5), 731-734,
- Porotto, M., Orefice, G., Yokoyama, C.C., Mungall, B.A., Realubit, R., Sganga, M.L., Aljofan, M., Whitt, M., Glickman, F. and Moscona, A. (2009). "Stimulating Henipavirus Multicycle Replication in a Screening Assay Leads to Identification of a Promising Candidate for Therapy," *Journal of Virology*. 83(10), 5148-5155.
- Queensland (Australia) Government, Brisbane (2009 cited 2010). *Guidelines for veterinarians handling potential Hendra virus infection in horses*. 3rd ed (Jan 14), <http://www.dpi.qld.gov.au>.
- R Development Core Team (2011). "R: A Language and Environment for Statistical Computing," R Foundation for Statistical Computing.
- Ramsdell, J.V., Jr., Rishel, J.P. (2007). *Tornado Climatology of the Contiguous United States (NUREG/CR-4461, Revision 2; PNNL-15112, Revision 1)*. Division of Risk Assessment and Special Projects, U.S. NRC.

- Randolph, T.F., Morrison, J.A., and Poulton, C. (2005). "Evaluating Equity Impacts of Animal Disease Control: The Case of Foot and Mouth Disease in Zimbabwe " *Review of Agricultural Economics*. 27, 465-472.
- Reed, S. E. (1975). "An investigation of the possible transmission of Rhinovirus colds through indirect contact," *J Hyg (Lond)*. 75, 249-258.
- Reeves, A. (2011). "Using data from the individual animal level to inform unit-level disease state parameters for NAADSM," <http://www.naadsm.org/techpapers>.
- Rego, A., Roley, L. (1999). "In-use barrier integrity of gloves: Latex and nitrile superior to vinyl," *American Journal of Infection Control* 27, 405-410.
- Reimer, J.J. (2006). "Vertical integration in the pork industry," *American Journal of Agricultural Economics*. 88 (1), 234, 0002-9092.
- Reynes, J. M., Counor, D., Ong, S., Faure, C., Seng, V., Molia, S., Walston, J., Georges-Courbot, M.C., Deubel, V., and Sarthou, J. (2005). "Nipah Virus in Lyle's Flying Foxes, Cambodia," *Emerging Infectious Disease*, 11, 1042-1047,
- Rich, K. (2005). "Spatial Models of Animal Disease Control in South America: The Case of Foot-and-Mouth Disease," *PhD Dissertation*. University of Illinois at Urbana-Champaign.
- Rich, Karl and Alex Winter-Nelson (2007). "An Integrated Epidemiological-Economic Analysis of Foot and Mouth Disease: Applications to the Southern Cone of South America," *American Journal of Agricultural Economics*. 682-697.
- Rich, K.M., Winter-Nelson, A., and Miller, G.Y. (2005). "Enhancing economic models for the analysis of animal disease," *Rev. sci. tech. Off. int. Epiz.* 24 (3), 847-856.
- Richard A, Pledger (1960). "Effect of neutral red on plaque formation by foot-and-mouth disease virus," *Virology*, 10(1), 50-56, <http://www.sciencedirect.com/science/article/pii/0042682260900052>.
- Richmond, J. Y. (1971). "Mouse Resistance Against Foot-and-Mouth Disease Virus Induced by Injections of Pyran," *Infect Immun.* 3, 249-253.
- Rife, Daran L., Pinto, James O., Monaghan, Andrew J., Davis, Christopher A. and Hannan, John R. (2010). "Global Distribution and Characteristics of Diurnally Varying Low-Level Jets," *Journal of Climate*. 23 (19), 5041-5064, DOI: 10.1175/2010jcli3514.1, 0894-8755 1520-0442.
- Riley County (2009). *Solid Waste Management Plan*,
- Robinson, S. E. and Christley, R. M. (2007). "Exploring the role of auction markets in cattle movements within Great Britain," *Preventive Veterinary Medicine*. 2007/05/08, 81 (1-3), 21-37, DOI: 10.1016/j.prevetmed.2007.04.011, 0167-5877 (Print), 0167-5877 (Linking), Retrieved: Sep 14.

- Rockx, Barry, et al. (2011 Aug). "Clinical Outcome of Henipavirus Infection in Hamsters Is Determined by the Route and Dose of Infection," *Journal of Virology*. Vol. 85 (No. 15), 7658-7671, Received 8 March 2011/Accepted 10 May 2011.
- Rockx, Barry, Bossart, Katharine N., Feldmann, Friederike, Geisbert, Joan B., Hickey, Andrew C., Brining, Douglas, Callison, Julie, Safronetz, David, Marzi, Andrea, Kercher, Lisa, Long, Dan, Broder, Christopher C., Feldmann, Heinz and Geisbert, Thomas W. (2010). "A Novel Model of Lethal Hendra Virus Infection in African Green Monkeys and the Effectiveness of Ribavirin Treatment," *J. Virol.*, 84(19), 9831-9839, <http://jvi.asm.org/cgi/content/abstract/84/19/9831>.
- Roth, James A. and Spickler, Anna Rivid (2008). *Emerging and Exotic Diseases of Animals*, Iowa State University.
- Round, J. I. (1983). "Nonsurvey Techniques: A Critical Review of the Theory and the Evidence," *International Regional Science Review* 8 (3), 189-212.
- Rusin, P., Maxwell, S. and Gerba, C. (2002). "Comparative surface-to-hand and fingertip-to-mouth transfer efficiency of gram-positive bacteria, gram-negative bacteria, and phage," *Journal of Applied Microbiology*. 2002/09/18, 93 (4), 585-592, DOI: 1734 [pii], 1364-5072 (Print) 1364-5072 (Linking), <http://www.ncbi.nlm.nih.gov/pubmed/12234341>.
- Rutala, William A., Weber, David J. (2008). *Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008*. DHHS/CDC.
- Sahini, M., et.al. (2001). "Nipah virus infection among abattoir workers in Malaysia, 1998-1999," *International Journal of Epidemiology*. 2001:30, 1017-1020.
- Sandia National Laboratories (2009, December 17). "NBAF Threat and Risk Assessment," pp. 82.
- Sandia National Laboratories (2009, June). "Design Basis Threat."
- Sanson, R.L. (2000). "A re-analysis of the start of the United Kingdom 1967-8 foot-and-mouth disease epidemic to calculate transmission probabilities," *9th Symposium of the International Society for Veterinary Epidemiology and Economics.*, Retrieved: Augus 6-11, 2000.
- Sattar, S. A., Jacobsen, H., Springthorpe, V. S., Cusack, T. M. and Rubino, J. R. (1993). "Chemical disinfection to interrupt transfer of rhinovirus type 14 from environmental surfaces to hands," *Applied and Environmental Microbiology*. 1993/05/01, 59 (5), 1579-1585, 0099-2240 (Print) 0099-2240 (Linking), Retrieved: May, <http://www.ncbi.nlm.nih.gov/pubmed/8390817>.
- Schijven, Jack, et al. (2005). "Quantitative Risk Assessment of FMD Virus Transmission via Water," *Risk Analysis*. Vol 25 No. 1, 13-21.
- Schlenker, W. and S. B. Villas-Boas (2009). "Consumer and Market Response to Mad-Cow Disease," *American Journal of Agricultural Economics*. 91 (4), 1140-1152.
- Schuenemann, K.C., Cassano, J.J. and Finnis, J. (2009). "Synoptic Forcing of Precipitation over Greenland: Climatology for 1961-99," *Journal of Hydrometeorology*. 10 (60-78).

- Scudamore, J.M. (2007). "Consumer attitudes to vaccination of food-producing animals," *Rev. sci. tech. Off. int. Epiz.* 26 (2), 451-459.
- Sellers, R.F., Parker, J. (1969, May 17). "Airborne excretion of foot-and-mouth disease virus," *The Journal of Hygiene.* 67, 671-677, Cambridge University Press, Retrieved: February 12, 2010, <http://www.jstor.org/pss/3861463>.
- Sellers, R.F., Donaldson, A.I., and Herniman, K.A.J. (1970, May 22). "Inhalation, persistence and dispersal of foot-and-mouth disease virus by man," *The Journal of Hygiene.* 68, 565-573, Cambridge University Press, Retrieved: January 27, 2010, <http://www.jstor.org/pss/3861566>.
- Sellers, R.F. (1971, June). "Quantitative aspects of the spread of foot and mouth disease," *The Veterinary Bulletin.* 41 (6), 431-439.
- SES, Inc. Multi-State Partnership for Security in Agriculture. (2009, December). "Animal Stop Movement Order Functional and Full-Scale Exercise After-Action Report and Improvement Plan.."
- SES Inc. (2011). "Interview with Pottawatomie County Producer 3," In Deimeke B (ed.).
- Sharma, et al. (1981). "Foot-and-mouth disease in sheep: Pattern of virus excretion and distribution in the experimentally infected animals," *Indian J. Anim. Sci.* 51 (January), (1): 61-66.
- Shields, D.A., and Mathews, K.H. (2003, June). "Interstate Livestock Movements," *Electronic Outlook Report from the Economic Research Service.* LDP-M-108-01, USDA, Retrieved: March 15, 2010, <http://www.ers.usda.gov/publications/ldp/jun03/ldpm10801/ldpm10801.pdf>.
- Snowden, W.A. (1966). "Growth of foot-and-mouth disease virus in monolayer cultures of calf thyroid cells," *Nature.* 210, 1079-1080.
- Sorensen, J. H. (2003). "Modelling the Atmospheric Spread of Foot-and-Mouth Disease," *Danish Meteorological Institute.* 26.
- Sorensen, J. H., Mackay, D. K., Jensen, C. O. and Donaldson, A. I. (2000). "An integrated model to predict the atmospheric spread of foot-and-mouth disease virus," *Epidemiology and Infection.* 2000/09/12, 124 (3), 577-590, 0950-2688 (Print), 0950-2688 (Linking), Retrieved: Jun.
- Spurgin, Anthony J. (2009). *Human Reliability Assessment Theory and Practice*, CRC Press.
- Suarez, D.L., Spackman, E., Senne, D.A., Bulage, L., Welsch, A.C., & Froberg, K. (2003 abstract accessed online 19 December 2011). "The Effect of Various Disinfectant on Detection of Avian Influenza Virus by Real Time RT-PCR," *Avian Diseases.* Vol. 47 (No. s3), pp. 1091-1095, <http://www.aaapjournals.info/doi/abs/10.1637/0005-2086-47.s3.1091?journalCode=avdi>.
- Sullivan, Robert, et al. (1971 July). "Inactivation of Thirty Viruses by Gamma Radiation," *Applied Microbiology.* Vol 22 No. 1, 61-65.

- Sutmoller, P., and Vose, D.J. (1997). "Contamination of animal products: the minimum pathogen dose required to initiate infection," *Rev. Sce Tech Off. int. Epiz.* 16 (1).
- Sutmoller, P. and McVicar, J. W. (1972). "Foot-and-Mouth Disease: Changes in Serum-Neutralizing Activity of Immunized Cattle Shortly After Virus Exposure," *Infection and Immunity*, 6(5), 718-722,
- Sutmoller, P. and McVicar, J. W. (1972). "Three variants of foot-and-mouth disease virus type O: exposure of cattle," *Am J Vet Res.* 1972/08/01, 33 (8), 1641-1647, 0002-9645 (Print), 0002-9645 (Linking), Retrieved: Aug, <http://www.ncbi.nlm.nih.gov/pubmed/4340054>.
- Sutmoller, P. and McVicar, J. W. (1976). "Pathogenesis of foot-and-mouth disease: the lung as an additional portal of entry of the virus," *J Hyg (Lond).* 1976/10/01, 77 (2), 235-243, 0022-1724 (Print), 0022-1724 (Linking), Retrieved: Oct, <http://www.ncbi.nlm.nih.gov/pubmed/185288>.
- Sutmoller, P., McVicar, J. W. and Cottral, G. E. (1968). "The epizootiological importance of foot-and-mouth disease carriers. I. Experimentally produced foot-and-mouth disease carriers in susceptible and immune cattle," *Arch Gesamte Virusforsch.* 1968/01/01, 23 (3), 227-235, 0003-9012 (Print), 0003-9012 (Linking), <http://www.ncbi.nlm.nih.gov/pubmed/5680590>.
- Sykes, R.I., Parker, S.F., Henn, D.S. and Chowdhury, B. (2008). *SCIPUFF Version 2.4 Technical Documentation*. Sage Management Enterprise LLC.
- Tammero, Lance, Gansemer, Jim, Holmstrom, Lindsey, Hullinger, Pam, Melius, Carl and Robertson, Alex (2010). "The Multiscale Epidemiological Simulation and Analysis (MESA) Model: Parameterization of MESA for FMD," LLNL-TM-432205.
- Taul, T. (2011). Interview with the Kansas Artificial Breeding Service Unit (KABSU) Manager, In Wilson A (ed.), SES, Inc.
- Taylor, G. R. and Butler, M. (1982). "A comparison of the virucidal properties of chlorine, chlorine dioxide, bromine chloride and iodine," *The Journal of Hygiene*, 89(2), 321-328,
- Taylor, N.M., et al., (2004). "Risk of foot-and-mouth disease associated with proximity in space and time to infected premises and the implications for control policy during the 2001 epidemic in Cumbria," *Vet Rec*, 154, 617-626,
- Taylor, Scott (2011). "Interview with Nebraska Game and Parks Commission's Wildlife Division."
- Team RDC (2011). "R: A Language and Environment for Statistical Computing," R Foundation for Statistical Computing, Vienna, Austria.
- Terpstra, C. (1972). "Pathogenesis of foot-and-mouth disease in experimentally infected pigs," *Bull Off Int Epizoot* 77, 859-874.
- Teunis, P.F., A.H. Havelaar (2000). "The Beta Poisson dose-response model is not a single-hit model.," *Risk Anal* (20), 513-520.

- Thilmany, D., Umberger, W., and Ziehl, A. (2004). "Consumer Response to Beef due to the December 2003 BSE Incident in the U.S.," Colorado State University DARE Extension publication AMR 04-01.
- Tildesley, M. J., Savill, N. J., Shaw, D. J., Deardon, R., Brooks, S. P., Woolhouse, M. E., Grenfell, B. T. and Keeling, M. J. (2006). "Optimal reactive vaccination strategies for a foot-and-mouth outbreak in the UK," *Nature*. 2006/03/03, 440 (7080), 83-86, DOI: nature04324 [pii], 10.1038/nature04324, 1476-4687 (Electronic), 0028-0836 (Linking), Retrieved: Mar 2, <http://www.ncbi.nlm.nih.gov/pubmed/16511494>.
- Tonsor, G. T., Mintert, J. R., & Schroeder, T. C. (2010). "US Meat Demand: Household Dynamics and Media Information Impacts," *Journal of Agricultural and Resource Economics*. 35.
- Torres-Velez, F. J., Shieh, W. J., Rollin, P. E., Morken, T., Brown, C., Ksiazek, T. G. and Zaki, S. R. (2008). "Histopathologic and Immunohistochemical Characterization of Nipah Virus Infection in the Guinea Pig," *Veterinary Pathology Online*, 45(4), 576-585, <http://vet.sagepub.com/content/45/4/576.abstract>.
- Townsend, E., Halvorson, D.A., Nagaraja, K.V., & Shaw, D.P. (1999, 2000 abstract accessed online 20 December 2011). "Susceptibility of an Avian Pneumovirus isolated from Minnesota Turkeys to Physical and Chemical Agent," *Avian Diseases*. Vol. 44, pp. 336-342, <http://www.jstor.org/pss/1592548>.
- Tozer, P., Marsh, T.L., and Perevodchikov, E.V., (2010). "Domestic and Trade Impacts of Foot and Mouth Disease on the Australian Beef Industry," Contributed paper 2010 Meeting of the Australian Agricultural and Resource Economics Society, http://www.impact.wsu.edu/MarshFiles/Tozer%20Manuscript_170310.pdf.
- Twomey, T., France, L. L., Hassard, S., Burrage, T. G., Newman, J. F. E. and Brown, F. (1995). "Characterization of an acid-resistant mutant of foot-and-mouth disease virus," *Virology*, 206(1), 69-75, <http://www.sciencedirect.com/science/article/pii/S0042682295800204>.
- U.S. GAO. "U.S. GAO - Biological Research: Observations on DHS's Analyses Concerning Whether FMD Research Can Be Done as Safely on the Mainland as on Plum Island." from <http://www.gao.gov/products/GAO-09-747>.
- United Kingdom, Department for Environment, Food and Rural Affairs (UK DEFRA) "Family Food – Data Sets," Retrieved: 8/23/2010, <http://www.defra.gov.uk/evidence/statistics/foodfarm/food/familyfood/documents/index.htm>.
- United States Post Office (2009). *USNaviguide (Free USPS Lookup and Boundary map)*. Vol. 2011, <http://www.usnaviguide.com/>.
- University of Georgia College of Veterinary Medicine (2007). "Southeastern Cooperative Wildlife Disease Study," Vol 2011, <http://128.192.20.53/nfsms/index.jsp>.
- USACE (U.S. Army Corps of Engineers) (2001, April). "Earthquake Effects on the Dam," *Heartland Engineers Fact Sheet*. USACE Kansas City District.

- USAHA (2008). "Foreign Animal Diseases (The Gray Book)," <http://www.usaha.org/pubs/fad.pdf>.
- USDA (2007). "National Veterinary Stockpile Countermeasures Working Group Report Foot-and-Mouth Disease ", USDA Agricultural Research Service.
- USDA (2009). "2007 Census of Agriculture: Summary and State Data In Agriculture."
- USDA Research Education and Economics (2002). *ARS Facilities Design Standards*. 242.241-ARS.
- USDA (2011). "NAHEMS Guidelines: Vaccination for contagious diseases. Appendix A: foot-and-mouth disease."
- USDA-APHIS (2009). "Beef 2007-08, Part II: Reference of Beef Cow-calf Management Practices in the United States, 2007–08," (Table D.8.a), 84, http://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/downloads/beef0708/Beef0708_dr_PartII.pdf.
- USDHHS/CDC *National Health and Nutrition Examination Survey, 1999-2002*.
- USDHHS/CDCP (2007). "Biosafety in Microbiological and Biomedical Laboratories, 5th Edition," Retrieved: May 28, 2010, http://www.cdc.gov/biosafety/publications/bmbl5/BMBL5_introduction.pdf.
- USGS (2011). "USGS Surface-Water Monthly Statistics for the Nation," *USGS Water Resources*. http://waterdata.usgs.gov/nwis/monthly/?referred_module=sw&site-no=06887000&por_06887000-6+92416,00060,6,1950.
- Vande Woude, George F., Polatnick, Jerome and Ascione, Richard (1970). "Foot-and-Mouth Disease Virus-Induced Alterations of Baby Hamster Kidney Cell Macromolecular Biosynthesis: Inhibition of Ribonucleic Acid Methylation and Stimulation of Ribonucleic Acid Synthesis," *Journal of Virology*, 5(4), 458-463,
- Vogelmann, J. E., Howard, S. M., Yang, L., Larson, C. R., Wylie, B. K. and Van Driel, J. N. (2001). "Completion of the 1990's National Land Cover Data Set for the conterminous United States," *Photogrammetric Engineering and Remote Sensing*. 67, 650-662.
- Walker, J.S., et al. (1984). "The thermal death time curve for foot-and-mouth disease virus contained in primarily infected milk," *Journal of Biological Standardization*. 12, 185-189.
- Wang, Wenli, Winters, Philip J. (2004). "Statistically Significant Efficiency Testing of HEPA Filters," *Journal of the IEST*. 2004 Edition, 101-106.
- Ward, M. P., Laffan, S. W. and Highfield, L. D. (2011). "Disease spread models in wild and feral animal populations: application of artificial life models," *Rev Sci Tech*. 2011/10/04, 30 (2), 437-446, 0253-1933 (Print), 0253-1933 (Linking), Retrieved: Aug, <http://www.ncbi.nlm.nih.gov/pubmed/21961216>.

- WasteCare Corporation (2011). *Trash Compactors and Waste Disposal*.
http://www.wastecare.com/Products-Services/Compactors/Compactors_About.htm.
- Weingartl, Hana, Czub, Stefanie, Copps, John, Berhane, Yohannes, Middleton, Deborah, Marszal, Peter, Gren, Jason, Smith, Greg, Ganske, Shelley, Manning, Lisa and Czub, Markus (2005). "Invasion of the Central Nervous System in a Porcine Host by Nipah Virus," *J. Virol.* 79 (12), 7528-7534,
<http://jvi.asm.org/cgi/content/abstract/79/12/7528>.
- Weingartl, Hana M., Berhane, Yohannes, Caswell, Jeff L., Loosmore, Sheena, Audonnet, Jean-Christophe, Roth, James A. and Czub, Markus (2006). "Recombinant Nipah Virus Vaccines Protect Pigs against Challenge," *J. Virol.* 80 (16), 7929-7938,
<http://jvi.asm.org/cgi/content/abstract/80/16/7929>.
- Westcott, P.C., Young, E.C., and Price, J.P. (2002). "The 2002 Farm Act: Provisions and Implications for Commodity Markets," *USDA, Economic Research Service*. AIB778,
<http://www.ers.usda.gov/Publications/AIB778/>.
- Williams, Tara (2010, April 22). "Health Cert - Swine & Cattle Imports 2009," Personal correspondence, Veterinary Division, North Carolina Department of Agriculture and Consumer Services.
- Williamson, Mm, Hooper, Pt, Selleck, Pw, Gleeson, Lj, Daniels, Pw, Westbury, Ha and Murray, Pk (1998). "Transmission studies of Hendra virus (equine morbilli-virus) in fruit bats, horses and cats," *Australian Veterinary Journal.* 76 (12), 813-818, 1751-0813,
<http://onlinelibrary.wiley.com/doi/10.1111/j.1751-0813.1998.tb12335.x/abstract>.
- Williamson, M. M., Hooper, P. T., Selleck, P. W., Westbury, H. A. and Slocombe, R. F. (2000). "Experimental Hendra Virus Infection in Pregnant Guinea-pigs and Fruit Bats (*Pteropus poliocephalus*)," *Journal of Comparative Pathology.* 122 (2-3), 201-207, 0021-9975,
<http://www.sciencedirect.com/science/article/pii/S002199759990364X>.
- Winther, B., McCue, K., Ashe, K., Rubino, J.R. and Hendley, J.O. (2007). "Environmental contamination with rhinovirus and transfer to fingers of healthy individuals by daily life activity," *Journal of Medical Virology.* 79 (10), 1606-1610, 1096-9071.
- Wong, K.T., et al. (2009). "Human Hendra virus infection causes acute and relapsing encephalitis," *Neuropathology and Applied Neurobiology* 35, 296-305.
- Wood, J., et al. (2004). "Destruction Efficiency of Microbiological Organisms in Medical Waste Incinerators: A Review of Available Data," Proceedings, 23rd Annual International Conference on Incineration & Thermal Treatment Technologies (Phoenix, AZ, May 10-14,), Air & Waste Management Association, Pittsburgh, PA, 011.
- World Health Organization (2010, March 10). "Nipah Virus Fact Sheet N262,"
<http://www.who.int/mediacentre/factsheets/fs262/en/print.html>.
- Wright, C. F., Gloster, J., Mazelet, L., Paton, D. J. and Ryan, E. D. (2010). "Short-lived carriage of foot-and-mouth disease virus in human nasal cavities after exposure to infected animals," *The Veterinary Record,* 167(24), 928-931, <http://www.ncbi.nlm.nih.gov/pubmed/21262692>.

- Yu, C.-Y., Hsu, Y.-W., Chen, C.-Y. (2008). "Determination of hand surface area as a percentage of body surface area by 3D anthropometry," *Burns* 34, 1183-1189.
- Yu, C.-Y., Tu, H.-H. (2009). "Foot surface area database and estimation formula," *Applied Ergonomics*. 40, 767-774.
- Yu, C.-Y., Lin, C.-H., Yang, Y.-H. (2010). "Human body surface area database and estimation formula," *Burns* 36, 616-629.
- Zhao, Z., Whal, T., and Marsh, T. (2006). "Invasive Species Management: Foot-and-Mouth Disease in the U.S. Beef Industry," *Agricultural and Resource Economics Review*. 35 (1), 98-115, <http://purl.umn.edu/10174>.
- Zhu, Zhongyu, Bossart, Katharine N., Bishop, Kimberly A., Crameri, Gary, Dimitrov, Antony S., McEachern, Jennifer A., Feng, Yang, Middleton, Deborah, Wang, Lin-Fa, Broder, Christopher C. and Dimitrov, Dimiter S. (2008). "Exceptionally Potent Cross-Reactive Neutralization of Nipah and Hendra Viruses by a Human Monoclonal Antibody," *Journal of Infectious Diseases*. 197 (6), 846-853, <http://jid.oxfordjournals.org/content/197/6/846.abstract>.
- Zohrabian, A.M., et al. (2004). "West Nile Virus Economic Impact, Louisiana, 2002," *Emerging Infectious Diseases*. 10, 1736-1744.
- Zollinger, B. (2004). "Kansas Department of Wildlife and Parks Survey of Landowners on Opinions About Deer Populations in Kansas."
- Zollinger, B., and Wheeler, B. (2007, January). "Public Opinion Survey of Deer Management in Kansas," The Docking Institute of Public Affairs. Fort Hays State University.
- Zollinger, B. (2010, March 3). "Addendum to the 2008 Kansas Department of Wildlife and Parks Survey of Land Operators on Opinion About Deer Populations in Kansas," The Docking Institute of Public Affairs.
- Zoni, R., Zanelli, R., Riboldi, E., Bigliardi, L. and Sansebastiano, G. (2007). "Investigation of virucidal activity of chlorine dioxide, experimental data on feline calicivirus, HAV and Coxsackie B5," *J. Prev. Med. Hyg*, 48(3), 91-95,