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FINAL TEST REPORT
FOR
JACK RABBIT (JR) II

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UNDER CONTRACT NO. W911S6-16-C-0003

Report Produced By
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14. ABSTRACT
This test report summarizes the findings from Jack Rabbit II (JRII) conducted at WDTC, US Army Dugway Proving Ground (DPG), Utah, from August 2015 through September 2016. It should not be construed as the Army Test and Evaluation Command system evaluation report or system assessment for JRII.

The JRII test was designed to safely replicate accidental or intentional releases of chlorine gas from pressurized tanks and to document the downwind movement of the gas through an urban setting and in an open area. During 2015, five trials were completed in a simulated urban area containing multiple vehicles with chlorine gas releases ranging in size from 5 to 9 tons. Mass, pressure, chlorine vapor concentration, temperature, and meteorological data were collected to track the chlorine cloud movement downrange.

During 2016, four trials were completed with minimal urban structures and vehicles, using chlorine gas releases ranging in size from 10 to 20 tons. Three chlorine dissemination angles were tested; 180 degrees (downward), 135 degrees and 0 degrees (upward). Data can be found on the Homeland Security Information Network (HSIN). (https://hsin.dhs.gov)

15. SUBJECT TERMS
Jack Rabbit; JR; rapid phase transition; RPT; command post; CP; light detection and ranging; LIDAR; Urban Test Grid; UTG; meterological; MET, chlorine; Cl_2.

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1. The JRII Test was sponsored by the following organizations:

a. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Chemical Security Analysis Center (CSAC).

b. Department of Defense (DoD) Defense Threat Reduction Agency (DTRA) Information Systems and Surveillance Division.

c. Transport Canada and Defence Research and Development Canada (DRDC) Center for Security Science (CSSS).

2. The following organizations participated in studies and testing at DPG:

d. Allied Universal, Conshohocken, Pennsylvania.

e. Argonne National Laboratory, Lemont, Illinois.

f. American Association of Railroads, Washington, D.C.

g. BSNF Railroad, Fort Worth, Texas.

h. Center for Toxicology & Environmental Health, North Little Rock, Arkansas.

i. Clarkson University, Potsdam, New York.

j. Defense Science and Technology Laboratory, Salisbury Wiltshire, United Kingdom.

k. Defense Science Organization, Singapore.

l. DHS, Federal Emergency Management Agency, Washington, DC.

m. National Fire Academy, Emmitsburg, Maryland.

n. Eastern Municipal Water District, Perris, California.

o. Gutteridge Haskins & Davey (GHD) Engineering Company, Sydney, Austraila

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q. Hawkins Inc., Roseville, Minnesota.

r. K2 Pure Solutions, Toronto, Canada.

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t. Occidental Petroleum Company, Washington, DC.

u. Olin Corporation, Clayton, Missouri.

v. RAE Systems, San Jose, California.

w. Honeywell Analytics, Lincolnshire, Illinois.

x. Rand Corporation, Santa Monica, California.

y. Signature Sciences, Austin, Texas.

z. Spectral Sensor Solutions, Herndon, Virginia.

aa. Texas A & M, College Station, Texas.

bb. Mary Kay O’Conner Process Safety Center, College Station, Texas.

cc. The Chlorine Institute, Arlington, Virginia.

dd. The Dow Chemical Company, Auburn, Minnesota.

ee. The Kuehne Company, South Kearny, New Jersey.

ff. Union Pacific Railroad, Omaha, Nebraska.

gg. University of Arkansas, Fayette, Arkansas.

hh. Martin Department of Chemical Engineering, University of Arkansas, Fayetteville, Arkansas.

ii. Utah Valley University Emergency Services, Provo, Utah.

jj. Westlake Chemical Corporation, Calvert City, Kentucky.

SECTION 1. EXECUTIVE DIGEST

1.1 SYSTEM DESCRIPTION

a. None. This is not a system test.

1.2 SUMMARY

1.2.1 Testing Authority

a. On 5 March 2014, US Army Test and Evaluation Command (ATEC), Aberdeen Proving Ground (APG), Maryland, issued a test support order (Appendix B) through the ATEC Decision Support System (ADSS) authorizing West Desert Test Center (WDTC), US Army Dugway Proving Ground (DPG), Utah, to conduct the Jack Rabbit (JR)II Test, ATEC Project Number 2015-DT-DPG-SNIMT-F9735.

1.2.2 Test Concept

a. The JRII test program was conducted at DPG from August 2015 through September 2016. During 2015, five trials were completed within a simulated urban area with chlorine gas releases ranging in size from 5 to 9 tons. During the 2016 trials, the urban area was cleared of urban obstructions, with the exception of two urban structures and two vehicles used for indoor and vehicle infiltration studies. A limited number of necessary chlorine support mechanisms remained in the test area. The 2016 test iteration consisted of three 10-ton trials and one 20-ton trial. JRII was sponsored by the Department of Homeland Security Science and Technology Directorate (DHS S&T) of Washington, DC; the Defense Threat Reduction Agency (DTRA) of Fort Belvoir, Virginia; and Transport Canada and Defence Research and Development Canada (DRDC) Center for Security Science (CSSS) of Toronto, Canada. Program oversight was provided by the Chemical Security Analysis Center (DHS S&T CSAC) of APG, Maryland. Test execution was provided by WDTC.

b. The project objectives supported improvements to the manner in which DHS and its partners address toxic inhalation hazard (TIH) risks. Building on the success of the 2010 JRI chlorine and ammonia trials (Reference 1), project goals for 2015 and 2016 included the following:

(1) Improved chemical hazard modeling.

(2) Better planning and resilience for release incidents.

(3) More efficient and effective emergency responses.

(4) Improved mitigation measures to reduce the impact to affected populations and infrastructure.

1.2.2.1 Background

a. The previously executed JRI test was conducted to develop, test, and evaluate the physio-chemical characteristics of a disseminated gas and aerosol cloud (Reference 1). JRI investigated chlorine and ammonia TIHs, gas transport, dispersion, mitigation via deposition, and reactions with water and soil. The project evaluated instruments, test methods, and strategies for future industrial-scale tests. Two pilot tests and eight record tests were completed in 2010 with a chlorine or ammonia mass of 907 or 1814 kg (1 or 2 tons) used for each test (Reference 1). The results demonstrated the following:

(1) Downwind transport and turbulent mixing are initially reduced by a dense persistent gas/aerosol cloud under low wind conditions.

(2) Rapid phase transition (RPT) eruptions presented a previously unobserved chlorine spill hazard.

(3) Source phenomena are nonlinear with increasing release volumes.

(4) Reactivity with soil containing water and organic matter is an important removal mechanism for chlorine.

1.2.2.2 Scope

a. JRII expanded upon the work of JRI (Reference 1) with controlled chlorine field experiments on a larger scale. It should be noted that JRI releases were conducted within a prepared geographic depression under light winds, which restricted the downwind movement of the chlorine gas. The JRII 2015 releases were conducted on a relatively flat area containing simulated urban fixtures, with the intention of allowing downwind dispersion of the chlorine gas within a simulated urban setting. The JRII 2016 releases were conducted on a relatively flat area with only two buildings and two cars 85 meters from the dissemination point.

(1) During the JRII Phase I 2015 trials, a specialized storage tank was used to disseminate a mass of chlorine up to 8303 kg (9 tons). During the JRII Phase II 2016 trials, a specialized storage tank was used to disseminate 9072 kg (10 tons) of chlorine, and a transport tanker was used to disseminate 17690 kg (19.5 tons) of chlorine. The JRII goals were to collect source term data, cloud transport and dispersion information, chemical reactions with the environment, infiltration data, and exposure effects on equipment and infrastructure.

(2) Test data were collected in 2015 and 2016 through ground-based video and infrared (IR) instruments, point detectors, standoff detectors, and concentration determination instruments. The 2016 trials also included unmanned aerial system (UAS) optical data. The data were shared with all project participants. The data and findings facilitate an improved understanding of the basic science, improved operational hazard prediction modeling, more effective emergency response and training, and improved preparedness and mitigation strategies of large scale chlorine releases.

b. The purpose of the DPG JRII test was to:

(1) Improve understanding and fill critical knowledge gaps for chlorine releases through operationally relevant large-scale releases represented by tanker truck and storage tank release scenarios.

(2) Support the DHS enterprise and stakeholders through transitioning of quality-assured data, scientifically based guidance, and knowledge products to guide and advance the following:

(a) Provide modeling data for release source, atmospheric transport and dispersion, hazard and risk, and consequence assessment.

(b) Enhance emergency preparedness, planning, and response.

(c) Provide safety and security in the use, transport, and storage of TIH chemicals.

(d) Assess hazard and risk mitigation strategies.

(e) Enhance the nation's resiliency to accidental or intentional TIH release disasters.

(f) Provide information for policy decisions.

c. During testing, nine releases ranging from 4509 to 17690 kg (5 to 19.5 tons) of chlorine were conducted. The trials satisfied the stated program goals and objectives (e.g., enhance confidence in modeling data, revise emergency response guidelines, and improve emergency response related to a large chlorine release).

d. The JRII test program was conducted with a collaborative team of partners from government, industry, and academia. The field trials, and subsequent data analysis, filled critical knowledge, data, and capability gaps for TIH chemical release modeling and emergency response procedures. JRII provided the first experimental chlorine release opportunities for testing and validation at levels represented by tanker trucks and large storage tanks.

1.2.3 Test Objectives

a. The test objectives are in Table 1.

1.3 CONCLUSIONS

a. The 2015-2016 JRII test program released nearly 85 tons of chlorine over the course of nine trials. These releases provided data that will enable DHS, DTRA, and the emergency response community to meet the numerous objectives critical to large scale TIH studies. By providing dissemination devices, a near- and far-field test grid with urban structures, and a wide-ranging suite of instrumentation and data collection, DPG met its objective to conduct testing using large quantities of chlorine in a safe and repeatable manner.

Table 1. Test Objectives; JRII Trials.

Subtest	Objective	Met/Not Met
2.2 2.3[a]	Safely perform the controlled release of compressed, liquefied chlorine to the atmosphere in a series of up to 21 trials in masses ranging from 4536 to 18,144 kg (5 to 20 tons) from simulated chlorine tank ruptures.	Met
2.2 2.3[a]	Use standard methodology to ensure relevant data precision, accuracy, validity, and quality in a common format.	Met
2.2 2.3[a]	Observe and measure the simulated ruptured tank thermodynamic and mass parameters during dissemination to improve model source terms.	Met
2.2 2.3[a]	Quantitatively monitor and collect gas cloud concentration data from the initial phase of a very dense, two-phase cloud near the source to dispersion of the cloud further downwind using point detectors and standoff spectroscopic instruments. Data collection from the release will allow personnel to quantify and characterize cloud retrograde.	Met
2.2 2.3[a]	Characterize and quantitatively measure chlorine cloud removal by deposition on vertical and horizontal surfaces, hydrolysis, photolysis, reaction with organic and inorganic constituents of soil, and reaction with vegetation.	Met[c]
2.2[a]	Investigate the small-scale movement of a chlorine cloud through, around, and above a mock urban environment.	Met
2.2[a]	Study building infiltration rates in a mock urban environment. **NOTE**: Defense Threat Reduction Agency (DTRA) is responsible for this study.	Met
2.2[a]	Assess exposure and damage effects in a mock urban setting.	Met
2.3[a]	Validate and characterize rapid phase transition (RPT) events observed in Jack Rabbit (JR)I tests (Reference 1).	Met[d]
2.2 2.3[a]	Study exposure impacts on equipment and materials. **NOTE**: Department of Homeland Security (DHS) is responsible for this study.	Met
2.2 2.3[a]	Study emergency response guidelines. **NOTE**: DHS is responsible for this study.	Met
2.2 2.3[a]	Study industrial risk and hazard mitigation procedures. **NOTE**: DHS is responsible for this study.	Met
2.2 2.3[a]	Provide a realistic observable hazardous release environment for the education and training of emergency response personnel. **NOTE**: US Army Dugway Proving Ground (DPG) will provide the training environment.	Met
2.3[b]	Determine the origin and character of the RPTs phenomenon.	Met[d]
2.2[b]	Determine the effectiveness of sheltering in place, including concentration and duration, to determine probable survivability.	Met
2.2 2.3[b]	Determine a reliable vertical concentration gradient (i.e., the gas density of chlorine at a concentration gradient in which a responder can survive above the cloud will be considered).	Met

Table 1. Test Objectives; JRII Trials (Cont'd).

Subtest	Objective	Met/Not Met
2.2[b]	Determine if internal combustion engines (gas and diesel) can operate in high concentrations of chlorine (consider the behavior of the combustion engine and determine the probability of driving out of the plume as an emergency tactic).	Met
2.2 2.3[b]	Determine if low wind speeds increase the probability of retrograde creep of the cloud. Further validate that the initial isolation zones [at a ground distance of 1000 m (3281 feet)] and downwind protective action recommendations contained in the *2012 Emergency Response Guidebook* (Reference 2) are appropriate.	Met
2.2[b]	Determine the significance of various urban barriers and plume behavior when encountering those barriers.	Met
2.2[b]	Determine the possibility of secondary post-release cloud evolution if contaminated surfaces are disturbed and the duration of long-term off-gassing.	Not Met
2.2 2.3[b]	Determine the level to which flash freezing and thawing occur on the surface at the release point.	Met
2.2 2.3[b]	Determine the behavior of common building components and urban surfaces. Specifically, determine the behavior of both new and aged asphalt when in contact with high concentrations of chlorine gas or liquid chlorine. Assess the absorption of chlorine gas into water.	Met

Test objectives came directly from DHS or were requested through DHS by members of the first responder community (Reference 3).

Supplementary objectives are from the Emergency Response Group (Reference 4).

Hydrolysis and photolysis were not investigated due to test limitations.

[d]Only conducted during 2015 trials.

b. JRII has met the readily observable objectives of releasing large amounts of chlorine in a realistic observable environment, providing the opportunity to measure source term data; building infiltration rate data; and near field, far field, and retrograde concentrations. The releases allowed the Emergency Response community to collect data that will be used to assess response and safety requirements. Future data analysis will provide information that will continue to improve the understanding and modeling of chlorine gas. No RPT events were observed during testing.

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SECTION 2. SUBTESTS

2.1 TEST SETUP

2.1.1 Command and Operations Setup

a. During the 2015 Trials, one command post (CP) and two support locations were set up as follows:

(1) Surface Layer (SL) Test Site. Site included the primary CP, an emergency response CP, two support trailers, the laser-induced fluorescence (LIF) instrument, a West Desert [light detection and ranging (LIDAR)] (WDL), and an optical data control center.

(2) Vertical (V)-Grid. Site included one support facility used for Jaz™ and Chlorine Institute support, and an open area for chlorine delivery transfer operations (Figure 1).

(3) Sprung® (Sprung Instant Structures, Aldersyde, Alberta) Facility. Site included one instrumentation facility used to store, repair, calibrate, and stage ToxiRAEs and MiniRAEs for test setup (Figure 1).

b. During the 2016 Trials, one CP and three support locations were set up as follows:

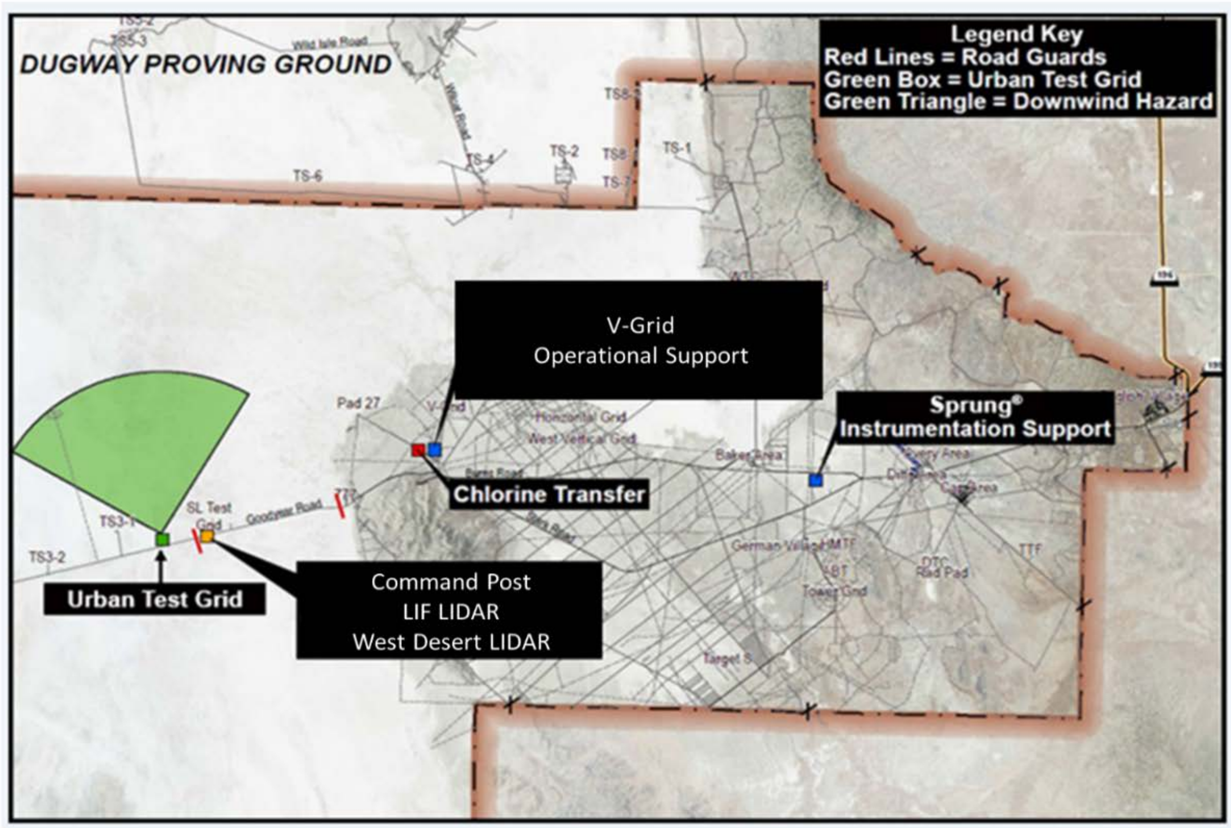
(1) SL Test Site. Site included the primary CP, an emergency response CP, one support trailer, the LIF instrument, WDL, ultraviolet (UV)-visible (Vis) Hyperspectral Camera, Thermal Imager, Real-time Eyesafe Visualization Evaluation and Analysis LIDAR (REVEAL) and an optical data control center.

(2) V-Grid. Site included one support facility used for Jaz™ support (Figure 1).

(3) Granite Tunnel. Site included an area for chlorine delivery, transfer operations, and Chlorine Institute base of operations.

(4) Sprung® Facility. Site included one instrumentation facility used to store, repair, calibrate, and stage ToxiRAEs, MultiRAEs, and Gasmet™ for test setup (Figure 1).

c. Distributed Test Control Center (DTCC). During the 2015 and 2016 Trials, the DTCC was the primary location for non-DPG modeling efforts, and visualization of test events by very important persons (VIPs). **NOTE**: The DTCC was located in the Ditto technical area at DPG and is not pictured in any of the figures in this report.



NOTE: V-Grid – Vertical Grid; LIF – laser-induced fluorescence; LIDAR – light detection and ranging.

Figure 1. Jack Rabbit (JR)II Test Site; JRII.

2.1.2 Urban Test Grid (UTG) Site Layout

a. Within the test site, the UTG area was a 122- × 183-m (400- × 600-ft) gravel pad with a rebar-reinforced concrete pad 25-m (82-ft) × 15.2-cm (6 in) thick used for chlorine disseminations. The concrete dissemination pad was aligned in the horizontal middle of the UTG area and located 91 m (300 ft) vertically north from the southern edge of the UTG. The pad had a 2.54-cm (1 in) lip at the outside edge made of steel and could be removed or replaced as needed based on operational or test requirements. **NOTE**: The coordinates for grid center were World Geodetic System (WGS) 84 Zone 12 North, Northing 4445633.945 and Easting 288109.182.

b. There was a 3.7- × 793-m (12- × 2600-ft) access road that connects Goodyear Road to the UTG area. The height of the UTG and access road is approximately 61 cm (24 in) above the surrounding playa. The access road was graded using a gravel/fill mixture that has a high compaction rate (greater than 90 percent). **NOTE**: The grade was level within a tolerance of one degree.

2.1.3 UTG Setup (2015 Trials)

a. Conex Setup

(1) The UTG was set up using a combination of 86 conexes (shipping containers), which were between 5.48 and 12.19 m (18 and 40 ft) long, and two 5.48- × 2.74-m (18- × 9-ft) modified trailers. All conexes were 2.44 m (8 ft). The inside of the trailers had insulation and dry wall installed. The outside lower half of the trailers had wood skirting installed to cover the tires and empty space. The conexes were set up on the UTG in the configuration as depicted in Figure 2.

NOTE: Conex position numbers are not shown in Figure 2; however, the conex positions were enumerated from left to right by row number (e.g., row 1 had conex numbers 1.1, 1.2. 1.3). Figure 2 has been adapted from original layouts developed at Homeland Security Studies and Analysis Institute (Falls Church, Virginia; Reference 5).

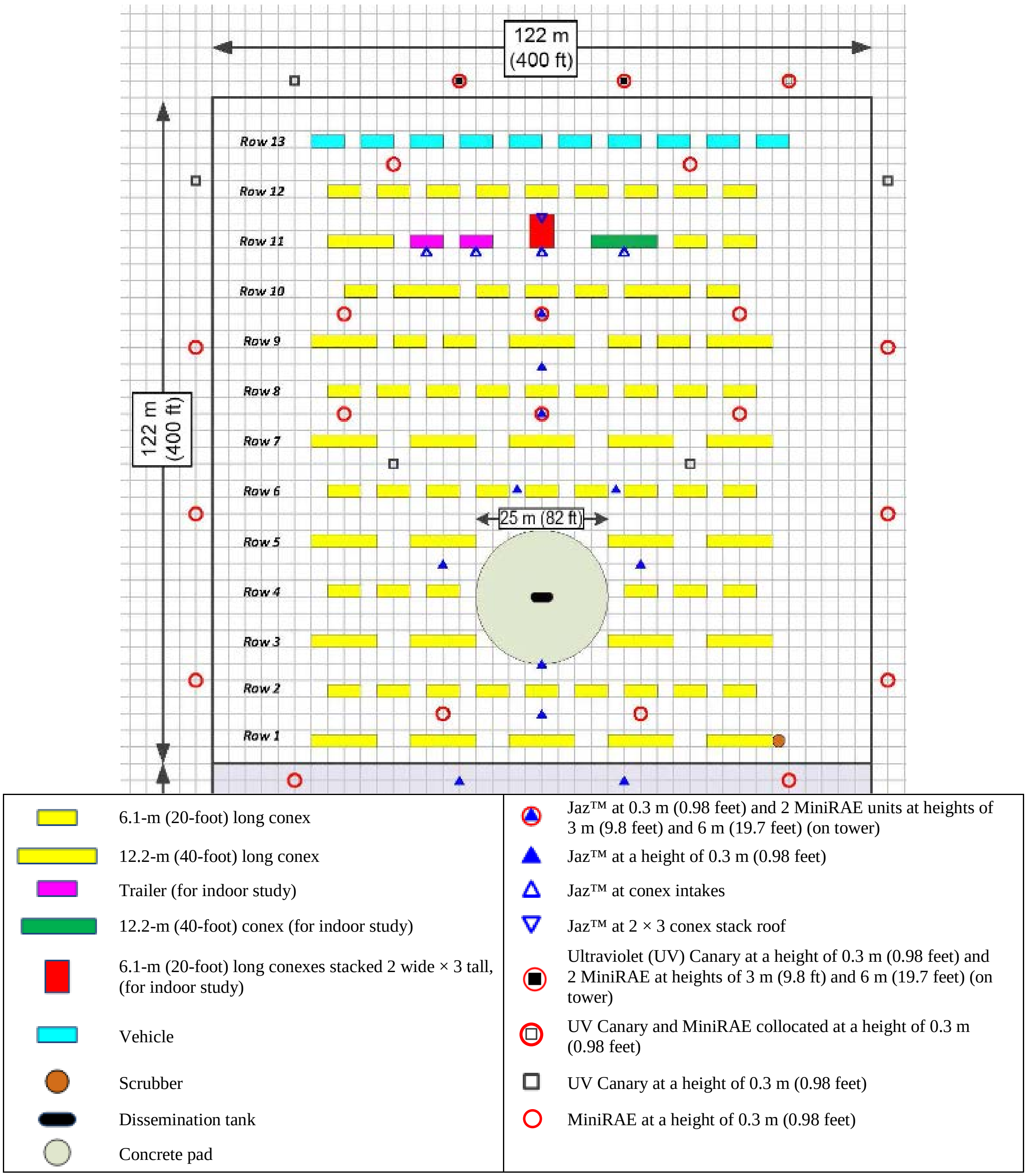
(2) During Trials 1 through 5, most of the conexes were placed on the UTG as single unstacked units. One structure was erected using six 6.1-m (20-ft) conexes stacked in a 2 × 3 conex configuration. This structure was aligned perpendicular to the rest of the conexes downwind of the dissemination tank (Figure 2).

NOTE: The detailed test plan (DTP, Reference 6) indicated that some of the conex trailers may be moved to accommodate an additional 2 × 3 stack; however, the additional 2 × 3 stack was not used because of time constraints.

(3) Indoor instrumentation was installed in the 2 × 3 conex stack, one 12.2-m (40-ft) conex, and two modified trailers to support indoor infiltration studies.

b. 2015 Vehicle Setup

(1) Three fire trucks, one ambulance, and three cars were placed at various positions on the UTG in support of the Emergency Response Group objectives. The data related to these vehicles can be found on the Homeland Security Information Network (HSIN) (Reference 7).



NOTES: 1. A description of the instrumentation is in Paragraph 2.1.4. This figure was provided by Homeland Security Studies and Analysis Institute (Falls Church, Virginia) and adapted by US Army Dugway Proving Ground (DPG; Reference 5).

2. During Trial 5, several vehicles were relocated. A map with these changes is found on the Homeland Security Information Network (HSIN; Reference 7).

Figure 2. 2015 Mock Urban Layout; JRII.

(2) During the test, several of the vehicles were instrumented with on-board diagnostics (OBD) and left running during the trials. For Trial 1, vehicle 5 had a Pegasus (StarGas Società a Responsabilità Limitata, Italy) OBD, and vehicle 7 had a Genisys Evolution (EVO; Bosch Automotive Service Solutions, Warren, Michigan) OBD. For Trial 2, vehicle 7 had a Pegasus OBD and vehicle 5 had an EVO OBD. For Trial 3, vehicle 6 had a Pegasus OBD and vehicle 5 had an EVO OBD. Trials 3 and 4 had no vehicles with OBD. During the final trial (Trial 5), vehicle 7 had an EVO OBD. The vehicles were instrumented with ToxiRAEs and/or MiniRAEs. The data related to these instruments can be found on the HSIN (Reference 7).

c. <u>2016 Vehicle Setup</u>

(1) During Trials 6 through 9, two cars and/or sport utility vehicles were placed on the UTG next to the indoor studies modular trailer and conex. The data related to these vehicles can be found on the HSIN (Reference 7).

(2) No vehicles were instrumented with OBDs for the 2016 trials. The vehicles were instrumented with ToxiRAEs and/or MiniRAEs and UV Canarys. The data related to these instruments can be found on the HSIN (Reference 7).

2.1.4 <u>Instrumentation Setup</u>

a. A complete data package, which includes specific instruments and their locations for each trial, can be accessed through the HSIN (Reference 7).

b. <u>Meteorology</u>

(1) <u>Portable Weather Information Display System (PWIDS)</u>. PWIDS are mobile meteorological (MET) measurement stations capable of collecting and displaying weather information at a predetermined rate. Each station consists of a tripod-mounted propeller-vane wind monitor, a temperature/humidity sensor mounted in a naturally aspirated radiation shield, a data logger, an optically isolated RS-232 interface, and a spread-spectrum radio/modem. Power is supplied by a solar panel and battery combination.

(a) The measurement height was 2 m (6.56 ft) above ground level (AGL). The PWIDS data acquisition rate is 1 hertz (Hz), and the data collected are averaged to 10-second intervals. The wind monitor (product 05103, R.M. Young Company, Traverse City, Michigan) has a wind speed accuracy of ±0.2 m/sec (0.66 ft/sec) and a wind direction accuracy of ±3 degrees. The Vaisala Humidity and Temperature Probe (HMP)-45 temperature/humidity probes (Vaisala, Helsinki, Finland) are accurate to ±0.4°C (±0.7°F) for temperatures ranging from -20°C through 55°C (-4°F through 131°F) and to ±2 percent for relative humidity (RH) ranging from 0 to 90 percent. Pressure is measured with the Vaisala PTB-101B pressure sensor (Vaisala, Helsinki, Finland), which has an accuracy rating of ±2 hectopascal (hPa) over the temperature range from -20°C through 45°C (-4°F through 113°F).

(b) PWIDS data were processed by the Campbell Scientific® CR1000 data logger (Campbell Scientific® Logan, Utah) and forwarded via a FreeWave® 1370 to 1390 megahertz (MHz) spread spectrum transceiver (FreeWave® Technologies, Boulder, Colorado) to the WDTC

Weather Station via a radio link and then routed to the test site through the DPG computer intranet or through a second radio network. PWIDS software displayed aerial photographs or a computer-aided design map of an area designated for data collection with MET parameters superimposed on the display. It also provided the user with a table of numeric data for collected parameters. Another feature of the software was the ability to display trend patterns for any given station. Automatic data archival was accomplished during data collection by directly porting information into a relational database.

(c) DPG deployed 49 PWIDS on the test site. Three 32-m (105-ft) MET towers were deployed with PWIDS at the 2-, 4-, 8-, 16-, and 32-m (6.56-, 13.12-, 26.3-, and 105-ft) levels for a total of 15 tower-mounted PWIDS. An additional 34 tripod-mounted PWIDS were deployed within the test grid and surrounding area. All data from the 49 PWIDS were viewable in real time at the CP.

(2) 32-m (105-ft) Tall MET Tower

(a) Three 32-m (105-ft) tall MET towers were used for the JRII test. PWIDSs and ultra-sonic anemometers were collocated on these towers at heights of 2, 4, 8, 16, and 32 m (6.6, 13.1, 26.2, 52.3, and 105 ft). The PWIDS sent real-time data to the CP, but the ultra-sonic anemometer datasets were collected daily after each test event.

(b) An ultrasonic anemometer consists of an array of three sets of ultrasonic transducer pairs designed to alternately transmit and receive pulses of acoustic energy, a system clock, and circuitry designed to measure transit time between the transmission and reception of acoustic signals between transducer pairs. The anemometers used for JRII are three dimensional (3D) sensors (model 81000) manufactured by R.M. Young Company (Traverse City, Michigan). Ultrasonic output included wind components and speed of sound at a rate of 10 Hz. Ultrasonic data were processed to produce wind and turbulence statistics and fluxes of heat and momentum.

(c) The 32-m (105-ft) tall towers were deployed along the centerline of the test grid at a distance of 100 m (328 ft) upwind of the UTG and 1 and 5 km (0.62 and 3.1 miles) downwind of the UTG.

(3) Ultrasonic Anemometers for wind characterization. DPG provided 30 ultrasonic anemometers to be used for turbulence characterization. Phase I was conducted October through November 2015 and phase II in March 2016. Specific weather conditions were required for data collection.

(a) The ultrasonic anemometers were mounted on 2-m (6.6-ft) tripods and on 5- and 10-m (16.4- and 32.8-ft) towers and placed within the UTG in two separate locations. The first location was a single 12.2-m (40-ft) conex centrally located at conex position 9.4 (row 9, conex 4) and the second location was a 2 × 3 stack of conexes located at position 2.5 (row 2, conex 5). Each obstacle design made use of 13 to 15 ultrasonic anemometers, which were placed on each side and on top of the conexes. A description of the ultrasonic anemometer setup is as follows:

(b) 12.2-m (40-ft) Conex

(1) Two 1-m (3.3-ft) tall tripods with one ultrasonic anemometer each at a height of 1 m (3.3 ft) AGL at a distance of 2.4 m (8 ft) and 4.9 m (16 ft) from the northern side of the conex.

(2) Two 2-m (6.6-ft) tall tripods with one ultrasonic anemometer each at a height of 1 m (3.3 ft) AGL at distances of 2.4 m (8 ft) and 4.9 m (16 ft) from the western and eastern sides of the conex.

(3) One 2-m (6.6-ft) tall tripod with one ultrasonic anemometer centered on the top of the conex at a height of 1.5 m (3.3 ft) above top of conex.

(4) One 5-m (16.4-ft) tall tower with three ultrasonic anemometers at heights of 1, 2, and 5 m (3.3, 6.6, and 16.4 ft) AGL at a distance of 1.2 m (4 ft) from the northern side of the conex.

(5) One 5-m tall tower with three ultrasonic anemometers at 1, 2, and 5 m (3.3, 6.6, and 16.4 ft) AGL at a distance of 2.4 m (8 ft) from the southern side of the conex.

(c) 2 × 3 Conex Stack

(1) Two 1-m (3.3-ft) tall tripods with ultrasonic anemometers at a height of 1 m (3.3 ft) AGL at distances of 2.4 m (8 ft) and 4.9 m (16 ft) from the northern side of the conex.

(2) Two 1-m (3.3-ft) tall tripods with one ultrasonic anemometer each at a height of 1 m (3.3 ft) AGL, at distances of 1.2 m (4 ft) and 2.4 m (8 ft) from the western and eastern sides of the conex.

(3) One 1-m (3.3-ft) tall tripod with an ultrasonic anemometer centered on the top of the conex at a height of 1 m (3.3 ft).

(4) One 10-m (32.8-ft) tall tower with four ultrasonic anemometers at heights of 1, 2, 5, and 10 m (3.3, 6.6, 16.4, and 32.8 ft) AGL at a distance of 1.2 m (4 ft) from the northern side of the conex.

(5) One 10-m (32.8-ft) tall tower with four ultrasonic anemometers at 1, 2, 5, and 10 m (3.3, 6.6, 16.4, and 32.8 ft) AGL at a distance of 2.4 m (8 ft) from the southern side of the conex.

(4) Energy Balance Station (EBS). The EBS provided in situ measurements of the surface vertical fluxes of sensible heat, latent heat, net radiation, and soil surface heat flux. The fluxes were obtained by the energy balance eddy covariance technique, a method that uses covariances between the vertical wind speed and temperature, and the vertical wind speed and gas density in combination with point measurements of net radiation and soil heat flow from five sets of soil sensors. This method was direct and simple, assuming the measurements of the appropriate variables were made sufficiently fast to capture the turbulent structure of the fluxes.

(a) The quantities that were measured were:

(1) Vertical wind speed using a CSAT-3 ultrasonic anemometer (Campbell Scientific®, Logan, Utah).

(2) Atmospheric moisture using a KH20 UV krypton hygrometer (Campbell Scientific).

(3) Upwelling and downwelling IR and visible radiation using a CNR1 net radiometer (Kipp and Zonen, Delft, Netherlands).

(4) Average soil temperature using TCAV soil thermocouples (Campbell Scientific®).

(5) Soil heat flux plates using a HFT3 heat flux plate (Campbell Scientific®).

(6) Soil moisture using a CS615 water content reflectometer (Campbell Scientific®).

(b) During the JRII trials, the EBS unit was located upwind.

(5) Sonic Detection and Ranging (SODAR). The SODAR (Scintec Corporation, Louisville, Colorado) is a high-frequency Doppler acoustic sounding system that is designed to measure the atmospheric vertical wind profile. The SODAR samples the atmosphere in three independent directions. These data were combined to deduce the horizontal and vertical wind profile directly above the antenna. DPG deployed one SODAR unit upwind of the test grid.

(6) 924 MHz Profiler. Wind profilers are Doppler radars that transmit pulses of electromagnetic radiation vertically and in two slightly off-vertical directions to generate a three dimensional vector wind. DPG deployed a 924 MHz station at SL Test Site during the 2016 Trials.

(7) 449 MHz Profiler. DPG deployed a 449 MHz Profiler near West Vertical Grid during both 2015 and 2016 Trials.

(8) Modeling. DPG provided real-time and posttest modeling of the downwind hazard using the Hazard Prediction and Assessment Capability (HPAC) software developed under DTRA sponsorship. Although HPAC was not actually a type of instrumentation, it was a valuable tool for use at the CP and had a verified and validated dense gas capability. In 2003, ATEC mandated that all test programs releasing any chemical or biological simulant must have near real-time modeling support during the conduct of the test in order to assess potential exposures to populated work areas downwind of the release location. During JRII, an onsite meteorologist ran the HPAC model and provided the test officer with a time series of model plots before, during, and after each of the releases. Templates for the HPAC model were constructed before the test conduct that simulated the type, duration, and amount of release. MET data from the test grid were used as inputted into the HPAC model. Model results were provided upon request from the test officer.

(9) Upper Air Vertical Profile Analysis. For the 2016 trials, DPG released a weather balloon immediately after the chlorine releases in Trials 6 through 8 to provide data about the atmospheric upper air vertical profile. Summary files provide an atmospheric upper air vertical profile evolution with time by incorporating the SODAR, tower, and radar profiler data. These files evaluate mixing height, stability category, and winds vs height/time and can be found in the data package on the HSIN (Reference 7).

NOTE: The Global Positioning System (GPS) sensor on the balloon malfunctioned and no data was collected during Trial 9.

(10) Wind Cube Vertical LIDAR. During the 2016 trials, Defense Science Organization (DSO) Laboratories (Singapore), working under an exchange agreement with DTRA, fielded this system to provide a measurement of the vertical wind profile. This will be linked to wind field modeling software, Parallel Micro Swift Spray (PMSS), for the characterization of the chlorine plume dispersion process. The LIDAR was located in the CP area, generally crosswind to the prevailing wind direction. The system deployed was the V2 model manufactured by LEOSPHERE (Orsay, France). The system uses a pulsed laser at 1.54 microns.

c. Vapor Point Sensors

(1) MiniRAE. MiniRAE 3000 (PGM-7320) detectors (RAE® Systems, San Jose, California) were used. These are handheld volatile organic compound (VOC) photoionization detectors equipped with 11.7-eV lamps, which are optimal for the detection of chlorine gas. A brief laboratory study was conducted that determined that the MiniRAEs were best calibrated with 509 ppm±2 percent chlorine gas (Proxair, Morrisville, Pennsylvania), and the most stable calibration occurred after the freshly installed batteries ran for 3 hours, with a calibration temperature of 22°C (71.6°F).

NOTE: Because of scheduling constraints, a portion of the laboratory study was conducted after the 2015 trials to validate the methods.

(a) The MiniRAE units were operated in accordance with (IAW) the RAE user's guide (Reference 8) and the operating procedure developed by DPG [contact West Desert Technical Information Center (WDTIC) for procedures]. The MiniRAE data provided the concentration of chlorine at discrete short time intervals to show concentration changes throughout the progression of the test event.

(b) The data were collected in the onboard data loggers for all of the MiniRAE detectors and downloaded after each trial at the Sprung® Facility.

(1) The data were logged from the time the detectors were placed on the test grid, before the beginning of each trial, to 2 hours past the trial's end period (3 to 5 hours, depending on the trial). The MiniRAE units were time synchronized to the second before calibration using the satellite clock.

(2) Chlorine concentration measurements were expected to be within the range of 100 to 2000 ppm. Lower levels were detected, but the accuracy of the reported concentration falls off significantly for concentrations less than 100.7±5 percent ppm. A laboratory experiment

characterized the effective concentration range that the MiniRAE units measured. All units were calibrated before each trial and checked with a 100.7±5 percent ppm chlorine (Proxair, Morrisville, Pennsylvania) bump test after calibration to verify that the units remain within the acceptable calibration range. Units that did not meet calibration specifications were not used. Data collected before the trial were used to collect background VOC concentrations.

(c) During the trials, the MiniRAE units were located throughout the grid in vehicles, conexes, and on the instrumentation arcs. The angle of the outer arcs was 90 degrees (spanning from 300 to 30 degrees). There were a total of 152 MiniRAEs available (102 MiniRAE units provided by DPG and an extra 50 MiniRAE units provided by RAE® Systems). Only 125 MiniRAEs were used for the test and the remainder were used for backups.

(2) ToxiRAE Pro. During the trials, ToxiRAE Pro (PGM-7320) electrochemical detectors (RAE® Systems, San Jose, California) sampled ambient air and measured concentrations of chlorine gas. The ToxiRAE Pro provided measurements of approximate chlorine concentrations in far-field and near-field locations, including off post locations to satisfy state of Utah requirements.

(a) ToxiRAE Pro concentration data (in ppm) were logged on a set time scale. A GPS clock was used to verify the manually entered time.

(b) The ToxiRAE Pro has a detection limit of approximately 0.1 to 50 ppm per manufacturer specifications (Reference 9).

(c) During the 2015 trials, 61 ToxiRAE Pro units were used on the test grid and 76 were used for safety monitoring, as backups, and for environmental monitoring south of the test site at Fish Springs Wildlife Preserve, along Interstate (I)-80, and along the northern and western borders of DPG.

(d) During the 2016 trials, 75 ToxiRAE Pro units were used on the test grid and 62 were used for safety monitoring, as backups, and for environmental monitoring south of the test site at Fish Springs Wildlife Preserve, along I-80, and along the northern and western borders of DPG.

(e) The ToxiRAE Pro units were operated IAW the user's guide (Reference 9) and the operating procedure developed by DPG (contact WDTIC for procedures).

(3) Gasmet™. The Gasmet™ DX-4000 multicomponent Fourier-transform IR spectrometer (FTIR) gas analyzer (Gasmet™ Technologies Inc., Oy, Helsinki, Finland) was used as a point detector to measure the concentration of sulfur hexafluoride (SF_6) for the indoor/outdoor transport of a dense gas study in 2015 (Paragraph 2.2.3.i) and for the indoor and vehicle dense gas studies in 2016 (Paragraph 2.3.4.f(3)). The Gasmet™ DX-4000 operates between 11 and 42 microns with a resolution of 2,500 microns. Their minimum detection limit is 0.1 ppm.

(4) UV Canary

(a) The UV Canary (Cerex Monitoring Solutions, Inc., Atlanta, Georgia) is a portable point detector that uses UV-Differential Optical Absorption Spectroscopy (DOAS) and is equipped with a deuterium lamp. The chlorine-specific UV Canary has a detection range of 10 to 10,000 ppm. The UV Canary units were calibrated in advance of testing. However, a posttest concentration correction was applied to reflect the differences between the temperature and pressure at the time of calibration and during testing. The full details of the correction can be read in the metadata file on the HSIN (Reference 7).

(b) Twelve UV Canary units were placed on the test grid and eight units were used for the indoor study. A majority of the UV Canary units sampled at a height of 0.3 m (1 ft) AGL, except for those used for the indoor study, in the obstacle array, or for sampling at the 3, 6, and 9 m heights.

(5) Jaz™

(a) The Jaz™ (Signature Science, Inc., Houston, Texas) is a portable point detector that uses UV-DOAS. The Jaz™ is a chlorine-specific detector with a detection range of 100 to 100,000 ppm-volume. DHS provided 16 Jaz™ instruments, which were calibrated in advance of testing, and spot-checked daily with 5000-ppm-certified chlorine gas standards by Signature Science.

(b) During the 2015 trials, 16 Jaz™ instruments were emplaced on the grid; 5 were used outside the structure intakes, 9 were within the obstacle array, and 2 were on the urban pad perimeter.

(c) During the 2016 trials, 11 Jaz™ instruments were emplaced on the grid and 5 were used in the indoor study.

(d) The Jaz™ instruments were operated and maintained by Signature Science, Inc. For all trials, the Jaz™ units sampled at a height of 0.3 m (1 ft) AGL, except for units located on towers within the obstacle array.

(6) Copper Strips

(a) During the 2015 trials, Trials 2 and 3 had copper strips [0.5 in × 3 in (1.27 cm × 7.62 cm)] placed at each surveyed position, usually next to a MiniRAE or ToxiRAE as well as in the conexes. The strips that were exposed to chlorine discolored and were converted to copper(II) chloride and saved for later analysis. The same experiment was performed for all trials during 2016.

(b) After each trial, the strips were removed, inspected, and stored. If there was strong discoloration, it was recorded as a detect. If only a spot or two was noted, it was recorded as a non-detect.

d. Particulate Point Sensors

(1) GRIMM Aerosol Spectrometer. The GRIMM Aerosol portable laser aerosol spectrometer and dust monitor model 1.109 (Ainring, Bavaria, Germany) is a particle-sizing instrument that measures mean size diameters using laser scattering. The aerosol spectrometer was calibrated by the factory before the test. The aerosol spectrometer was operated IAW the operations manual (Reference 10). Collected data provided continuous particle-size information throughout the progression of the test event. The aerosol spectrometer is a nonselective detector and did not discriminate among detected particles and aerosols (e.g., dust, background aerosols, chlorine, chlorohydrates, or water).

(a) The data were logged for one to two hours before the trial and one hour past the trial end. The data logger recorded data at a rate of 1 data point per second. Time synchronization was done before each trial using GPS time.

(2) High Magnification Shadow Imaging Device. For the 2016 trials, a new aerosol device developed by Clarkson University (Potsdam, New York) was fielded under DTRA sponsorship. This used high magnification shadow imaging to image particles in the field, applicable to particles larger than 5 microns. The volume interrogated was 2 mm × 2 mm across and 20 microns in depth, able to resolve 5 to 500 micron diameter particles. The system used a pulsed laser to illuminate the scene. For Trial 6 it was located 85 m from the release, but it was moved for Trials 7, 8, and 9, because of limited partical signals, to a new station approximately 55 m from the release and along the pad centerline.

e. Thermocouples

(1) Exterior

(a) Up to 36 type K 24 American Wire Gauge (AWG) wiring thermocouple arrays were deployed during the 2015 trials and 35 thermocouple arrays during the 2016 trials. Each array consisted of six thermocouples placed at 2 cm (0.8 in) below grade and at elevations AGL of 15 cm (5.9 in), 30 cm (11.8 in), 0.06 m (0.2 ft), 1.2 m (3.9 ft), and 2.4 m (7.9 ft). Data from the arrays were collected at a rate of 8 Hz for the 2015 trials and 1 Hz for the 2016 trials. **NOTE**: For sensors located on the playa, the lowest thermocouple was 5 cm (1.97 in) AGL.

(b) Mean Cloud Arrival Speed. During the 2015 trials, a set of vertical profile measurements were obtained in the spaces between conexes that provided an estimate of the mean along-wind cloud velocity and quantification of the lateral mean velocity (perpendicular to the wind field). Each array consisted of five thermocouples placed at 2 cm (0.8 in) below grade and at elevations AGL of 30 cm (11.8 in), 60 cm (23.6 in), 1.2 m (3.9 ft), and 2.6 m (8.5 ft).

(2) Interior

(a) Three thermocouple arrays were deployed in interior locations. These collected data at 1 Hz.

f. Standoff Detectors

(1) UV Sentry. The UV Sentry (Cerex Monitoring Solutions, Inc., Atlanta, Georgia) is a portable standoff detector that uses UV-DOAS. It is a chlorine-specific detector with a detection range of 10 to 10,000 ppm-meters (ppm-m). Two UV Sentry systems were calibrated in advance of testing and used during the trials.

(a) Each UV Sentry consists of two units: the sender unit and the receiver unit. The sender unit is a xenon arc lamp mounted on a tripod. The receiver unit has a receiving optic on a tripod, spectrometer unit, and a length of fiber optic that transmits the incoming signal from the optical receiver to the spectrometer unit. The sender and receiver units were 1 km (0.62 mi) apart.

(2) UV LIDAR System. The UV LIDAR (WDTC, Dugway, Utah) is a laser-based ranging and detection instrument that was used to measure chlorine gas concentrations. The UV LIDAR operates on the principle of measuring absorption of the 355-nm laser beam near the absorption maximum of chlorine from the background of aerosol signal. Two UV LIDARs (East LIDAR and West LIDAR) were placed 2 km from the dissemination point. The West UV LIDAR scanned horizontally while the East LIDAR scanned horizontally in 2015 and did vertical scans during the 2016 trials at ranges of 500, 2000, and 5000 meters.

NOTE: The UV LIDAR was not calibrated before the test because a known concentration of chlorine gas could not be produced outdoors before testing; however, point sensors were used during the trial to verify the UV LIDAR data.

(3) LIF System. The LIF (WDTC, Dugway, Utah) is a laser-based ranging and detection instrument used to measure chlorine gas concentrations. The LIF operates using a 355-nm laser beam. The UV LIDAR system scanned horizontally to track the cloud movement, and was located at the SL Test Site.

NOTE: The LIF was not calibrated before the test because a known concentration of chlorine gas could not be produced outdoors before testing; however, point sensors were used during the trial to verify the LIF data.

(4) WDL System. The DPG WDL system is an elastic-backscatter based LIDAR system that uses a 1064-nm laser. The WDL was used to detect and track chlorine aerosols. The WDL was located at the SL test site. The WDL was not calibrated for chlorine aerosol particle sizes, but size estimates were possible because the WDL was able to interrogate an area adjacent to a particle sizer. For the 2016 trials, the WDL used a two stage scan pattern. Stage 1 (0 to 4 minutes after release) consisted of vertical scans above GRIMM and High Magnification Shadow Imaging Device, and Stage 2 (4+ minutes) consisted of vertical scans at 1 km gates, then at 2 km and 5 km gates.

(5) There were three types of LIDARS used during 2016 testing that were placed on the grid by non-DPG personnel.

(a) REVEAL Systems. Sponsored by DTRA, Spectral Sensor Solutions (S3) of Herndon, Virginia deployed two eye-safe elastic aerosol-backscatter LIDAR systems called REVEAL to provide additional data supporting the characterization of the releases. The first system, REVEAL–Prototype, is the first generation system and was deployed in previous test fields at DPG. The second system, REVEAL-5000 is a more highly engineered version of the REVEAL and was developed and integrated just before these tests. The REVEAL Prototype was in operation and collected data during the four 2016 releases. The REVEAL-5000 was deployed later and collected data only during Trial 8. The REVEAL was used to characterize the chlorine plume on a large scale by mapping and tracking the associated aerosol content of the release as it dispersed in the surrounding environment. REVEAL was also used to characterize the chlorine release on a smaller scale by mapping the jet source at the chlorine release point and in the area immediately surrounding the release point.

(b) Wind Cube Scanning LIDAR. During the 2016 trials, DSO Laboratories, working under an exchange agreement with DTRA, fielded this system to provide a 3D wind measurement in the vicinity of the release using a scanning LIDAR system. This will be linked to wind field modeling software, PMSS, for the characterization of the chlorine plume dispersion process. The LIDAR was located at the road intersection, about half a mile upwind from the source. The system deployed was the 200S model manufactured by LEOSPHERE. The system uses a pulsed laser at 1.54 microns.

g. Optical Instrumentation. There were a variety of high-definition (HD), high-speed (HS), and IR cameras positioned throughout the test grid to visualize and record the chlorine release and resulting plume. Optical equipment was remotely operated from SL test site using an unmanned optics control trailer located on Goodyear Road at the turnoff to the UTG area. During the 2015 trials, IR, HS, and wide-angle HD cameras were mounted on a pole on top of a single conex located on the southeast side of the concrete pad, on towers placed at the corners of the gravel pad, on top of the 2 × 3 conex stack, and 150 m (492 ft) east and west of the dissemination pad. During the 2016 trials, IR, HS, and wide-angle HD cameras were mounted on scaffolding located to the east, west, and north of the dissemination pad.

(1) There were six types of optical instrumentation used during testing that were placed on the grid and operated by DPG personnel.

(a) HD. HD video cameras were used to record chlorine dispersion and downwind transport of the chlorine cloud. Sony® NXCAM Real-Time video cameras (Sony®, New York City, New York) were placed at each HS and IR camera position for visual documentation of the plume and captured optical data at the rate of 30 frames per second (fps) for the wider view of the tank and plume growth. Field of view (FOV) was determined the day of testing based on weather conditions.

(b) HS. HS Phantom® V711 video cameras (Vision Research, Wayne, New Jersey) were used to record the release of the dissemination tank flange, breach of the 18144-kg (20-ton) chlorine tank, and dispersion and downwind transport of the chlorine cloud. HS video cameras captured close-focus images of the tank at the rate of 1000 fps with a run time of approximately 21 seconds. The optics and respective FOVs for the HS cameras were determined during test-site preparation.

(c) IR. A FLIR® IR Camera SC660 microbolometer (FLIR®, Wilsonville, Oregon) was used for temperature analysis of the area surrounding the chlorine tank before, during, and after the release.

(d) UAS. During the 2016 trials, Utah Valley University (UVU) in Orem, Utah provided a Phantom 4 [Dà Jiāng Innovations (DJI), Shenzhen, China] which provided an aerial view of the test grid before, during, and after each chlorine release.

(e) Still Camera. Digital cameras were used to document test site setup and were taken before, during, and after releases. Typical sensor installations were photo-documented for each sensor type.

(f) Three Dimensional Cloud Analysis Visualization (3DCAV). During the 2016 trials, four HD video cameras were used to perform 3DCAV analysis. These cameras were located at varying distances from the test pad. These positions were selected for the optimum upwind and crosswind views of the detonations and the clouds.

(2) There were three types of optical instrumentation used during testing that were placed on the grid and operated by non-DPG personnel.

(a) UV-Vis Hyperspectral Camera. During the 2016 trials, DSO Laboratories, working under an exchange agreement with DTRA, fielded the Spectrocam™ (Pixelteq, Largo, Florida) system to study the feasibility of detecting chlorine based on chlorine's absorption in the UV spectrum. This camera was located in the CP area, crosswind to the prevailing wind direction.

(b) Variable and Near Infrared (VNIR) Hyperspectral Camera. During the 2016 trials, DSO Laboratories fielded the aisaEAGLE (SPECIM, Oulu, Finland) system to study the feasibility of detecting chlorine based on chlorine's absorption in the UV spectrum. This camera was located in the CP area, crosswind to the prevailing wind direction.

(c) Thermal Imager (Mid wave region). During the 2016 trials, DSO Laboratories fielded the Mid-wave Thermal Imaging Camera (TELOPS, Quebec City, Canada) system to study the feasibility of detecting chlorine plume/aerosol based on the temperature differences of the cryogenic plume and the ambient temperature. This camera was located in the CP area, crosswind to the prevailing wind direction.

h. Off-Post Monitoring. IAW the Utah Division of Air Quality (DAQ, Salt Lake City, Utah) approval order (AO, Reference 11) DPG conducted air monitoring with ToxiRAE Pro sensors at the following locations:

(1) Southern DPG boundary near Fish Springs Wildlife Reserve.

(2) Western DPG boundary near Bureau of Land Management land.

(3) Northern DPG boundary with the Utah Test and Training Range.

(4) I-80. **NOTE**: Before testing, DPG collected background data at I-80 locations during timeframes that are similar to the planned release schedule. Background data were collected for a minimum of 4 hours on 3 different days to capture weather-induced variability.

2.1.5 Tank and Specialized Disseminator

a. Disseminator Setup

(1) The dissemination system consisted of a 10 ton capacity chlorine tank mounted on a support system that incorporated load cells for continuous mass measurement.

(2) The support system for the 10-ton tank consisted of a structure built out of I-beam pillars instrumented with seven load cell assemblies for dynamic mass measurement. The pillars were attached using concrete anchors sealed with a chlorine-resistant epoxy. The tank was bolted onto the horizontal crossbeam and strapped to the cross beam using pre-tensioned steel cables for redundancy. Four load cell assemblies were used for vertical measurements and three were used for component measurement. The load cell assemblies were wrapped in a chlorine-resistant material to prevent any damage from corrosion. The support system was designed to ensure that the down-facing dissemination port was located 1 m (3.28 ft) AGL.

(3) The support system accommodated one 7571-L (2000-gal) size tank for releasing up to 9072 kg (10 tons) of chlorine. The tank was 5.64 m (222 in) long and 1.37 m (54 in) in diameter. The tank was provided with four dissemination ports oriented as follows: 0 degrees (upwards), 90 degrees (horizontal), 135 degrees downwards, and 180 degrees downwards. Each dissemination port could be used for disseminating chlorine via a 15.2-cm (6-in) diameter penetration or a 6.4-cm (2.5-in) diameter penetration using an insert.

NOTE: All trials were conducted using the 15.2-cm (6-in) diameter penetration.

(4) The support system cradle and the 10-ton dissemination tank were removed from the pad before Trial 9 and replaced with a 20-ton tanker for the final chlorine release.

(5) Explosive bolts were used to release the flanges on the 10-ton tank, which created breaches in the tank for disseminations. In order to provide a safe environment for the installation of the explosive bolts, a plug was used to seal the dissemination port and control any minor chlorine leaks. The plug was tightened and capped during preparation for the chlorine fill/refill process.

(6) Instrumentation ports were provided across the entire body of the tank. These were designed using standard flanges and penetration holes so that instruments could be easily replaced.

(7) The tank was filled with chlorine under a blanket of nitrogen. All vapors were collected and scrubbed through tanks of sodium hydroxide to create sodium hypochlorite (bleach).

b. 10-Ton Tank Instrumentation

(1) Bare-Wire Thermocouples

(a) In 2015, the temperature profiles were measured vertically at increments of approximately 10 percent of the tank diameter at two axial locations in the tank. Two clusters of thermocouple assemblies using type K 24 AWG diameter wire were immersed in the tank to take temperatures. The thermocouples were located on opposite sides of the tank. Sensors were located at varying distances along the length of the thermocouples and had a pave seal connector.

(b) aIn 2016, the temperature profiles were measured vertically with bare wire thermocouples at increments of approximately 10 percent of the tank diameter at two axial locations in the tank. One of the thermocouple assemblies was modified with 36 AWG wire to increase response times. The thermocouples were located at opposite lateral ends of the tank.

(2) Load Cells. Seven load cell assemblies (one load cell and two flexures) (Force Measurement Systems Inc., Fullerton, California) were placed on the support system to measure the exiting mass of chlorine from the tank and accounted for the forces generated by the tank as the pressure was being released. Model 1110AF-25KN (Interface Advanced Force Measurements, Scottsdale, Arizona), has very low nonlinearity, hysteresis, eccentric load sensitivity, and temperature sensitivity.

(3) Thermowell Thermocouple. Temperature profiles within the tank were measured vertically at increments of 10 percent of the tank diameter within the well. During the 2016 trials, there was one thermowell thermocouple in the tank. Ten Type K thermocouples were located at spacing of 12.7 cm (5 in) distances along the length of the thermowell thermocouple.

NOTE: The thermowell thermocouple was not used during the 2015 trials because it did not arrive in time to be installed for the start of the test.

(4) Pressure Sensors

(a) Absolute Pressure. Absolute pressure was measured with three Rosemount™ 3051T Coplanar™ Absolute Pressure Transmitters (Emerson, St. Louis, Missouri) at the 0-degree, 135-degree, and 180-degree dissemination ports.

NOTE: One of the four absolute pressure gauges was damaged during the 2015 installation and never replaced.

(b) Differential Pressure. Differential pressure was measured with three Rosemount™ 3051C Coplanar™ Differential Pressure Transmitters (Emerson, St. Louis, Missouri) vertically between the top of the tank and at elevations that corresponded to the top of three dissemination ports (at the 90-degree, 135-degree, and 180-degree dissemination ports). The differential pressure ports were outfitted with a well-line to enable measurement of the pressure in the center of the tank.

(5) Guided-Wave Radar (GWR). One Rosemount™ 5301 Level Transmitter Guided Wave Radar (Emerson, St. Louis, Missouri) was located on the tank to measure the change in the depth of liquid chlorine as the chlorine left the tank.

(6) All data were collected by LabView cBIO (National Instruments Corporation, Austin, Texas).

c. 20-Ton Tanker Instrumentation (2016 trials)

(1) During the 2016 trials, the 20-ton tanker was used throughout the test as a transfer vehicle to receive deliveries of bulk chlorine, which was then transferred to the 10-ton dissemination tank before each trial. Before the execution of Trial 9, the 10-ton dissemination tank and support structure were removed and replaced with the 20-ton tanker. The 20-ton tanker was breached as part of the final release.

(a) Absolute Pressure. Absolute pressure was measured at two locations on the tank using instrumentation from the 10-ton dissemination tank once the 10-ton trials were completed. The absolute pressure was measured at the top rear of the tanker in the manway, using one of the two vapor gas valves, and on the bottom center of the tank, using a liquid valve. The absolute pressure sensors were installed via stinger piping and flanges, which were isolated from the liquid chlorine in the tank. To span the distance between the two valves with the limited distance of the differential pressure arms, a stinger extension pipe was installed along the top of the tanker to minimize the span between the top and bottom of the tanker valves. Data for these instruments are not included in the available data sets.

(b) Differential Pressure. Differential pressure was measured vertically at two locations on the tank using instrumentation from the 10-ton dissemination tank once the 10-ton trials were completed. The differential pressure was measured at the top rear of the tanker in manway, using one of the two vapor gas valves, and on the bottom center of the tank, using a liquid valve. Data for these instruments are not included in the available data sets.

d. Pad Instrumentation and Setup

(1) Thermocouple. Vertical temperature profiles above and below grade provided additional information important for understanding the relevant phenomenon in the near source region. Vertical temperature profiles below grade provided estimates of the heat flux at the top surface of the concrete pad, which allowed determination of whether a significant quantity of rainout was present (heat transfer rates to boiling liquids are significantly greater than heat transfer rates to vapors). Vertical temperature profiles AGL provided information about the chlorine cloud temperature. The vertical temperature profile was made by attaching Type K 24 AWG thermocouples to a metal strut attached to the dissemination pad. Measurements below grade were collected by placing the thermocouples in predrilled holes.

(2) The dissemination pad had three locations that each contained 14 thermocouples, but only two of the locations had GWR instruments. The thermocouples were located at the following elevations with respect to grade level:

(a) At 3, 6, 9, 15, and 22 mm (0.12, 0.24, 0.35, 0.59, and 0.87 in) below grade.

(b) At 0.5, 1, 2.5, 10, 40, 100, 200, and 300 cm (0.2, 0.39, 0.98, 3.9, 15.8, 39.4, 78.7, and 118.1 in) AGL.

(c) At grade level.

(3) The pad had the means for grounding the tank and other instrumentation.

e. Tank Filling and Explosive Bolt Setup

(1) Personnel maintained the appropriate personal protective equipment (PPE), as designated by the incident management team (IMT) and approved by DPG command.

(2) After the specialized dissemination tank was filled with chlorine, the grid was cleared except for explosives personnel. A decontamination team and backups for the explosives operators were located 823 m (2700 ft) upwind of the grid.

(3) Six standard bolts were removed from the 12-bolt flange on the tank in a star pattern and replaced (one at a time) with exploding bridge wire (EBW) explosive bolts (Teledyne RISI, Tracy, California). The EBW explosive bolts were placed in alternating bolt holes and were according to the following specifications:

(a) The bolts had a minimum diameter of 2.22 cm (0.875 in) and required standard RP-2 firing parameters as described in Reference 12. The RP-2 firing initiation required 220 amps.

(b) The bolts contained 86-mg (0.00303-oz) pentaerythritol tetranitrate, 123-mg (0.00433-oz) polymer bonded explosive 94 percent (PBX9407), which contained cyclotrimethylenetrinitramine (RDX) as the explosive ingredient, plus an RP-81 output pellet [454 mg (0.0160 oz) PBX9407]. The net explosive weight for each bolt was about 660 mg or 0.660 g (0.0233 oz). The safety standoff distance from the bolts was 11.28 m (37 ft).

(4) The remaining six standard bolts were removed in a star pattern to maintain pressure and prevent leakage of chlorine. The flange was fitted with a center post to hold a plug over the opening into the tank to prevent leakage of chlorine gas during this procedure.

(5) The bolts were initiated based on procedures in the validated JRII Methodology Investigation Report (Reference 13).

(6) The EBW fireset was set up and fired IAW DPG Standing Operating Procedure (SOP) DP-0000-G-139 (Reference 14) and with the operating manual for the FS-43 fireset (Reference 12).

2.2 JRII 2015 TRIALS AND STUDIES

2.2.1 Objectives

NOTE: Test objectives came directly from DHS or were requested through DHS by members of the first responder community. Objectives from first responders are identified as the Emergency Response Group objectives (Reference 4).

a. DHS Objectives

(1) Safely perform the controlled release of compressed, liquefied chlorine to the atmosphere in a series of up to 21 trials in masses ranging from 4536 to 18,144 kg (5 to 20 tons) from simulated chlorine tank ruptures.

(2) Use standard methodology to ensure relevant data precision, accuracy, validity, and quality in a common format.

(3) Observe and measure the simulated ruptured tank thermodynamic and mass parameters during dissemination to improve model source terms.

(4) Quantitatively monitor and collect gas cloud concentration data from the initial phase of a very dense, two-phase cloud near the source to dispersion of the cloud further downwind using point detectors and standoff spectroscopic instruments. Data collection from the release will allow personnel to quantify and characterize cloud retrograde.

(5) Characterize and quantitatively measure chlorine cloud removal by deposition on vertical and horizontal surfaces, hydrolysis, photolysis, reaction with organic and inorganic constituents of soil, and reaction with vegetation.

(6) Investigate the small-scale movement of a chlorine cloud through, around, and above a mock urban environment.

(7) Study building infiltration rates in a mock urban environment. **NOTE**: DTRA is responsible for this study.

(8) Assess exposure and damage effects in a mock urban setting.

(9) Study exposure impacts on equipment and materials. **NOTE**: DHS is responsible for this study.

(10) Study emergency response guidelines. **NOTE**: DHS is responsible for this study.

(11) Study industrial risk and hazard mitigation procedures. **NOTE**: DHS is responsible for this study.

(12) Provide a realistic observable hazardous release environment for the education and training of emergency response personnel. **NOTE**: DPG will provide the training environment.

b. Emergency Response Group Objectives

(1) Determine the effectiveness of sheltering in place, including concentration and duration, to determine probable survivability.

(2) Determine a reliable vertical concentration gradient (i.e., the gas density of chlorine at a concentration gradient in which a responder can survive above the cloud will be considered).

(3) Determine if internal combustion engines (gas and diesel) can operate in high concentrations of chlorine (consider the behavior of the combustion engine and determine the probability of driving out of the plume as an emergency tactic).

(4) Determine if low wind speeds increase the probability of retrograde creep of the cloud. Further validate that the initial isolation zones, at a ground distance of 1000 m (3281 feet), and downwind protective action recommendations contained in the *2012 Emergency Response Guidebook* (Reference 2) are appropriate.

(5) Determine the significance of various urban barriers and plume behavior when encountering those barriers.

(6) Determine the possibility of secondary post-release cloud evolution if contaminated surfaces are disturbed and the duration of long-term off-gassing.

(7) Determine the level to which flash freezing and thawing occur on the surface at the release point.

(8) Determine the behavior of common building components and urban surfaces. Specifically, determine the behavior of both new and aged asphalt when in contact with high concentrations of chlorine gas or liquid chlorine. Assess the absorption of chlorine gas into water.

2.2.2 Criteria

None.

2.2.3 Indoor/Outdoor Transport of a Dense Gas

a. The Indoor/Outdoor Transport of a Dense Gas studies were conducted by Lawrence Berkeley National Laboratory (LBNL) through DTRA sponsorship. The test data and reports for these studies can be found on the HSIN (Reference 7).

b. Structure Specifications

(1) Indoor chlorine measurements were collected in three types of structures. The modular trailers provided empirical field-scale observations of cloud infiltration and chemical interactions with indoor surfaces.

(2) A number of conex structures were modified to allow for a controlled intake of outside air with a specific flow rate through a specific opening. The modified conex structures included single-story and a multistory structures. The multistory structure was two conexes wide by three conexes high (2 × 3 conex stack).

c. Modified Trailers

(1) Two modular trailers (Figure 3) were originally intended to represent indoor spaces that contained a large proportion of indoor surfaces. The decision was made by the test team to leave the trailers unfurnished with the exception of painted drywall and new wall-to-wall carpeting. Dimensions of the modular trailers were approximately 6.1 × 3 × 2.4 m (20 × 10 × 8 ft). Each was fitted with a heating, ventilating, and air conditioning (HVAC) system (Reference 15). The target total surface area-to-volume ratios were between 2.5 and 4.5 m^2 (8.2 and 14.8 ft^2) per 1 m^3 (3.3 ft^3) of room volume.

Figure 3. Illustrative Example of a Modular Trailer Unit; JRII.

(2) The HVAC air filter was checked for condition after each release trial. Windows, doors, and ceiling light fixtures were assumed to be resistant to chlorine and were not replaced.

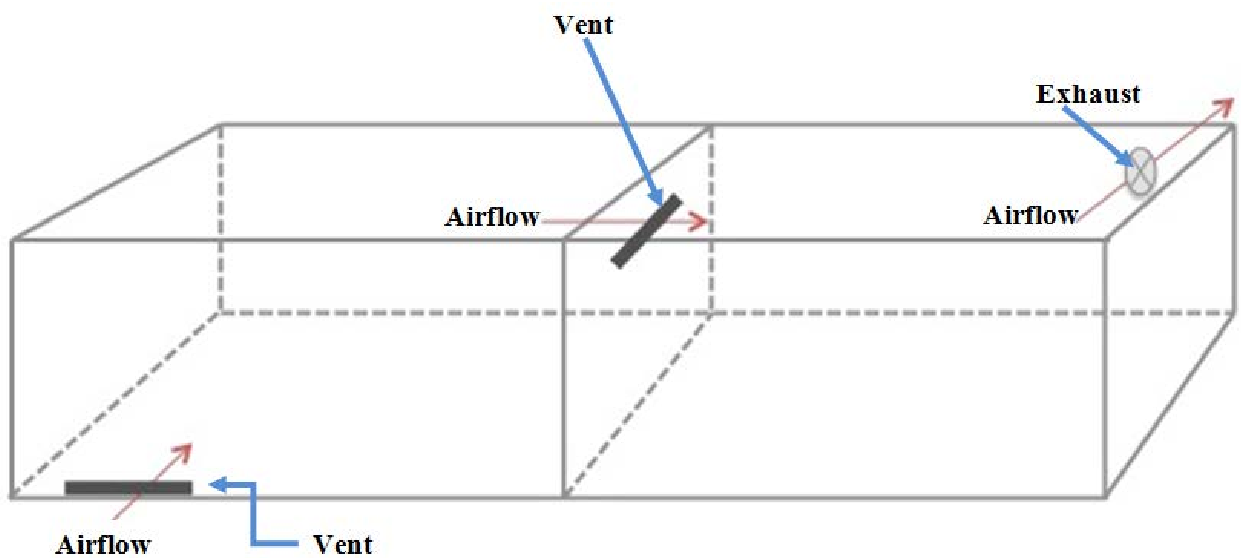
d. Modified Single-Story Conex

(1) One 12.2-m (40-ft) conex with dimensions of 12.2 × 2.7 × 3 m (40 × 9 × 10 ft) was configured for controlled experiments of airflow and transport in a single-floor structure. The container was modified to include insulation. The transfer of pollutant across the building envelope (i.e., from outside to inside) was monitored via a controlled artificial leak and an exhaust fan. The insulation, air sealing, and leakage pathway of the conexes is described in Reference 15.

(2) Interior Partitioning. The conex structure was subdivided into two equal-volume compartments to provide data for modeling the transport of chlorine in a two-zone building (Figure 4).

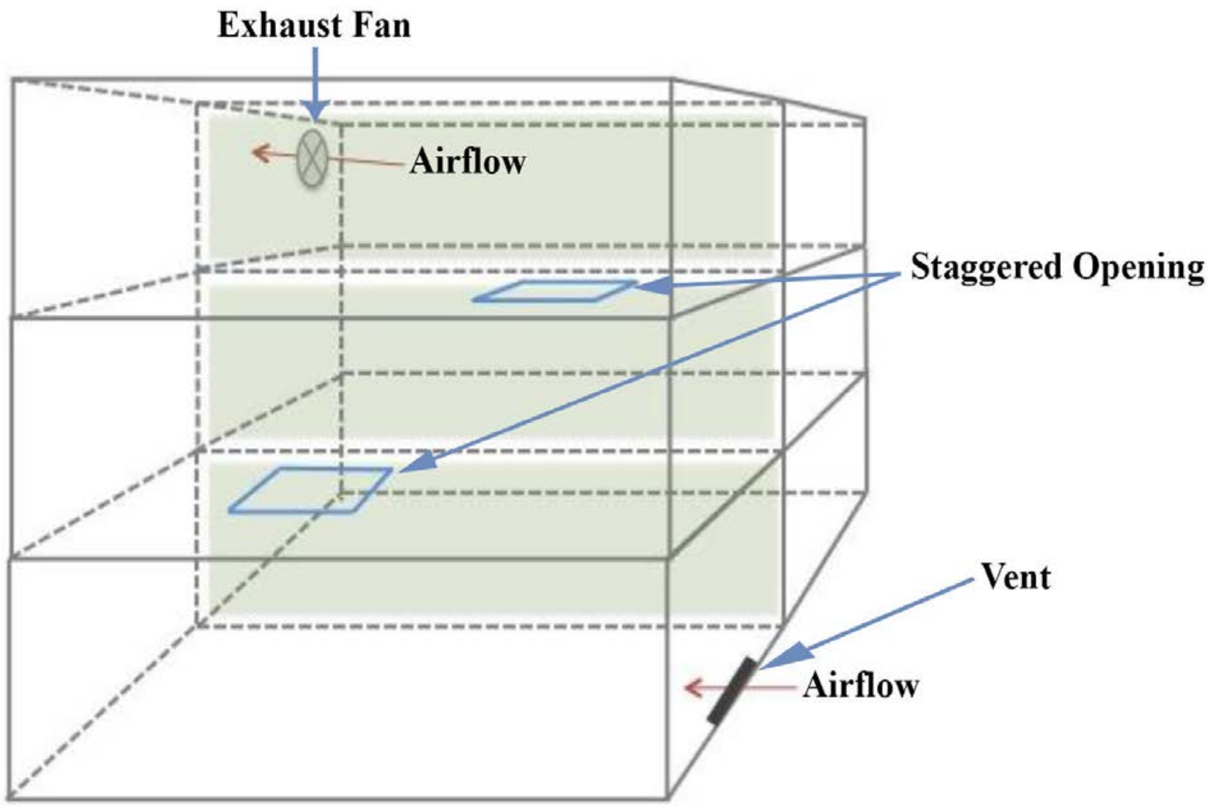
e. Modified Multistory Conex

(1) Six 6.1-m (20-ft) conexes were stacked two conexes wide by three conexes high (in a 2 × 3 conex stack) to create a multistory structure (Figure 5). The insulation requirements were the same as described for the single-story conex (Paragraph 2.2.3.c). An air exchange rate of 3 to 5 hour-1 occurred inside the conex.



NOTE: This figure was provided by Lawrence Berkeley National Laboratory (Berkeley, California).

Figure 4. Illustration of the Prevailing Flow Pathway for the Trailers; JRII.



NOTE: This figure was provided by Lawrence Berkeley National Laboratory (Berkeley, California).

Figure 5. Illustration of the Prevailing Flow Pathway of the Multistory Structure; JRII.

(2) The adjacent conexes were connected by cutting out parts of the envelope, as indicated by the areas shaded in green. The three floors were kept mostly separated, as in the case of most multistory buildings, but the floors were connected by an opening of approximately 1.5 ×1.5 m (5 × 5 ft), and the openings were staggered. A staircase ladder was required to allow field team access to the upper floors. Other safety measures were installed, including lighting on each floor, warning signs near the openings, and protective tape to caution for head injuries.

f. The prevailing flow pathway was through the exhaust fan, much like the single-story conex.

g. <u>Characterization Tests</u>

(1) The four test structures (two modular trailers, one single-story conex, and one multi-story conex) required measurement of air leakage and airflow rates before the chlorine release experiments.

(2) In addition, the HVAC was evaluated to make sure that performance adequately maintained indoor temperature and RH within a specific range.

h. Blower Door Test

(1) A blower door test was performed for the two modular trailers. This test determined the building envelope air leakage by measuring the airflow rate needed to depressurize the structure at various pressure differentials. This test required a blower door system, including a blower door, a calibrated fan, a pressure gauge, a computer controller, and other accessories. The goal of the test was to determine if the building envelope of the modular trailer had the appropriate level of airtightness. When the building envelope was too leaky, caulking was added. When the building envelope was too airtight, leakage pathways in the HVAC system were created to more accurately represent a typical structure. Thus, an iterative process was followed to perform adjustments and retesting to obtain a desirable building envelope air leakage.

(2) Blower door tests were conducted in the long, single-floor conex structure but not the multi-floor structure because the blower door could not be easily mounted. The intention was to seal the conex structures so that they were as airtight as possible.

i. SF_6 Tracer Decay Test

(1) This test was performed in all modular trailers and conex structures. SF_6 was injected inside the structure to a uniform concentration of approximate 1 to 5 ppm. SF_6 concentrations were measured by Gasmet™ instruments over a period of 30 minutes to 1 hour. The test was repeated at least three times in order to assess the variability in the leakages owing to wind or temperature conditions.

(2) The SF_6 test required one gas analyzer in each of the modular trailers. The single-story conex structures required two gas analyzers each during the SF_6 decay test. The multistory conex structure required at least four gas analyzers to ensure that the air remained well-mixed during the test. A small recirculating fan was operated in each of the modular trailers during the experiments and was used to provide mixing. During the test, the indoor temperature was roughly the same as the test condition, 18° through 25°C (64° through 77°F).

j. Airflow Rate Measurements. Airflow rates were estimated for all structures by comparing the SF_6 decay rates against theoretical first-order, well-mixed dispersion rates. Rates were computed for various HVAC operations.

k. Indoor Conditions Monitoring. Indoor air temperature and RH were monitored for 1 week (1 to 10-minute time intervals) before characterization testing to provide baseline data. These data helped identify what changes were needed to ensure that the indoor conditions were met during the release experiments.

l. Instrumentation. The instruments used for the indoor experiments were Jaz™, UV Canary, MiniRAE, and ToxiRAE. Instrumentation data for this study can be found on the HSIN (Reference 7).

m. Modified Trailers

(1) Indoor concentrations were measured in the center of the trailer, and at the HVAC inlet and outlet. The UV Canary measured chlorine concentrations at a height of 0.3 m (1 ft). One MiniRAE and one ToxiRAE were collocated and sampled at a height of 0.3 m (1 ft). Another set of a MiniRAE and a ToxiRAE sampled at a height of 1.5 m (5 ft), near breathing-zone height, to determine the vertical distribution of chlorine concentrations. Both MiniRAE and ToxiRAE were required for the modified trailers because it was expected that the chlorine concentration would be reduced when exposed to indoor surfaces; therefore, use of both instruments allowed for measurement of indoor concentrations over a broad range from 1 to 2000 ppm.

(2) After the release, the modified trailers were aired out by running the HVAC at 100 percent power in outside air mode for at least 1 hour. Indoor concentrations were measured again using impingers for up to 2 hours at three averaging times: 0.5, 1, and 2 hours. Chlorine deposition on various indoor surfaces were also measured using X-ray florescence (XRF).

n. Modified Single-Story Conex

(1) The UV Canary and MiniRAE were used to measure chlorine inside the conex. Indoor concentrations were measured at two heights [0.3 and 2.1 m (1 and 7 ft)] and at three longitudinal distances along the 12.2 m (40 ft) conex [3.0, 6.1, and 9.1 m (10, 20, and 30 ft)].

(2) Two of the six sampling locations were monitored by a second MiniRAE to provide duplicate measurements that aided data analysis. One UV Canary was placed in each of the two zones of the conex.

o. Modified Multistory Conex. The indoor concentrations in four of the six conexes that made up the multistory structure were measured by a UV Canary, and each conex was measured by a MiniRAE placed at a sampling height of 1.5 m (5 ft). The conex located closest to the chlorine intake and exhaust had an additional MiniRAE, and two of the six sampling locations were monitored by a second MiniRAE to provide duplicate measurements.

p. Post-Release Residual Chlorine Experiment

(1) Impinger Sampling. Impinger sampling, as stated in the 2015 Master Execution Plan (MEP; Reference 16), was not conducted.

(2) XRF Analysis. A handheld Innov-X Delta Premium XRF analyzer with tantalum X-ray tube, model number DP-4000 (Olympus Delta, Center Valley, Pennsylvania) was used to analyze the chlorine content of indoor surfaces and materials. Operation of the XRF followed the same procedure as described in the chemical reactivity and deposition experiment procedures (Reference 16).

2.2.4 Chlorine Reactivity and Deposition Experiments

a. The Chlorine Reactivity and Deposition Experiments were conducted by DHS S&T CSAC (Reference 17). The test procedures, data, and report for these experiments can be found on the HSIN (Reference 7).

b. Familiarization, testing, and evaluation of the XRF analyzer was completed during JRII chlorine chemical release experiments in 2015. The XRF was used to examine common building components and urban surfaces exposed to chlorine gas and to develop and evaluate a method of determining the extent of reaction by quantifying the chloride ion present. Analysis of the data determined that the XRF instrument could not detect chloride below approximately 2,000 parts-per-million by weight, and is not sufficient for quantifying chloride at lower concentrations resulting from the reaction of chlorine with these surfaces.

2.2.5 Test Execution/Dissemination Procedures

a. Chlorine Setup

(1) The procedures for filling the chlorine tank trailer from the mule trailer are described in the DPG letter of instruction (LOI) for Chlorine Operations (Reference 18).

(2) Before operations, the fill team conducted a safety meeting, reviewed the site safety plan, observed specific environmental conditions, and outlined the primary and secondary evacuation routes. They reviewed operations with the IMT and Emergency response teams. Fill operations did not start unless the IMT team was on site.

b. Filling. The specialized dissemination tank was filled with liquid chlorine before all releases and was conducted by Chlorine Institute (CI) personnel with the DPG Fire Department on emergency response standby. The area was cleared of all non-essential personnel before any hazardous operations. All personnel that were not emergency responders were located at a minimum distance of 1000 m (3281 ft) from hazardous operations. Personnel filling the tank maintained the appropriate PPE (as designated by the IMT and approved by DPG Command).

(1) The fill operation was monitored from the JRII operations CP by the site test control officer (TCO). The TCO reviewed real time MET modeling and updated the fill team of any changes in the primary and secondary evacuation routes. The TCO notified DPG Range Control of the filling operation and established contact with the emergency response representative.

(2) The filling operation continued IAW the DPG LOI for Chlorine Operations (Reference 18).

c. Release. Planned chlorine releases were conducted on a daily basis only after all safety and environmental requirements had been met. The releases were controlled by the TCO from the JRII Operations CP located at the SL test site. The grid was cleared of all personnel. If any requirements were not met, the TCO held the countdown and addressed unmet requirements. Once all requirements were met, the TCO resumed countdown until dissemination. The trials were conducted IAW the test matrix in Table 2. The Go/Hold checklist is found in the OPLAN (Reference 18).

d. Emergency Draining. An emergency draining procedure was planned for, but not required for testing (Reference 15).

e. Re-Entry

(1) After the trials, the concrete pad was monitored using the HD video cameras. At the point in time when no visible liquid was detected, as determined by TCO, the trial was considered complete and the reentry team reentered the test area to reattach the flange and seal the tank. The reentry team consisted of DPG explosives technicians and CI personnel who entered the grid in two phases.

(a) Phase I. DPG explosives technicians made the initial entry from the upwind direction into the area with full face respirators to monitor the gas level with ToxiRAEs. Explosives technicians inspected the area, and notified the TCO that the area was cleared of any explosive hazard. Re-entry teams maintained the appropriate PPE (as designated by the IMT and approved by DPG Command).

Table 2. Test Matrix for JRII 2015 Trials; JRII.

Trial Number	Date	Time of Release (UTC[a])	Amount of Chlorine [kg (US[b] ton)]	Nozzle Orientation	Release Point Size [cm (in)]
1	24 August	1335:45	4509 (4.97)	180 degrees (downward)	15.24 (6)
2	28 August	1524:21	8151 (8.98)	180 degrees (downward)	15.24 (6)
3	29 August	1356:55	4512 (4.97)	180 degrees (downward)	15.24 (6)
4	01 September	1438:50	6970 (7.68)	180 degrees (downward)	15.24 (6)
5	03 September	1328:19	8303 (9.15)	180 degrees (downward)	15.24 (6)

[a]Coordinated Universal Time.
[b]United States.

NOTE: Trial 5 was reserved to address emergency responder group objectives.

(b) Phase II. The TCO initiated the second phase of the reentry after authorizing the CI team to enter the test area and replace the flange on the tank.

(2) The re-entry operation continued as follows:

(a) The chlorine gas recovery scrubber was operated to reduce chlorine concentrations during the flange replacement operation.

(b) A new dissemination flange was installed.

(c) A blind flange was placed on dissemination ports that were not reused.

(d) The disseminator was prepared for next test.

2.2.6 JRII 2015 Trials and Studies Findings

a. There were five JRII trials in 2015. The test matrix can be found in Table 2.

b. Environmental conditions data were collected before, during, and after the dissemination. These release MET data are the mean of all the tripod PWIDS data recorded from the start of the dissemination until 60 minutes after release. The mean ambient temperature, RH, wind speed, and wind direction over the course of each trial is shown in Table 3.

c. This test report documents the setup, execution, and data collection for the JRII test. DHS and DTRA are responsible for the data analysis and storage of the data. The figures and tables in this report are intended to provide a snapshot of the test trials. A complete data package can be accessed through the HSIN (Reference 7).

Table 3. 2015 Environmental Mean Data; JRII.

Trial Number	Date	Wind Velocity (m/s)	Wind Direction (Degrees)	Relative Humidity (Percent)	Temperature (°C)
1	24 August	2.47	159	34.9	19.4
2	28 August	4.06	175	29.8	24.3
3	29 August	3.95	161	28.6	23.9
4	01 September	2.68	169	25.9	24.0
5	03 September	3.52	176	25.9	22.3

NOTE: Means were taken across the 34 tripod Portable Weather Information Display System (PWIDS) systems from moment of release to 60 minutes after release.

(1) MET Data. The MET data were collected using, PWIDS, 32-m MET towers, EBS, 924 and 449 MHz Profilers, and SODAR. These instruments were placed in the near field, far field, and in the surrounding test range. The PWIDS were used to determine the go/no go status before each trial.

(2) Tank Data

(a) The tank data include absolute pressure, differential pressure, mass, liquid chlorine depth, RH and ambient temperature, and internal temperature. These data were collected using

load cells, thermocouples, GWR, pressure sensors, and Vaisala temperature and humidity probes. These instruments were placed internally and externally to the dissemination tank and on the tank support system.

(b) The data acquisition system was specified to take data at 100 Hz, but the system functioned erratically (e.g., not necessarily recording 100 data points for every second of operation). Because of problems with data field transmitters, tank instrument data (with the exception of the load cells) was only sent at 0.5 Hz (every two seconds).

(3) Concrete Pad Data. Concrete pad data were collected using thermocouples and GWRs, which were used to measure pad temperature and liquid chlorine depth. These instruments were placed in three locations and measured data above and below grade.

(4) Vapor Point Sensor Data. Point detection data were collected using the following devices: thermocouples, copper strips, UV Canary, Jaz™, ToxiRAE Pro, and MiniRAE. These instruments were placed in the near field, including inside urban structures, and in the far field.

(5) Standoff Detection Data. Standoff detection concentration data were collected using UV Sentry, UV LIDAR, WDL, and the LIF. These instruments were placed in the near field and at the SL test site.

(6) Optical Data. Optical data were collected using HD, HS, IR, and still cameras. These instruments were placed in the near field and photographs were taken of the complete test site.

2.2.6.1 Trial 1

a. Trial 1 was conducted on 24 August 2015 at 1335:45 coordinated universal time (UTC). The modified chlorine tank was filled with 4509 kg (4.97 tons) of chlorine the previous night.

b. The main foci of this trial were to:

(1) Examine the thermodynamics and mass parameters of a downward flow and long range dispersion of compressed, liquefied chlorine from the 180-degree dissemination port on the dissemination tank.

(2) Examine the effects of urban barriers on a chlorine dispersion.

(3) Examine the indoor and outdoor transport of chlorine.

(4) Examine upwind chlorine hazards.

(5) Examine the effects of chlorine gas on vehicle operation and sheltering in place.

c. The following instruments were not available at the time of release during Trial 1.

(1) One HD camera (instrument malfunction).

(2) One IR camera (instrument malfunction).

(3) Multiple indoor and outdoor thermocouples (data collection malfunction and late instrument delivery).

(4) Thermowell thermocouple (leaked and not reinstalled during the 2015 trials).

(5) One absolute pressure transmitter (damaged during initial installation and never replaced).

d. MET Thermocouple Data. Thermocouple data were captured and are shown in Figure C.1. In Figure C.1, 60 cm (23.6 in) instrument height was chosen to represent the data because it showed the greatest temperature drop across all stations and trials.

e. Point Vapor Sensor Data. Representations of chlorine concentrations at the instrument locations are shown in Figures C.2 through C.4.

f. Standoff Detection Data. Data from the LIDAR instruments are in Figure C.5.

g. Optical Data. A representative photograph is shown in Figure C.6.

h. Tank Data. The data acquisition system was specified to take data at 100 Hz with a resolution of 1 second, but the system functioned erratically (e.g., not necessarily recording 100 data points for every second of operation).

2.2.6.2 Trial 2

a. Trial 2 was conducted on 28 August 2015 at 1524:21 UTC. The modified chlorine tank was filled with 8151 kg (8.98 tons) of chlorine the previous night.

b. The main foci of this trial were to:

(1) Examine the thermodynamics and mass parameters of a downward flow and long range dispersion of compressed, liquefied chlorine from the 180-degree dissemination port on the dissemination tank.

(2) Examine the effects of urban barriers on a chlorine dispersion.

(3) Examine the indoor and outdoor transport of chlorine.

(4) Examine upwind chlorine hazards.

(5) Examine the effects of chlorine gas on vehicle operation and sheltering in place.

c. The following instruments were not available at the time of release during Trial 2.

(1) Five HD cameras (lift equipment malfunction).

(2) Four IR cameras (lift equipment malfunction).

(3) Multiple outdoor thermocouples (late instrument delivery).

(4) East UV LIDAR (instrument malfunction).

d. The following instrument locations were modified for Trial 2.

(1) MiniRAEs on the 200-m arc were raised from 0.3 m to 3 m.

(2) All MiniRAEs removed from UTG perimeter and placed inside and on top of the 2 × 3 conex stack and on the upwind and downwind camera towers.

e. MET Thermocouple Data. Thermocouple data were captured and are shown in Figure D.1. In Figure D.1, 60 cm (23.6 in) instrument height was chosen to represent the data because it showed the greatest temperature drop across all stations and trials.

f. Point Vapor Sensor Data. Representations of chlorine concentrations at the instrument locations are shown in Figures D.2 through D.4.

g. Standoff Detection Data. Data from the LIDAR instruments are in Figure D.5.

h. Optical Data. A representative photograph is shown in Figure D.6.

i. Tank Data. The data acquisition system was specified to take data at 100 Hz with a resolution of 0.1 seconds, but the system functioned erratically (e.g., not necessarily recording 10 data points for every 0.1 seconds of operation).

NOTE: The data resolution was changed from 1 second to 0.1 seconds for the remaining trials based on a preliminary review of Trial 1 data.

2.2.6.3 Trial 3

a. Trial 3 was conducted on 29 August 2015 at 1356:55 UTC. The modified chlorine tank was filled with 4512 kg (4.97 tons) of chlorine the previous night.

b. The main foci of this trial were to:

(1) Examine the thermodynamics and mass parameters of a downward flow and long range dispersion of compressed, liquefied chlorine from the 180-degree dissemination port on the dissemination tank.

(2) Examine the effects of urban barriers on a chlorine dispersion.

(3) Examine the indoor and outdoor transport of chlorine.

(4) Examine upwind chlorine hazards.

(5) Examine the effects of chlorine gas on vehicle operation and sheltering in place.

c. The following instruments were not available at the time of release during Trial 3.

(1) Multiple outdoor thermocouples (late instrument delivery).

d. MET Thermocouple Data. Thermocouple data were captured and are shown in Figure E.1. In Figure E.1, 60 cm (23.6 in) instrument height was chosen to represent the data because it showed the greatest temperature drop across all stations and trials.

e. Point Vapor Sensor Data. Representations of chlorine concentrations at the instrument locations are shown in Figures E.2 through E.4.

f. Standoff Detection Data. Data from the LIDAR instruments are in Figure E.5.

g. Optical Data. A representative photograph is shown in Figure E.6.

h. Tank Data. The data acquisition system was specified to take data at 100 Hz with a resolution of 0.1 seconds, but the system functioned erratically (e.g., not necessarily recording 10 data points for every 0.1 seconds of operation).

2.2.6.4 Trial 4

a. Trial 4 was conducted on 1 September 2015 at 1438:50 UTC. The modified chlorine tank was filled with 6970 kg (7.68 tons) of chlorine the previous night.

b. The main foci of this trial were to:

(1) Examine the thermodynamics and mass parameters of a downward flow and long range dispersion of compressed, liquefied chlorine from the 180-degree dissemination port on the dissemination tank.

(2) Examine the effects of urban barriers on a chlorine dispersion.

(3) Examine the indoor and outdoor transport of chlorine.

(4) Examine upwind chlorine hazards.

(5) Examine the effects of chlorine gas on vehicle operation and sheltering in place.

c. The following instruments were not available at the time of release during Trial 4.

(1) Two HD cameras (lift equipment malfunction).

(2) Two IR cameras (lift equipment malfunction).

(3) One HS camera (lift equipment malfunction).

(4) One indoor and multiple outdoor thermocouples (data collection malfunction and late instrument delivery).

d. MET Thermocouple Data. Thermocouple data were captured and are shown in Figure F.1. In Figure F.1, 60 cm (23.6 in) instrument height was chosen to represent the data because it showed the greatest temperature drop across all stations and trials.

e. Point Vapor Sensor Data. Representations of chlorine concentrations at the instrument locations are shown in Figures F.2 through F.4.

f. Standoff Detection Data. Data from the LIDAR instruments are in Figure F.5.

g. Optical Data. A representative photograph is shown in Figure F.6.

h. Tank Data. The data acquisition system was specified to take data at 100 Hz with a resolution of 0.1 seconds, but the system functioned erratically (e.g., not necessarily recording 10 data points for every 0.1 seconds of operation).

2.2.6.5 Trial 5

a. Trial 5 was conducted on 3 September 2015 at 1328:19 UTC. The modified chlorine tank was filled with 8303 kg (9.15 tons) of chlorine the previous night.

b. The main foci of this trial were to:

(1) Examine the thermodynamics and mass parameters of a downward flow and long range dispersion of compressed, liquefied chlorine from the 180-degree dissemination port on the dissemination tank.

(2) Examine the effects of urban barriers on a chlorine dispersion.

(3) Examine the indoor and outdoor transport of chlorine.

(4) Examine upwind chlorine hazards.

(5) Examine the effects of chlorine gas on vehicle operation and sheltering in place.

(6) Examine the effects of chlorine on common building components and urban surfaces.

c. The following instruments were not available at the time of release during Trial 5.

(1) One Jaz™ (instrument malfunction).

(2) One IR camera (instrument malfunction).

(3) Multiple outdoor thermocouples (late instrument delivery).

d. MET Thermocouple Data. Thermocouple data were captured and are shown in Figure G.1. In Figure G.1, 60 cm (23.6 in) instrument height was chosen to represent the data because it showed the greatest temperature drop across all stations and trials.

e. Point Vapor Sensor Data. Representations of chlorine concentrations at the instrument locations are shown in Figures G.2 through G.4.

f. Standoff Detection Data. Data from the LIDAR instruments are in Figure G.5.

g. Optical Data. A representative photograph is shown in Figure G.6.

h. Tank Data. The data acquisition system was specified to take data at 100 Hz with a resolution of 0.1 seconds, but the system functioned erratically (e.g., not necessarily recording 10 data points for every 0.1 seconds of operation).

2.2.7 JRII 2015 Trials and Studies Data Analysis/Procedures

a. Data from the 2015 trials were collected and are found on the HSIN (Reference 7).

2.3 JRII 2016 TRIALS AND STUDIES

2.3.1 Objectives

NOTE: Test objectives came directly from DHS or were requested through DHS by members of the first responder community. Objectives from first responders are identified as the Emergency Response Group.

a. DHS Objectives

(1) Safely perform the controlled release of compressed, liquefied chlorine to the atmosphere in a series of up to 21 trials in masses ranging from 4536 to 18,144 kg (5 to 20 tons) from simulated chlorine tank ruptures.

(2) Use standard methodology to ensure relevant data precision, accuracy, validity, and quality in a common format.

(3) Observe and measure the simulated ruptured tank thermodynamic and mass parameters during dissemination to improve model source terms.

(4) Quantitatively monitor and collect gas cloud concentration data from the initial phase of a very dense, two-phase cloud near the source to dispersion of the cloud further downwind using point detectors and standoff spectroscopic instruments. Data collection from the release will allow personnel to quantify and characterize cloud retrograde.

(5) Characterize and quantitatively measure chlorine cloud removal by deposition on vertical and horizontal surfaces, hydrolysis, photolysis, reaction with organic and inorganic constituents of soil, and reaction with vegetation.

(6) Validate and characterize RPT events observed in JRI tests (Reference 1).

(7) Study exposure impacts on equipment and materials. **NOTE**: DHS is responsible for the study.

(8) Study emergency response guidelines. **NOTE**: DHS is responsible for this study.

(9) Study industrial risk and hazard mitigation procedures. **NOTE**: DHS is responsible for this study.

(10) Provide a realistic observable hazardous release environment for the education and training of emergency response personnel. **NOTE**: DPG will provide the training environment.

b. Emergency Response Group Objectives

(1) Determine the origin and character of the RPTs phenomenon.

(2) Determine a reliable vertical concentration gradient (i.e., the gas density of chlorine at a concentration gradient in which a responder can survive above the cloud will be considered).

(3) Determine if low wind speeds increase the probability of retrograde creep of the cloud. Further validate that the initial isolation zones, at a ground distance of 1000 m (3281 feet), and downwind protective action recommendations contained in the *2012 Emergency Response Guidebook* (Reference 2) are appropriate.

(4) Determine the level to which flash freezing and thawing occur on the surface at the release point.

(5) Determine the behavior of common building components and urban surfaces. Specifically, determine the behavior of both new and aged asphalt when in contact with high concentrations of chlorine gas or liquid chlorine. Assess the absorption of chlorine gas into water.

2.3.2 Criteria

None.

2.3.3 RPT Study

a. During Trial 8, 15 minutes and 30 seconds after the initial release, the liquid remaining in the tank was released via a 2-inch dump valve. The liquid chlorine was directed towards soil samples using a radial flow plate placed below the dump valve.

b. The soil samples were placed in 2-gallon buckets in the radial flow plate directly under the 180-degree dissemination port. Optical data collection was the primary means to verify any RPT activity.

c. No RPTs were observed.

2.3.4 Indoor/Outdoor Transport of a Dense Gas

a. The Indoor/Outdoor Transport of a Dense Gas studies were conducted by LBNL through DTRA and Department of Transportation sponsorship. The test data and reports for these studies can be found on the HSIN (Reference 7).

b. LBNL measured chlorine gas (Cl_2) concentrations inside four structures during 2015 trials. Measured concentrations suggested deposition of Cl_2 onto indoor surfaces greatly reduced indoor concentrations compared to a non-reactive gas. The two trailers had unpainted wallboard

and carpet, but were otherwise unfurnished. Testing was performed with the HVAC system on using recirculation rates of ~30 $hour^{-1}$ and outdoor air intake rates of ~3 $hour^{-1}$.

c. One conex and one modular trailer were tested to provide more data on higher indoor concentrations of airborne Cl_2 during shelter-in-place conditions with HVAC system on during the release.

d. Measurement of airflows. Buildings under shelter-in-place conditions had the HVAC system off during real releases. With the HVAC system off, air exchange with the outdoor via air infiltration was lower. Experiments to measure Cl_2 were conducted during periods with the HVAC system off, and periods with the HVAC system on. A small mixing fan was used to keep the indoor air mixed. Before the release of Cl_2, the air velocities in the trailer and long conex structure were measured to characterize the indoor conditions. Air-exchange rates were monitored concurrently throughout the experiment using SF_6 tracer gas. Surface and indoor air temperatures were monitored.

e. Indoor Materials in Structures. The modular trailer (20 ft × 10 ft × 8 ft) had an approximate volume of 45 m^3 and a surface area of 82 m^2. The approximate surface-to-volume (S/V) ratio was 1.8 m^2/m^3. The majority of the surfaces were unpainted wallboard (S/V ~1.3 m^{-1}) and carpet (S/V ~0.3 m^{-1}).

f. Instrumentation

(1) Single-Story conex. The same 40-ft (12.2 m) conex used in the 2015 releases was set up with an exhaust fan that could be turned on or off during a release. A Jaz™ (10 to 50,000 ppm) instrument was placed outside of the conex near the air intake.Two Jaz™ instruments were placed inside the conex, one in each room. In addition, two UV Canarys (10 to 10,000 ppm) were dispersed inside the trailers.

(2) Modified Trailer. A Jaz™ instrument was placed outside the air intake of the modified trailer. Inside the structure, one Jaz™, and two UV Canarys were used to measure indoor Cl_2 concentrations.

(3) SF_6 Tracer Decay Test. This test was performed in both the conex structure and the modular trailer. SF_6 was injected inside the test items to a uniform concentration to reach 1 to 3 ppm. Concentrations of SF_6 were monitored using a FTIR gas analyzer Gasmet™ DX-4000 at a central location inside the structure with the HVAC system off and with the HVAC system on.

g. Test Procedures

(1) Cl_2 concentrations were monitored inside and outside of the test items. The test sequence on each experimental day was as follows:

(a) Prepare instruments for measuring Cl_2 concentrations, indoor air, and surface temperature.

(b) After the all clear, structures were aired out by opening doors and turning on exhaust fans.

(c) Air filters in the wall-mount HVAC system of the modified trailer were reviewed to ensure their integrity.

(2) Observations of potential damages on indoor surfaces by exposure to Cl_2 were recorded, if any.

2.3.5 Vehicle Study

a. Background

(1) LBNL participated in the 2016 trials, which were a group of field experiments conducted to understand the release and transport of Cl_2 in outdoor and urban environments. LBNL was supporting experiments that would explain and model how chlorine is transported into and out of buildings.

(2) In another group of experiments, researchers at the DHS S&T CSAC and UVU measured the airborne concentration of Cl_2 in vehicles owing to an outdoor release, and analyzed the resulting data to assess the expected benefits of sheltering in vehicles from an outdoor Cl_2 release.

b. Description of Field Experiment Work Plan

(1) Vehicle Selection and Infiltration/Exfiltration Experiments

(a) DHS and UVU selected three test vehicles.

(b) LBNL conducted infiltration-exfiltration studies in each vehicle, using SF_6 as a tracer gas. DPG provided and operated analysis instrumentation.

(c) LBNL analyzed the resulting data and characterized the expected rate of infiltration of SF_6.

(2) In-Vehicle Release of Cl_2

(a) LBNL directed the release of a fixed amount of Cl_2 from a tank into each of the test vehicles and measured the rate of concentration decay. The amount of Cl_2 released was determined in consultation with DPG and IAW environmental health and safety recommendation, and instrument detection limits. Peak concentrations were anticipated to be less than 10 ppm.

(b) LBNL analyzed the data and compared the resulting rate of loss relative to a non-reactive gas.

(3) In-Vehicle Measurement of Chlorine During the Full-Scale JRII Tanker Release

(a) LBNL coordinated with DHS and UVU to determine which vehicle/test combinations were likely to yield the highest quality results.

(b) The principle objective of these tests was to find out how much Cl_2 protection a vehicle provides. The ventilation rate for the vehicles could vary considerably and the in-vehicle

reactive loss rate for Cl_2 was unknown. Protection depends on these two parameters (ventilation and loss). Low ventilation rates with high loss rates provided a high degree of protection, but posed a measurement challenge. The peaks in a vehicle could be a factor of several hundred less than outdoors. On the other end of the spectrum, a highly ventilated vehicle with minimal reaction losses could result in peak attenuations of only a factor of ten (or less). For simple vehicles (e.g., cars or fire truck cabs) a single sample location was sufficient. With ambulances, sample locations in the cab and the patient compartment were tested.

(c) For each test involving vehicles, LBNL coordinated with DPG and UVU for specific vehicle/instrument placements.

2.3.6 Test Execution/Dissemination Procedures

a. The procedures for test execution/dissemination were identical to the procedures used in 2015 (Paragraph 2.2.5). The 2016 trials were conducted IAW the test matrix in Table 4.

2.3.7 JRII 2016 Trials and Studies Findings

a. There were four JRII trials in 2016. The test matrix can be found in Table 4. For Trials 7 and 8, the tank initially depressurized and partially drained with the specialized dissemination port at the angle listed in Table 4 and finally drained with a 2-inch (5.08-cm) drain valve. The times for the drain valve release are shown as the second release times in Table 4.

b. Environmental conditions data were collected before, during, and after the dissemination. These release MET data are the mean of all the tripod PWIDS data recorded from the start of the dissemination until 60 minutes after release. The mean ambient temperature, RH, wind speed, and wind direction over the course of each trial is shown in Table 5.

Table 4. Test Matrix for JRII 2016 Trials; JRII.

Trial Number	Date	Time of Primary Release (UTC[a])	Time of Secondary Release (UTC)	Total Amount of Chlorine [kg (tons)]	Nozzle Orientation	Release Point Size [cm (in)]
6	31 August	1423:35	NA[b]	8373 (9.2)	180 degrees (downward)	15.24 (6)
7	02 September	1356:00	1407:08	9067 (10)	135 degrees	15.24 (6)
8	11 September	1501:45	1517:16	9081 (10)	0 degrees (upward)	15.24 (6)
9	17 September	1405:30	NA	17690 (19.5)	180 degrees (downward)	15.24 (6)

[a]Universal coordinated time.
[b]Not applicable.

Table 5. 2016 Environmental Mean Data; JRII.

Trial Number	Date	Wind Velocity (m/s)	Wind Direction (Degrees)	Relative Humidity (Percent)	Temperature (°C)
6	31 August	2.88	147	20.9	22.7
7	02 September	4.27	156	54.9	19.5
8	11 September	1.87	162	22.3	16.7
9	17 September	3.34	162	43.5	11.0

NOTE: Means were taken across the 34 tripod Portable Weather Information Display System (PWIDS) systems from moment of release to 60 minutes after release.

c. The data were measured for each trial and are found in the accompanying data package.

(1) MET Data. The MET data were collected using, PWIDS, 32-m MET towers, EBS, 924 and 449 MHz Profilers, and SODAR. These instruments were placed in the near field, far field, and in the surrounding test range. The PWIDS were used to determine the go/no go status before each trial.

(2) Tank Data. The tank data include absolute pressure, differential pressure, mass, liquid chlorine depth, RH and ambient temperature, and internal temperature. These data were collected using load cells, thermocouples, GWR, pressure sensors, and Vaisala temperature and humidity probes. These instruments were placed internally and externally to the dissemination tank and on the tank support system. Modifications were made to the data acquisition system, and it was found to function consistently when recording data at 25 Hz. The data transmission settings were set to transmit data to match the 25 Hz acquisition rate.

(3) Concrete Pad Data. Concrete pad data were collected using thermocouples and GWRs, which were used to measure pad temperature and liquid chlorine depth. These instruments were placed in three locations and measured data above and below grade.

(4) Vapor Point Sensor Data. Point detection data were collected using the following devices: thermocouples, UV Canary, Jaz™, ToxiRAE Pro, and MiniRAE. These instruments were placed in the near field, including inside urban structures, and in the far field.

(5) Standoff Detection Data. Standoff detection concentration data were collected using UV Sentry, Wind Cube Vertical LIDAR, Wind Cube Scanning LIDAR, UV LIDAR, WDL, and the LIF. These instruments were placed in the near field and at the SL test site.

(6) Optical Data. Optical data were collected using Thermal Imager, 3DCAV, UV-Vis Hyperspectral, VNIR Hyperspectral, HD, HS, IR, UAS, and still cameras. These instruments were placed in the near field and photographs were taken of the complete test site.

NOTE: References to specific instrument locations can be found in maps and survey data available on the HSIN (Reference 7).

2.3.7.1 Trial 6

a. Trial 6 was conducted on 31 August 2016 at 1423:35 UTC. The modified chlorine tank was filled with 8373 kg (9.23 tons) of chlorine the previous night.

b. The main foci of this trial were to:

(1) Examine thermodynamics and mass parameters of a downward flow and long range dispersion of compressed, liquefied chlorine from the 180-degree dissemination port on the dissemination tank.

(2) Examine the indoor and outdoor transport of chlorine.

(3) Examine upwind chlorine hazards.

c. The following instruments were not available at the time of release during Trial 6.

(1) UV-LIDAR (instrument malfunction).

(2) GRIMM units (instrument malfunction).

(3) DSO Wind Cube Scanning LIDAR (delayed transit to test site).

(4) DSO Wind Cube Vertical LIDAR (delayed transit to test site).

(5) DSO VNIR Hyperspectral Camera (delayed transit to test site).

(6) DSO IR (delayed transit to test site).

(7) DSO UV-Vis Hyperspectral Camera (delayed transit to test site).

d. MET Thermocouple Data. Thermocouple data were captured and are shown in Figure H.1. In Figure H.1, 60 cm (23.6 in) instrument height was chosen to represent the data because it showed the greatest temperature drop across all stations and trials.

e. Vapor Point Sensor Data. Representations of chlorine concentrations at the instrument locations are shown in Figures H.2 through H.4.

f. Standoff Detection Data. No UV LIDAR data was collected.

g. Optical Data. A representative photograph is shown in Figure H.5.

2.3.7.2 Trial 7

a. Trial 7 was conducted on 2 September 2016 at 1356:00 UTC. The modified chlorine tank was filled with 9067 kg (9.99 tons) of chlorine the previous night. The initial release did not empty all of the chlorine in the dissemination tank. The tank initially drained with the specialized dissemination port at 135 degrees and finalized with the 2-inch (5.08-cm) drain valve at 1407:08 UTC.

b. The main foci of this trial were to:

(1) Examine thermodynamics and mass parameters of a downward flow and long range dispersion of compressed, liquefied chlorine from the 135-degree dissemination port on the dissemination tank.

(2) Examine the indoor and outdoor transport of chlorine.

(3) Examine a secondary release of the remaining chlorine from the 180-degree drain valve.

(4) Examine upwind chlorine hazards.

c. The following instruments were not available at the time of release during Trial 7.

(1) East side HS camera (instrument malfunction).

(2) DSO Wind Cube Scanning LIDAR(delayed transit to test site).

(3) DSO Wind Cube Vertical LIDAR (delayed transit to test site).

(4) DSO UV-Vis Hyperspectral Camera (delayed transit to test site).

(5) One GRIMM unit (instrument malfunction).

d. The following instrument locations were modified for Trials 7 through 9, unless noted.

(1) UV Canarys located at 120-8 and 120-9 were relocated to 500-10 and 500-20.

(2) UV Canary sampling ports located at 120-2 and 120-5 were elevated from 0.3 m to 3 m.

(3) MiniRAEs located at 200-13 and 200-14 were relocated to 50 m and 100 m directly upwind of the dissemination tank.

(4) MiniRAEs located on the 500-m arc were reallocated to westerly positions on the 5- and 11-km arcs.

e. MET Thermocouple Data. Thermocouple data were captured and are shown in Figure I.1. In Figure I.1, 60 cm (23.6 in) instrument height was chosen to represent the data because it showed the greatest temperature drop across all stations and trials.

f. Vapor Point Sensor Data. Representations of chlorine concentrations at the instrument locations are shown in Figures I.2 through I.4.

g. Standoff Detection Data. Data from the LIDAR instruments are in Figure I.5.

h. Optical Data. A representative photograph is shown in Figure I.6.

2.3.7.3 Trial 8

a. Trial 8 was conducted on 11 September 2016 at 1501:45 UTC. The modified chlorine tank was filled with 9081 kg (10.0 tons) of chlorine on 7 September 2016. The initial release did not empty all of the chlorine in the dissemination tank. The tank initially drained with the specialized dissemination port at 0 degrees and finalized with 2 inch (5.08-cm) drain valve at 1517:16 UTC.

> **NOTE**: The release date was delayed for four days because of unfavorable MET conditions.

b. The main foci of this trial were to:

(1) Examine thermodynamics and mass parameters of a downward flow and long range dispersion of compressed, liquefied chlorine from the 0-degree dissemination port on the dissemination tank.

(2) Examine the indoor and outdoor transport of chlorine.

(3) Examine a secondary release of the remaining chlorine from the 180-degree drain valve.

(4) Validate and characterize RPT events.

(5) Examine upwind chlorine hazards.

c. The following were not available at the time of release during Trial 8.

(1) High Magnification Shadow Imaging Device (instrument malfunction).

(2) Two GRIMM units (instrument malfunction).

(3) DSO Wind Cube Scanning LIDAR (delayed transit).

(4) DSO Wind Cube Vertical LIDAR (delayed transit).

(5) Onsite MET modeling files (MEDOC). **NOTE**: Second-order Closure Integrated Puff (SCIPUFF) files were used as an alternative.

(6) East UV LIDAR (instrument malfunction).

d. Observation.

(1) No RPT events were observed.

e. MET Thermocouple Data. Thermocouple data were captured and are shown in Figure J.1. In Figure J.1, 60 cm (23.6 in) instrument height was chosen to represent the data because it showed the greatest temperature drop across all stations and trials.

f. Vapor Point Sensor Data. Representations of chlorine concentrations at the instrument locations are shown in Figures J.2 through J.4.

g. Standoff Detection Data. Data from the LIDAR instruments are in Figure J.5.

h. Optical Data. Representative photographs are shown in Figures J.6 and J.7.

2.3.7.4 Trial 9

a. Trial 9 was conducted on 17 September 2016 at 1405:30 UTC. The 20-ton transport tanker was filled with 17690 kg (19.5 tons) of chlorine on 13 September 2016.

NOTE: The release date was delayed for four days because of unfavorable MET conditions.

b. The main foci of this trial were to:

(1) Examine the effects of a 20-ton transport tanker rupture.

(2) Examine the thermodynamics of a downward flow and long range dispersion of compressed, liquefied chlorine from the 180-degree breach on the 20-ton transport tanker.

(3) Examine the indoor and outdoor transport of chlorine.

(4) Examine upwind chlorine hazards.

c. The following instruments were not available at the time of release during Trial 9.

(1) One GRIMM unit (instrument malfunction).

(2) Posttrial weather balloon (GPS error).

d. Observations

(1) The explosive breaching of the tank created a circular disk that was pushed inside the tank. The disk remained near the breach, creating an uneven flow of chlorine from the tanker.

(2) The force of the explosion from the release ruptured the data cable and no tank data was collected. The West UV LIDAR collected data for the first half of the trial, but lost alignment over time as the ambient temperatures increased and could not be corrected remotely. This resulted in decreased detection later in the trial.

e. The following instrument locations were modified for Trial 9:

(1) UV Canarys located at 500-10 and 500-20 were relocated to 500-15 and 500-25.

(2) MiniRAEs located at 200-12 through 200-16 were replaced with ToxiRAEs.

(3) MiniRAEs which were reallocated to the 5- and 11-km arc after Trial 6 were shifted along those arcs toward a more central location.

f. MET Thermocouple Data. Thermocouple data were captured and are shown in Figure K.1. In Figure K.1, 60 cm (23.6 in) instrument height was chosen to represent the data because it showed the greatest temperature drop across all stations and trials.

g. Vapor Point Sensor Data. Representations of chlorine concentrations at the instrument locations are shown in Figures K.2 through K.4.

h. Standoff Detection Data. Data from the LIDAR instruments are in Figure K.5.

i. Optical Data. A representative photograph is shown in Figure K.6.

2.3.8 JRII 2016 Trials and Studies Data Analysis/Procedures

a. Data from the 2016 trials were collected and are found on the HSIN (Reference 7).

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SECTION 3. APPENDICES

APPENDIX A. TEST CRITERIA

None.

APPENDIX B. TEST SUPPORT ORDER

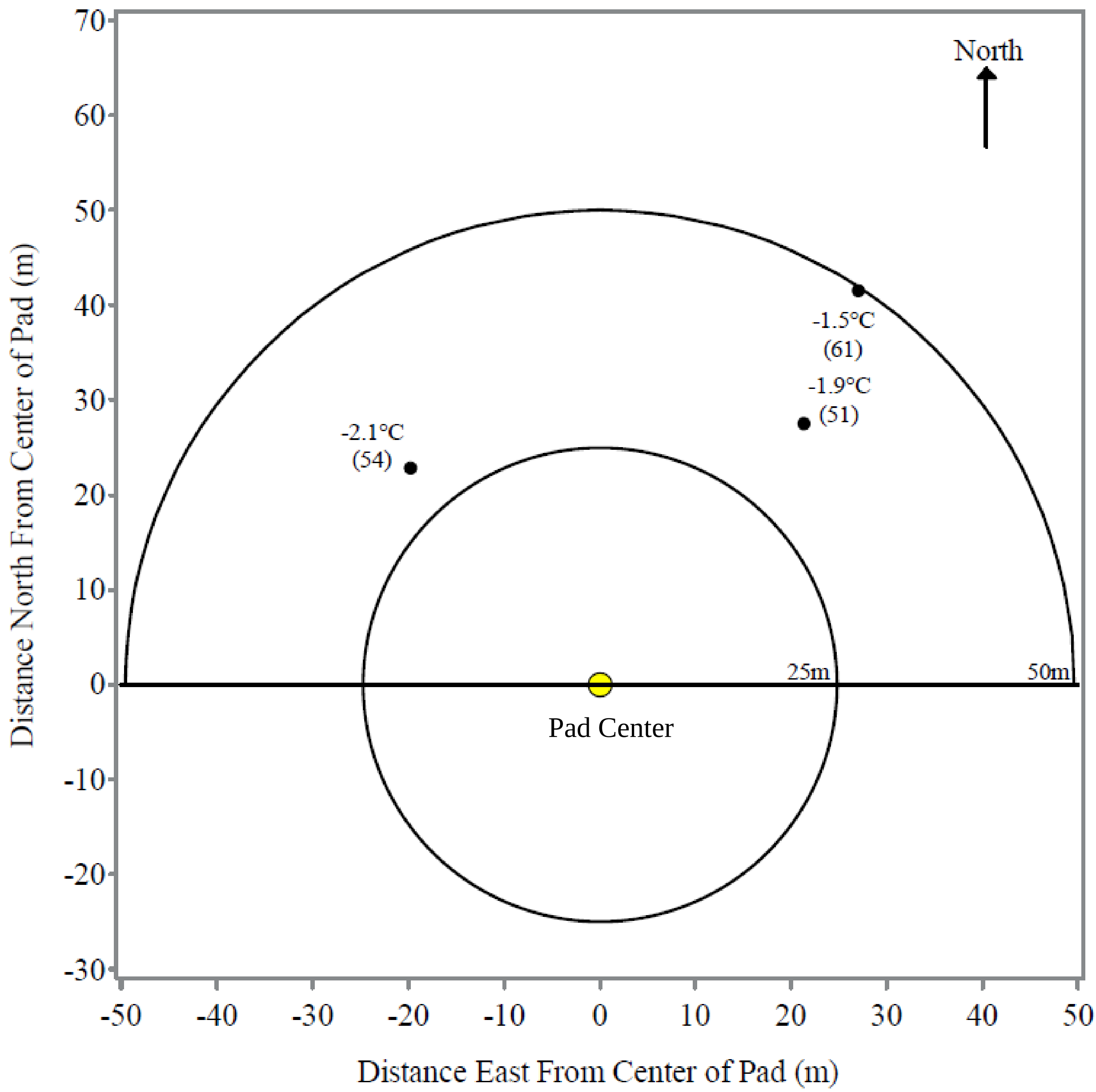
2015-DT-DPG-SNIMT-F9735 (Methodology (DT)) Jack Rabbit II Planning	
System	Methodology (DT)
Test Title	Jack Rabbit II Planning
Test Support Order	Activation in ADSS constitutes authority to begin planning IAW Project: 2014-DT-DPG-SNIMT-F9735. Upon receipt of this directive, immediately review the test milestone schedule in light of known other workload and projected available resources. If rescheduling is necessary and the sponsor non-concurs, forward a memorandum citing particulars, together with recommendations, to ATEC G9 - Test Business Management Division (Mr. Michael K. Joiner), within 15 days after receipt of this directive. Reschedules concurred in by the sponsor can be entered directly by the Test Center. Test Execution is authorized after approval of Test Plan (TP)/Detailed Test Plan (DTP) and conduct of Test Readiness Review (TRR).
Scope of Work	The Jack Rabbit test program is a study to improve the understanding of rapid large-scale releases of pressurized, liquefied toxic inhalation hazard (TIH) gases from a railcar or other toxic industrial chemical / toxic industrial material (TIC/TIM) transports. The program supports a Department of Homeland Security / Transportation Security Administration (DHS/TSA) initiative aimed at deterring terrorist attacks on TIH railcars or attacks against U.S. rail yards. Along with the counter-terrorism aspect, knowledge gained from the program has proven to be a valuable asset to the TIC/TIM and scientific communities and more importantly, to first responders of large chemical incidents. The first Jack Rabbit test program was funded by DHS/TSA and conducted at Dugway Proving Ground (DPG) during April/May 2010. Currently, the DHS Science and Technology Directorate (S&T), is proposing a follow-on test to Jack Rabbit (Jack Rabbit II), to be conducted at DPG. This phase of Jack Rabbit will be a multi-year program with field testing to be executed in July-September 2015 and July-September 2016. Jack Rabbit II addresses many issues not examined in the original Jack Rabbit test, such as the long-range dispersion of the chemical. Another component of this new program is an urban element to see how much of the chemical infiltrates buildings and automobiles. Lastly, reactivity with soil and vegetation will be studied, along with the solar decay of the cloud. Current stakeholders in the Jack Rabbit II program include: the Defense Threat Reduction Agency (DTRA); Joint Program Executive Office (JPEO); Joint Program Project Manager for Protection (JPM P); Joint Program Project Manager for Contamination Avoidance (JPM CA); Edgewood Chemical Biological Center (ECBC); Naval Surface Warfare Center – Dahlgren (NSWC-Dahlgren); Air Force Research Laboratory (AFRL); Unmanned Aerial Systems (UAS) Rapid Integration and Acceptance Center (RIAC); and the National Guard. The scope of this ADSS entry is to provide planning and limited provisioning for the Jack Rabbit II test program. The majority of provisioning and all of the test conduct will be accomplished as another ADSS entry/program.
Test Documentation	Plans and Reports will be IAW with the ADSS milestones and DTC Pam 73-1. Test plans are to be approved prior to the start of test. Maximum use of TOPS/ITOPS will be made during test planning.

2015-DT-DPG-SNIMT-F9735 (Methodology (DT)) Jack Rabbit II Planning	
	Storage: Unclassified plans/reports/data will be uploaded to the VISION Digital Library per DTC PAM 73-1. References: References to support creation of Detailed Test Plan/Test Plan, to include any Safety, Security and Environmental documents, as well as cost estimates, will be posted to the VISION Digital Library.
Security Considerations	Jack Rabbit II test program is UNCLASSIFIED.
Safety Considerations	As part of the planning phase of this test program, a safety risk assessment will be conducted at the local Command (DPG) level. Safety Assessment Report (SAR) will be provided by the sponsor. Local risk assessment will be performed prior to test commencement. If a Safety Assessment Report (SAR) is not available, the test center will review scope of the test to identify, classify, mitigate, and accept all hazards associated with the test item and test conditions IAW local standard operating procedures; completion of this review will be documented as the actual date for the 2270 milestone.
Environmental Considerations	An environmental assessment (EA) will be conducted at the local level Command (DPG) level and be available for public comment. Title-V air quality permits and Migratory Bird Treaty Act (MBTA) agreements will also be managed at the local Command (DPG) level. Environmental documentation should be requested, in writing, from the test sponsor. Site-specific environmental documentation should be prepared and concurrence obtained from the Test Center Environmental Office. Immediately contact the Safety and Environmental Risk Management Point of Contact if lack of sponsor-developed documentation results in significant data gaps which preclude the preparation of such documentation.

APPENDIX C. TRIAL 1 TEST DATA

FIGURE LIST

FIGURE | PAGE



NOTES: 1. Temperature shown is the maximum temperature drop during the trial.
2. Numbers in parenthesis are time to maximum temperature drop in seconds.
3. Only maximum temperature drops less than -0.5°C are shown.

Figure C.1. Trial 1 Meteorological (MET) Thermocouple Data at 60 cm (23.6 in) Height; JRII.

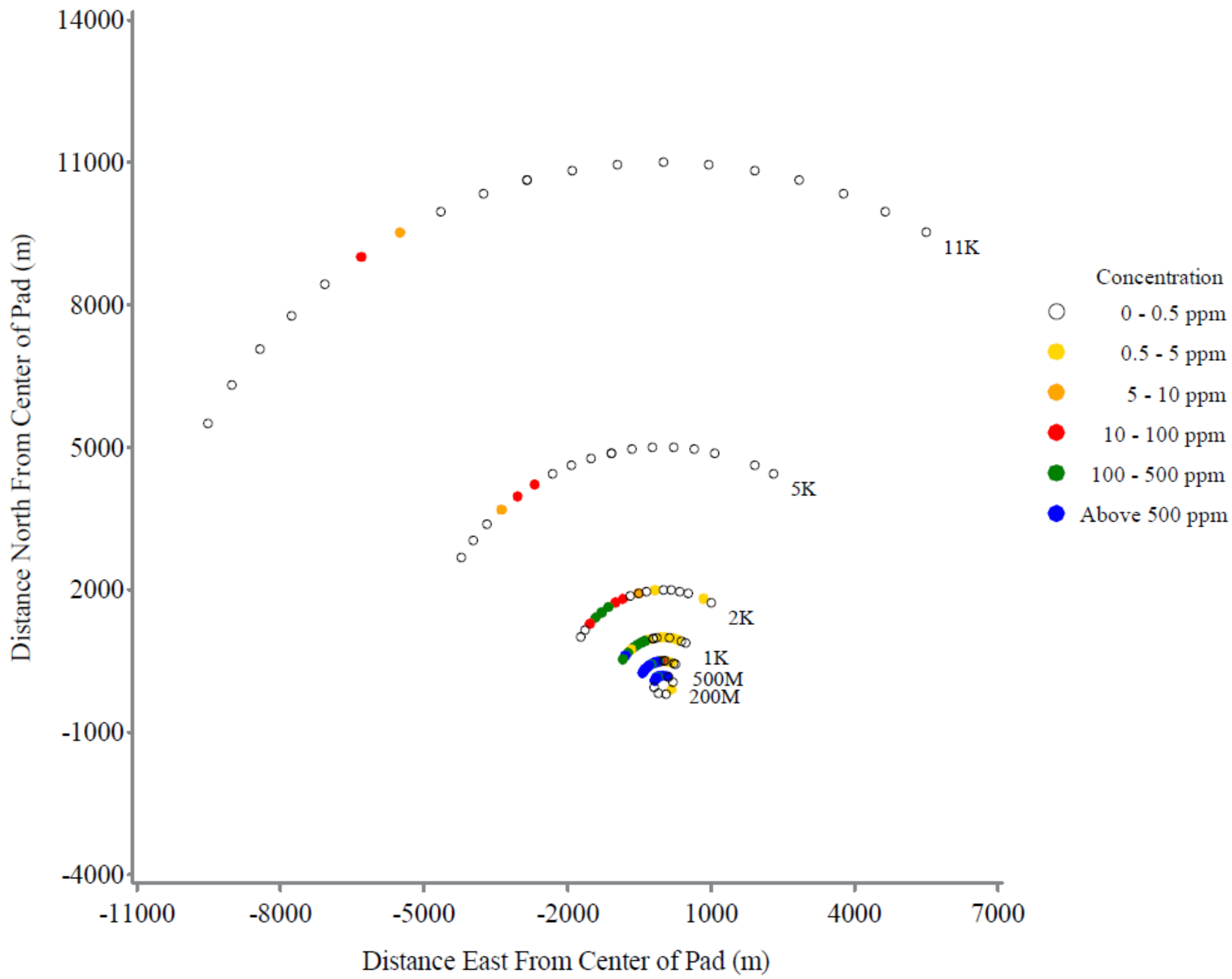


Figure C.2. Trial 1 Far Field Maximum Chlorine Concentrations; JRII.

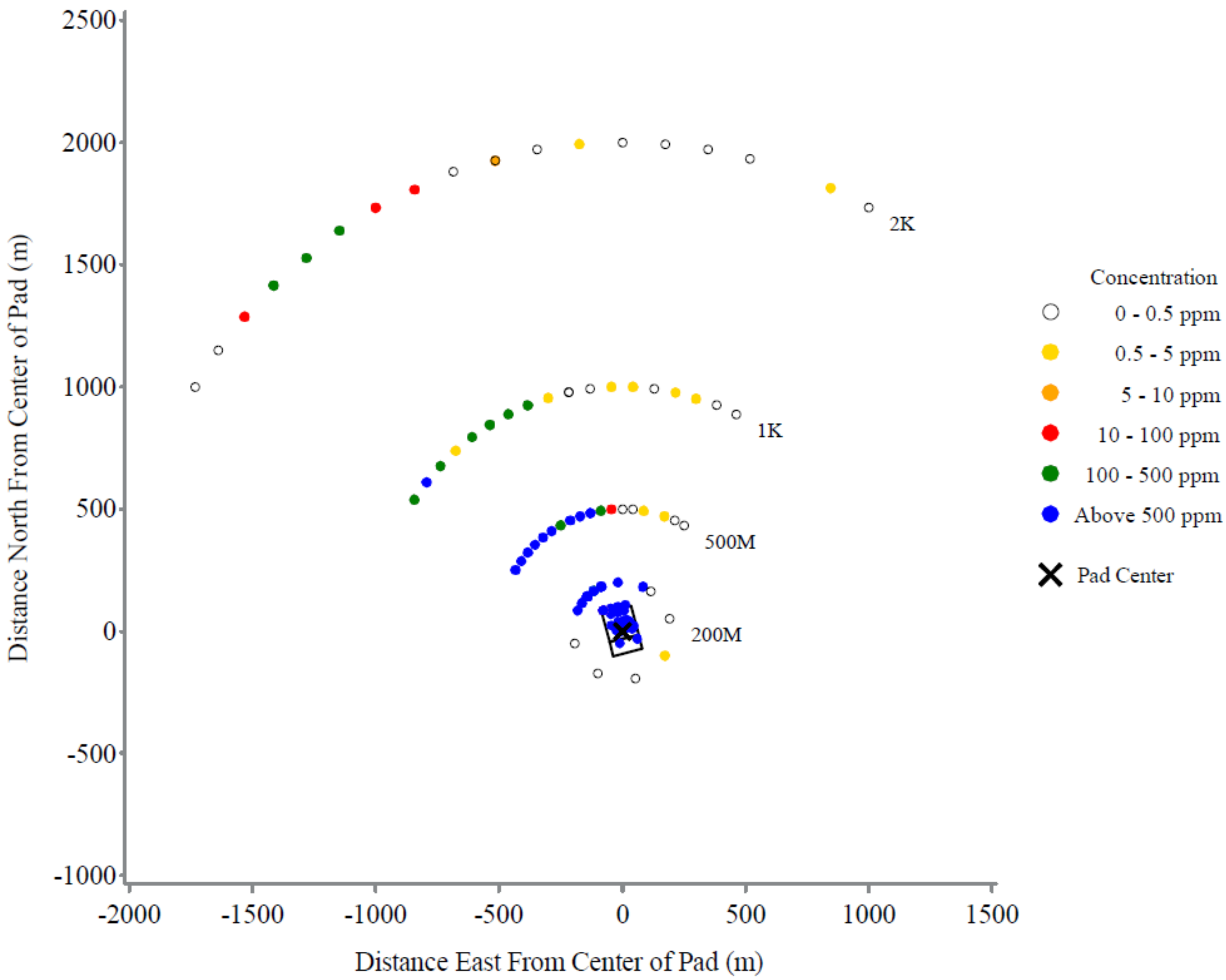


Figure C.3. Trial 1 Mid Field Maximum Chlorine Concentrations; JRII.

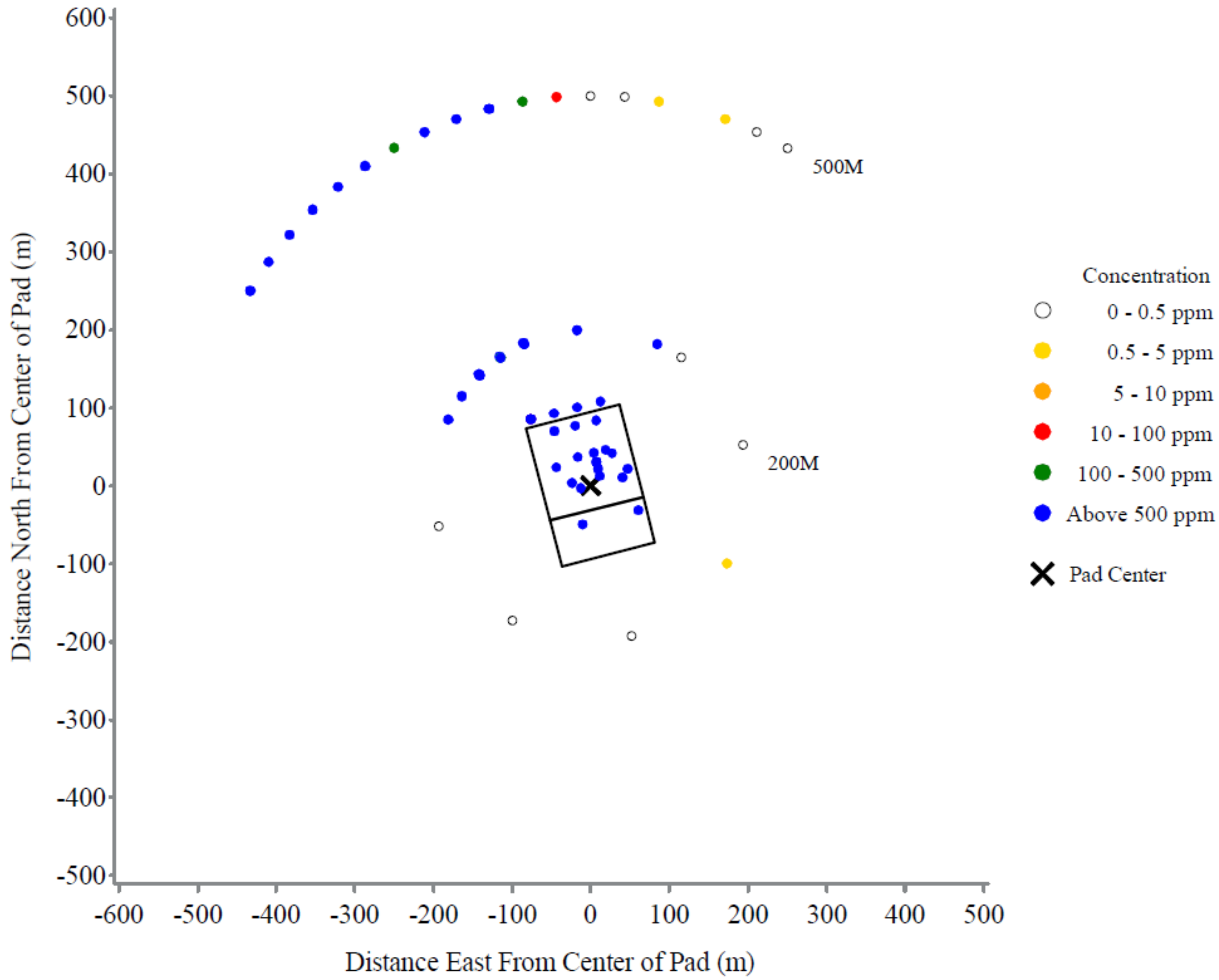
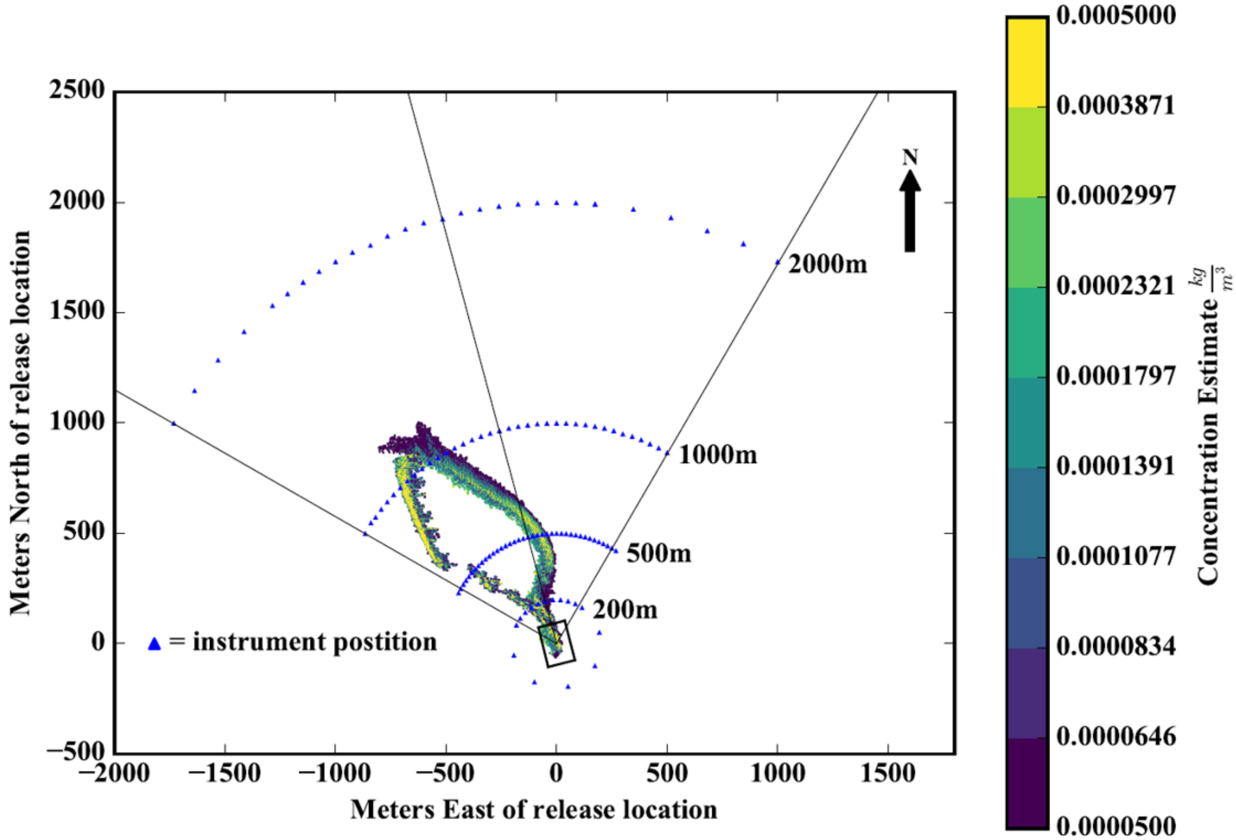


Figure C.4. Trial 1 Near Field Maximum Chlorine Concentrations; JRII.



NOTES: 1. Elapsed Time: T+00:06:00 to T+00:06:16.
2. This figure represents measurements taken of the east and west sides of the chlorine cloud and displays only the outline of the cloud. The UV LIDAR could not penetrate the entire cloud.

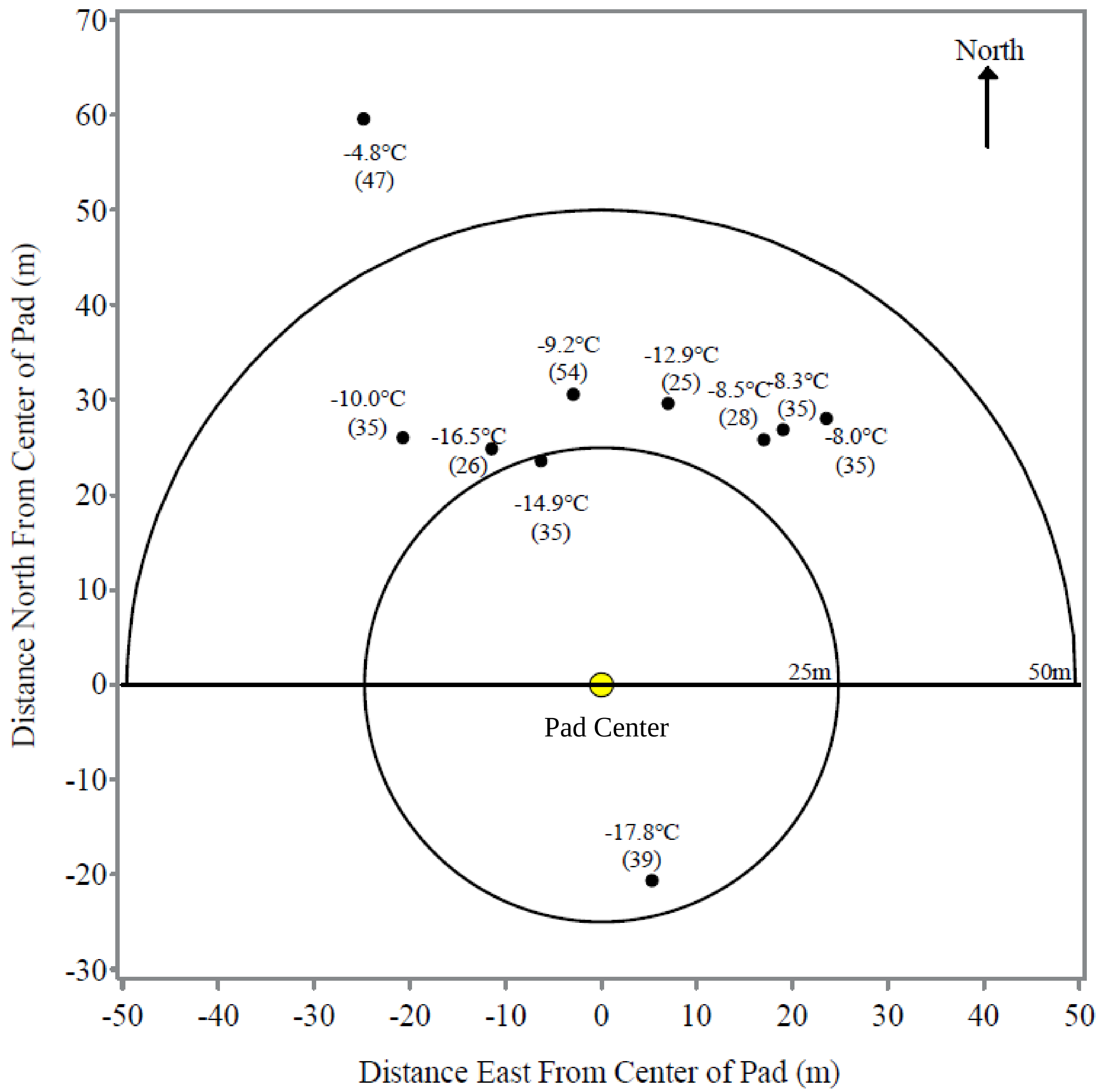
Figure C.5. Trial 1 Ultraviolet (UV) Light Detection and Ranging (LIDAR); JRII.

Figure C.6. Trial 1 Representative Photograph of Release; JRII.

APPENDIX D. TRIAL 2 TEST DATA

FIGURE LIST

FIGURE PAGE



NOTES:
1. Temperature shown is the maximum temperature drop during the trial.
2. Numbers in parenthesis are time to maximum temperature drop in seconds.
3. Only maximum temperature drops less than -0.5°C are shown.

Figure D.1. Trial 2 Meteorological (MET) Thermocouple Data at 60 cm (23.6 in) Height; JRII.

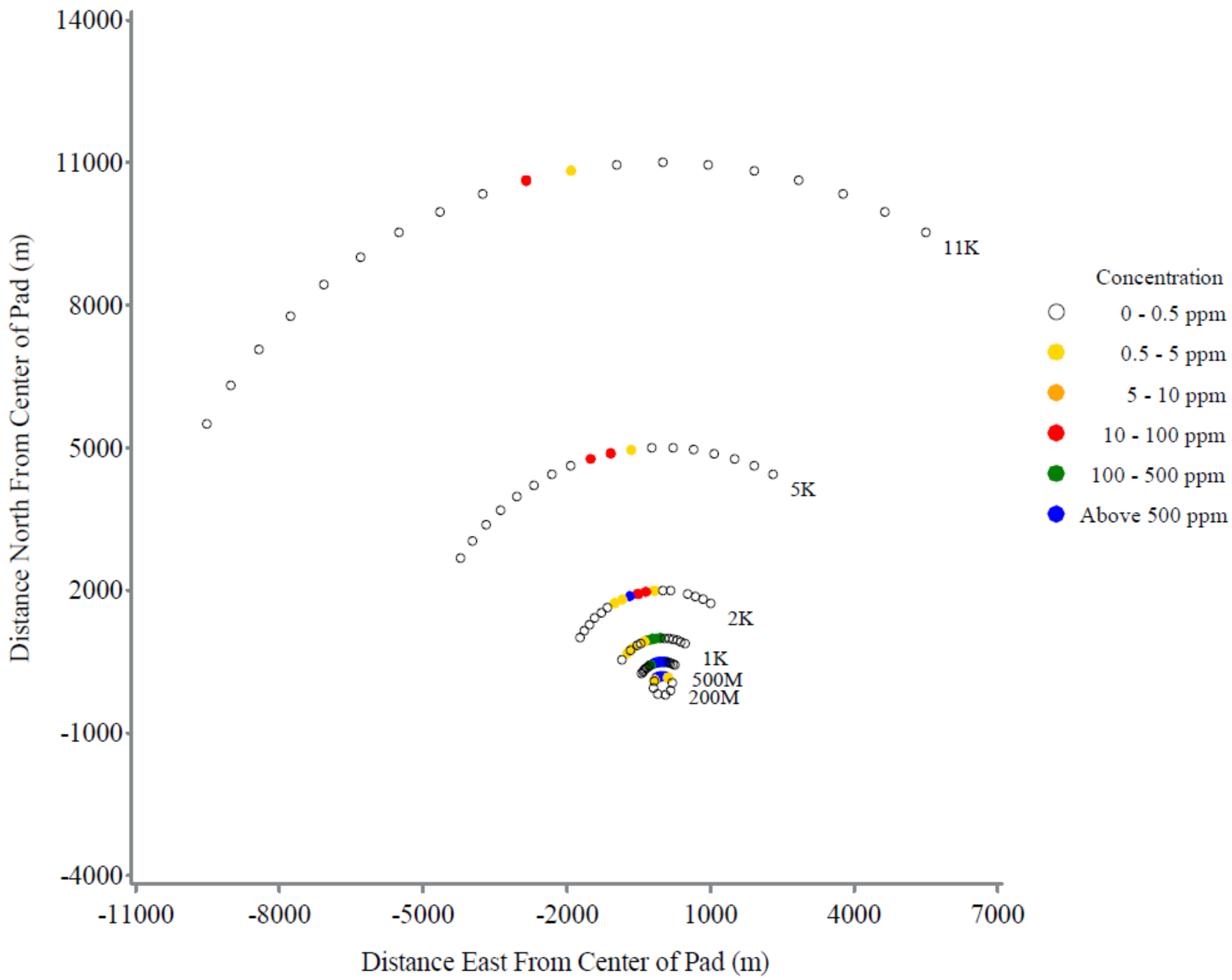


Figure D.2. Trial 2 Far Field Maximum Chlorine Concentrations; JRII.

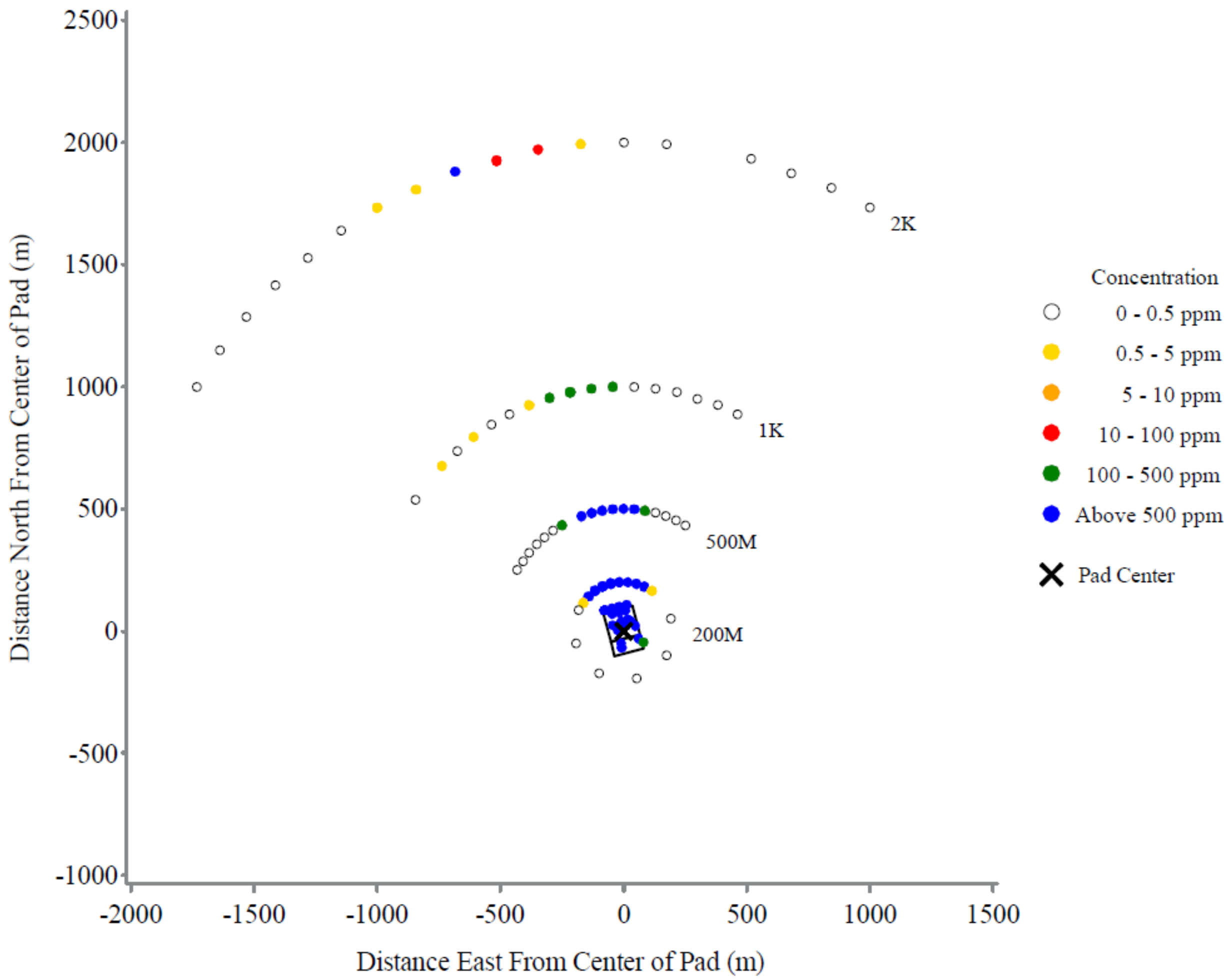


Figure D.3. Trial 2 Mid Field Maximum Chlorine Concentrations; JRII.

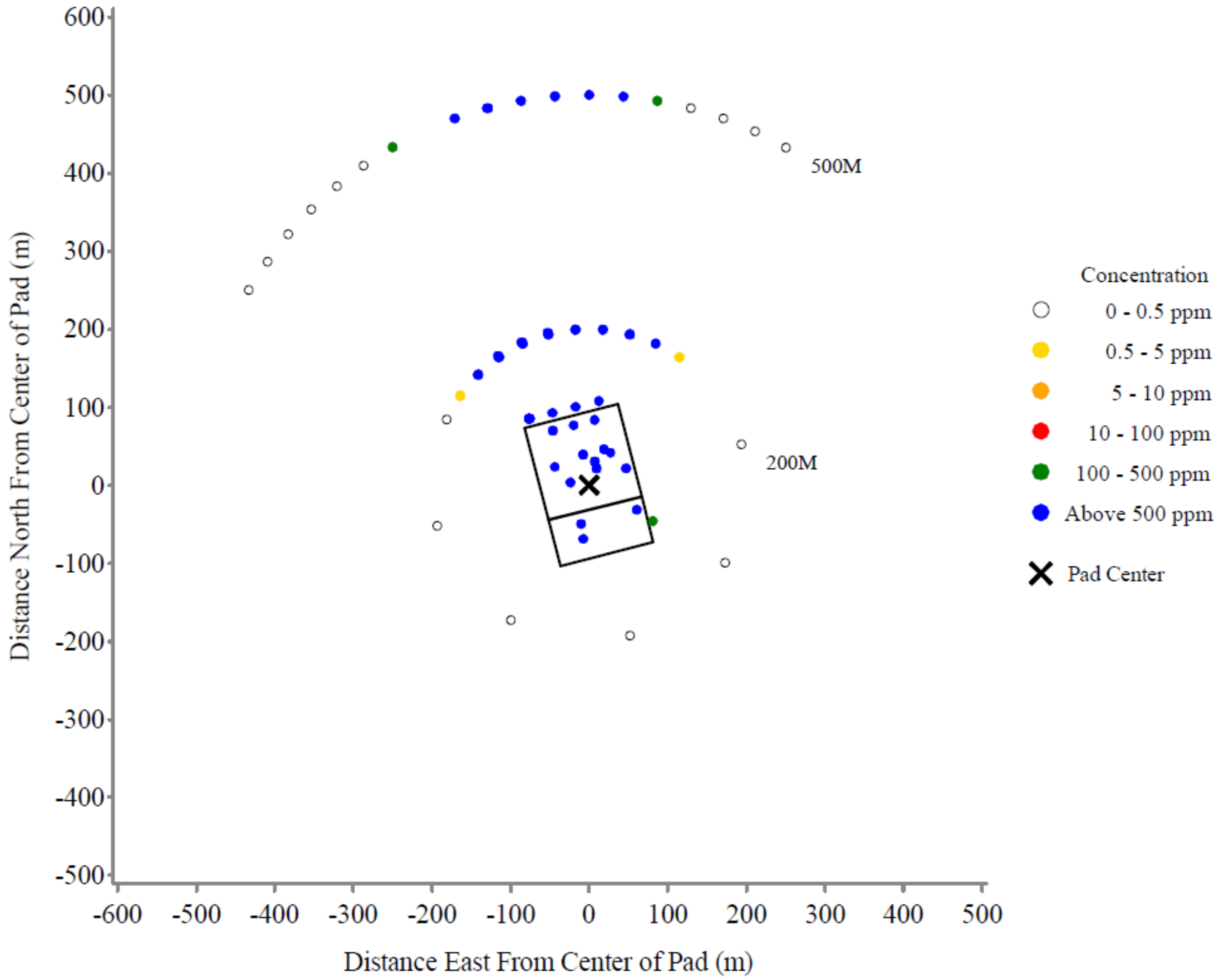
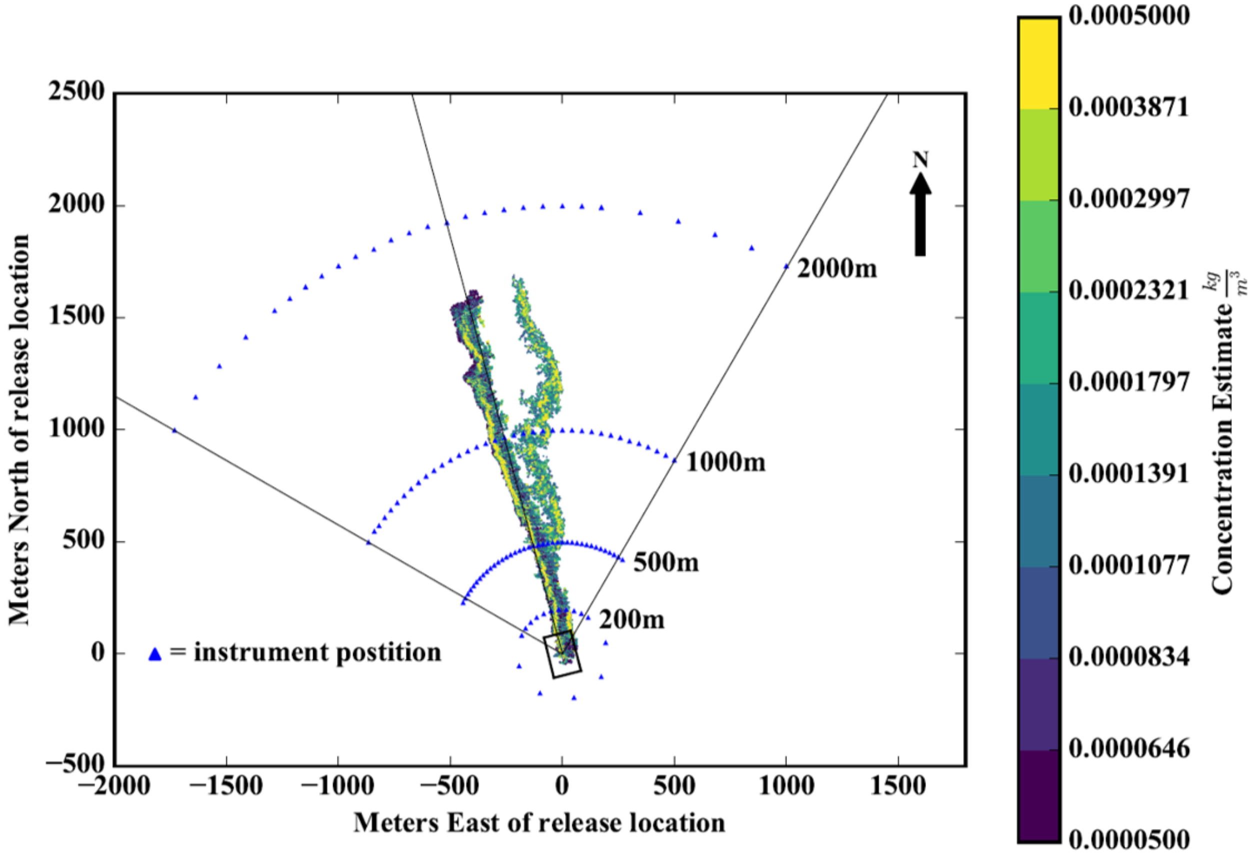


Figure D.4. Trial 2 Near Field Maximum Chlorine Concentrations; JRII.



NOTES: 1. Elapsed Time: T+00:05:24 to T+00:05:49.

2. This figure represents measurements taken of the east and west sides of the chlorine cloud and displays only the outline of the cloud. The UV LIDAR could not penetrate the entire cloud.

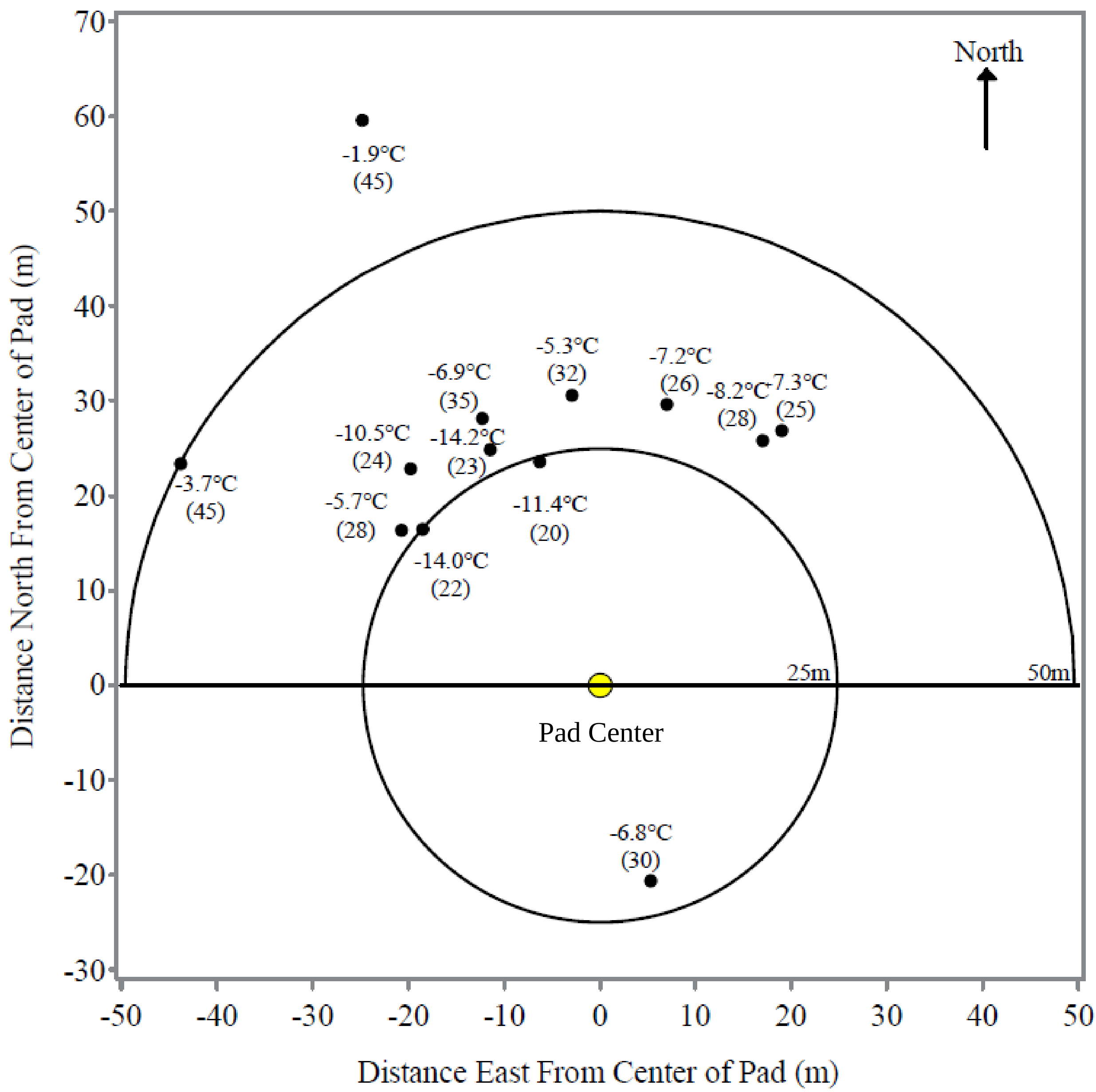
Figure D.5. Trial 2 Ultraviolet (UV) Light Detection and Ranging (LIDAR); JRII.

Figure D.6. Trial 2 Representative Photograph of Release; JRII.

APPENDIX E. TRIAL 3 TEST DATA

FIGURE LIST

FIGURE PAGE



NOTES: 1. Temperature shown is the maximum temperature drop during the trial.
2. Numbers in parenthesis are time to maximum temperature drop in seconds.
3. Only maximum temperature drops less than -0.5°C are shown.

Figure E.1. Trial 3 Meteorological (MET) Thermocouple Data at 60 cm (23.6 in) Height; JRII.

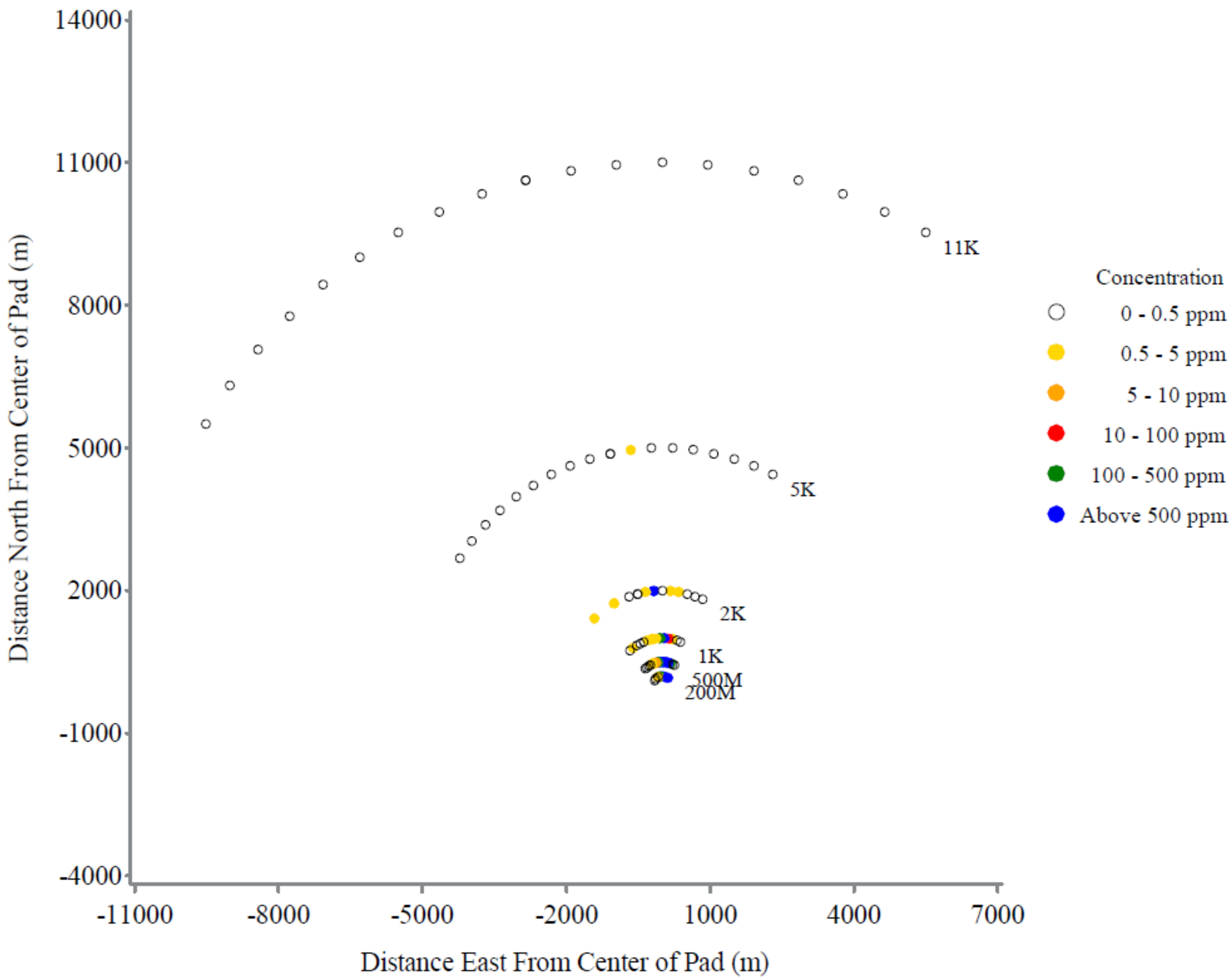


Figure E.2. Trial 3 Far Field Maximum Chlorine Concentrations; JRII.

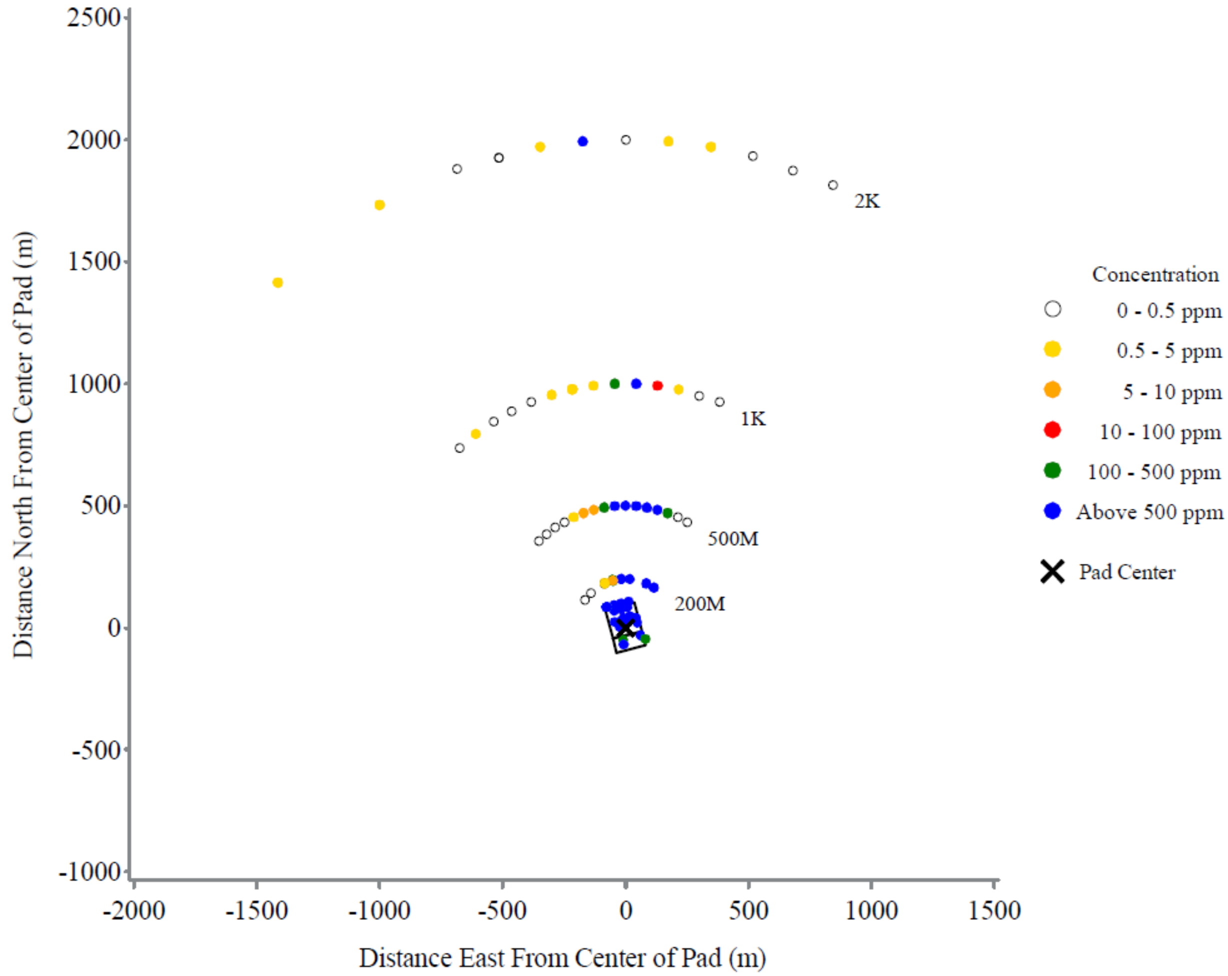
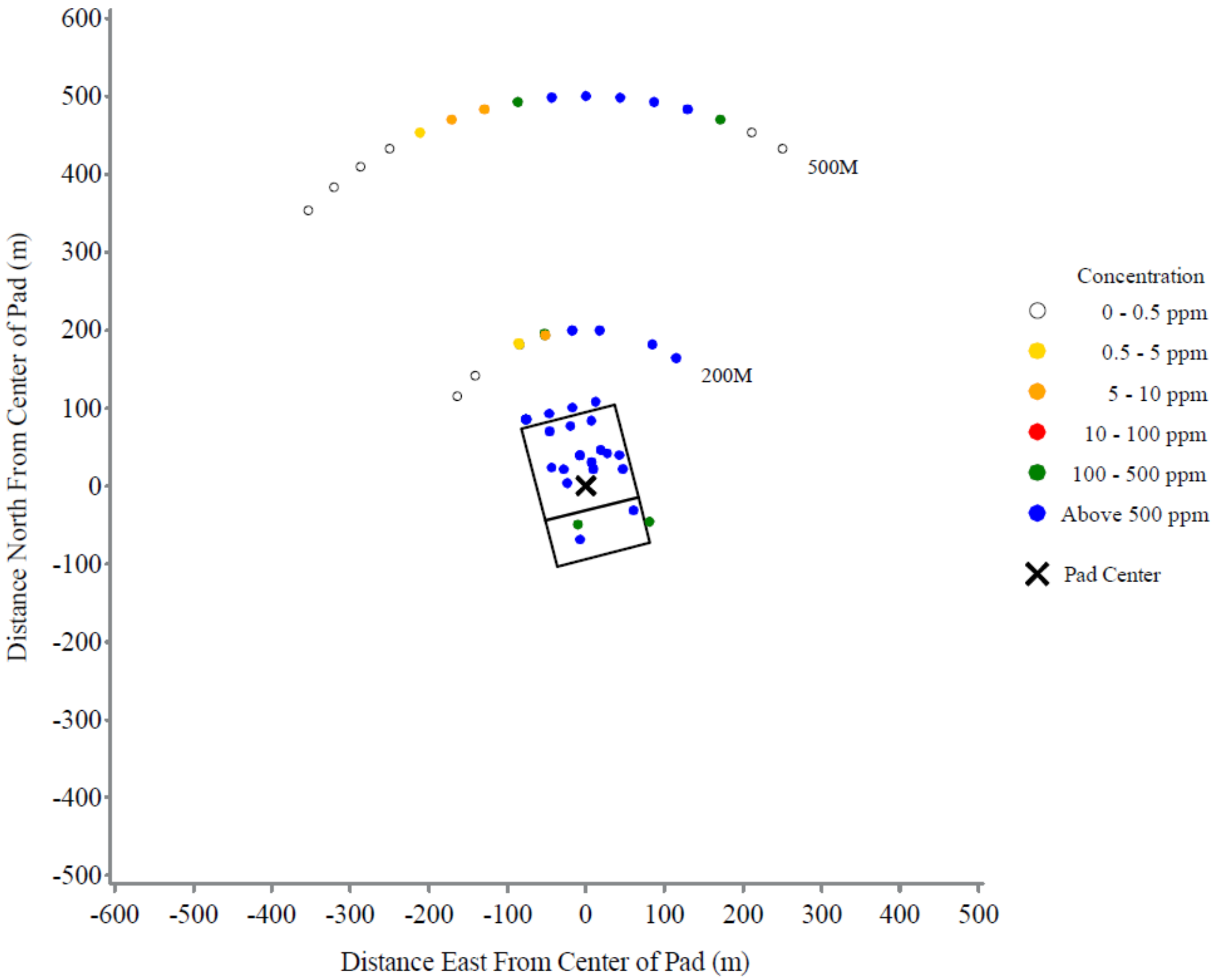


Figure E.3. Trial 3 Mid Field Maximum Chlorine Concentrations; JRII.



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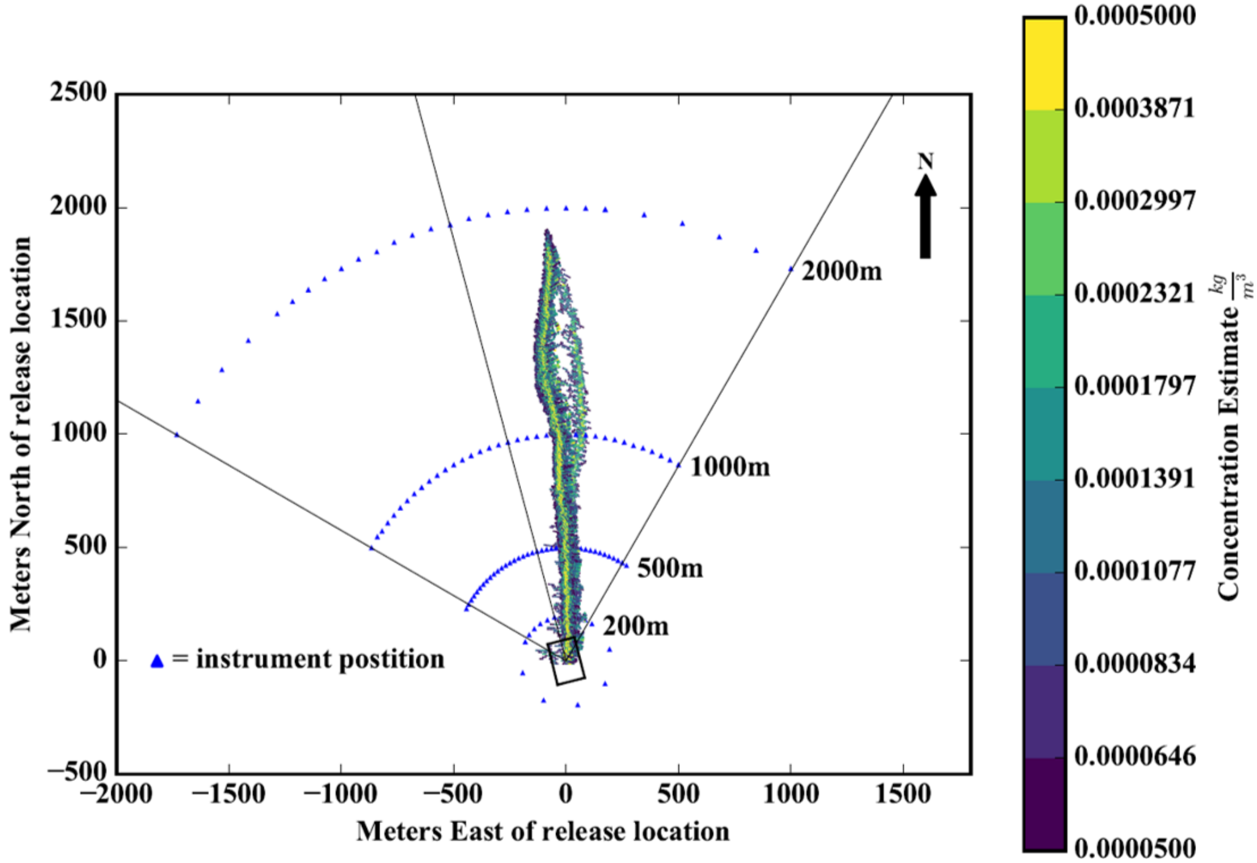


NOTES:
1. Elapsed Time: T+00:05:13 to T+00:05:27.
2. This figure represents measurements taken of the east and west sides of the chlorine cloud and displays only the outline of the cloud. The UV LIDAR could not penetrate the entire cloud.

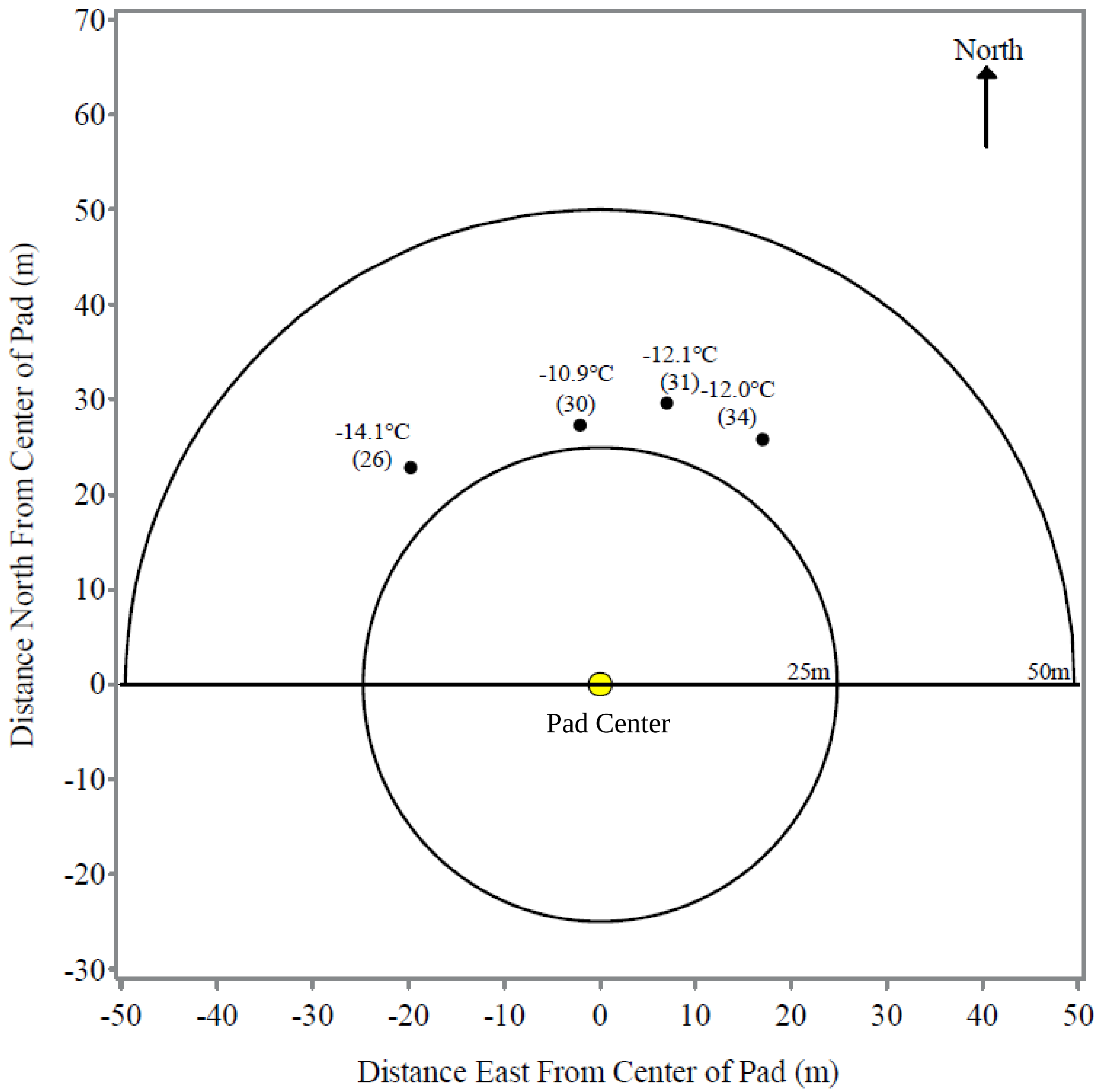
Figure E.5. Trial 3 Ultraviolet (UV) Light Detection and Ranging (LIDAR); JRII.

Figure E.6. Trial 3 Representative Photograph of Release; JRII.

APPENDIX F. TRIAL 4 TEST DATA

FIGURE LIST

FIGURE | PAGE



NOTES:
1. Temperature shown is the maximum temperature drop during the trial.
2. Numbers in parenthesis are time to maximum temperature drop in seconds.
3. Only maximum temperature drops less than -0.5°C are shown.

Figure F.1. Trial 4 Meteorological (MET) Thermocouple Data at 60cm (23.6 in) Height; JRII.

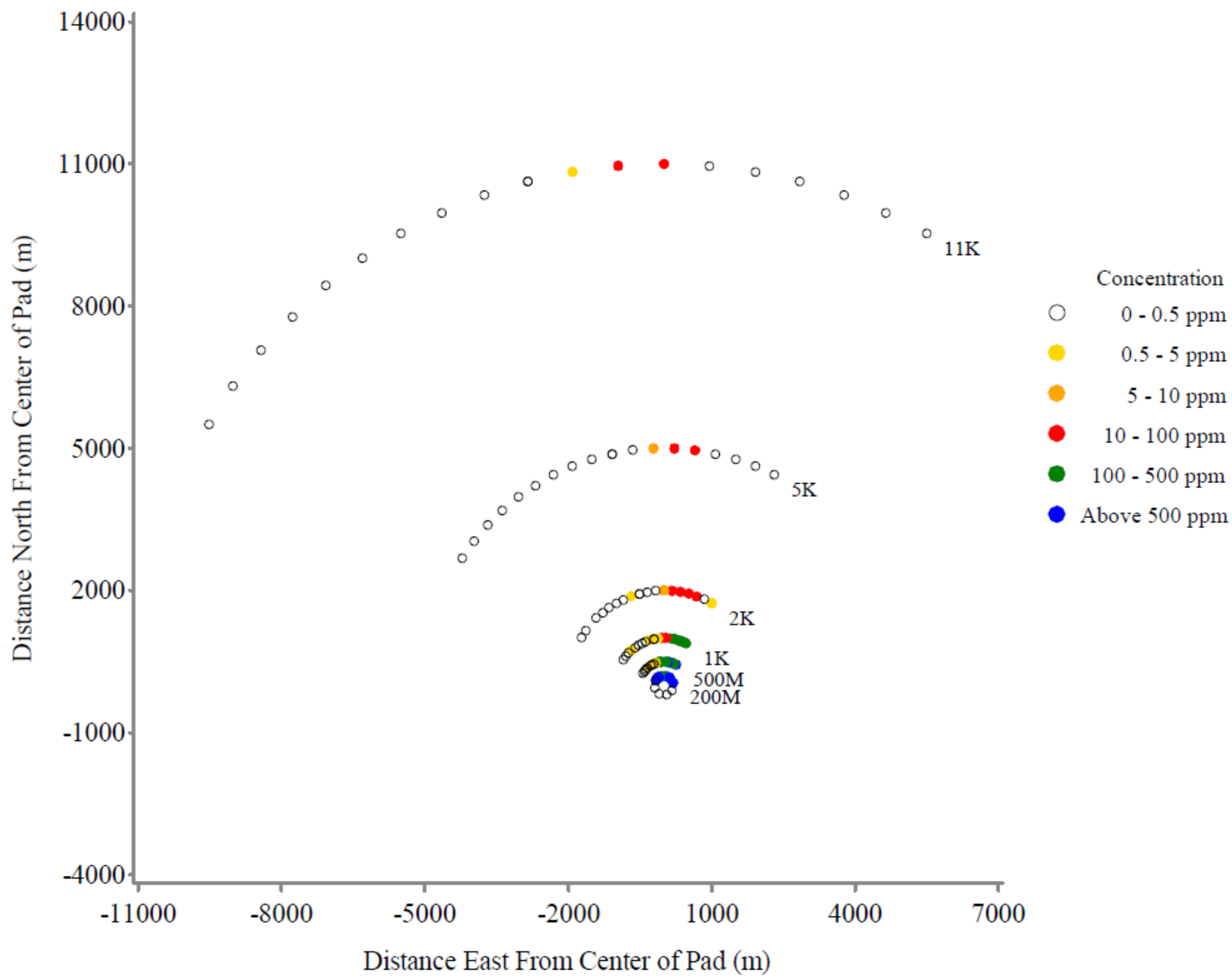
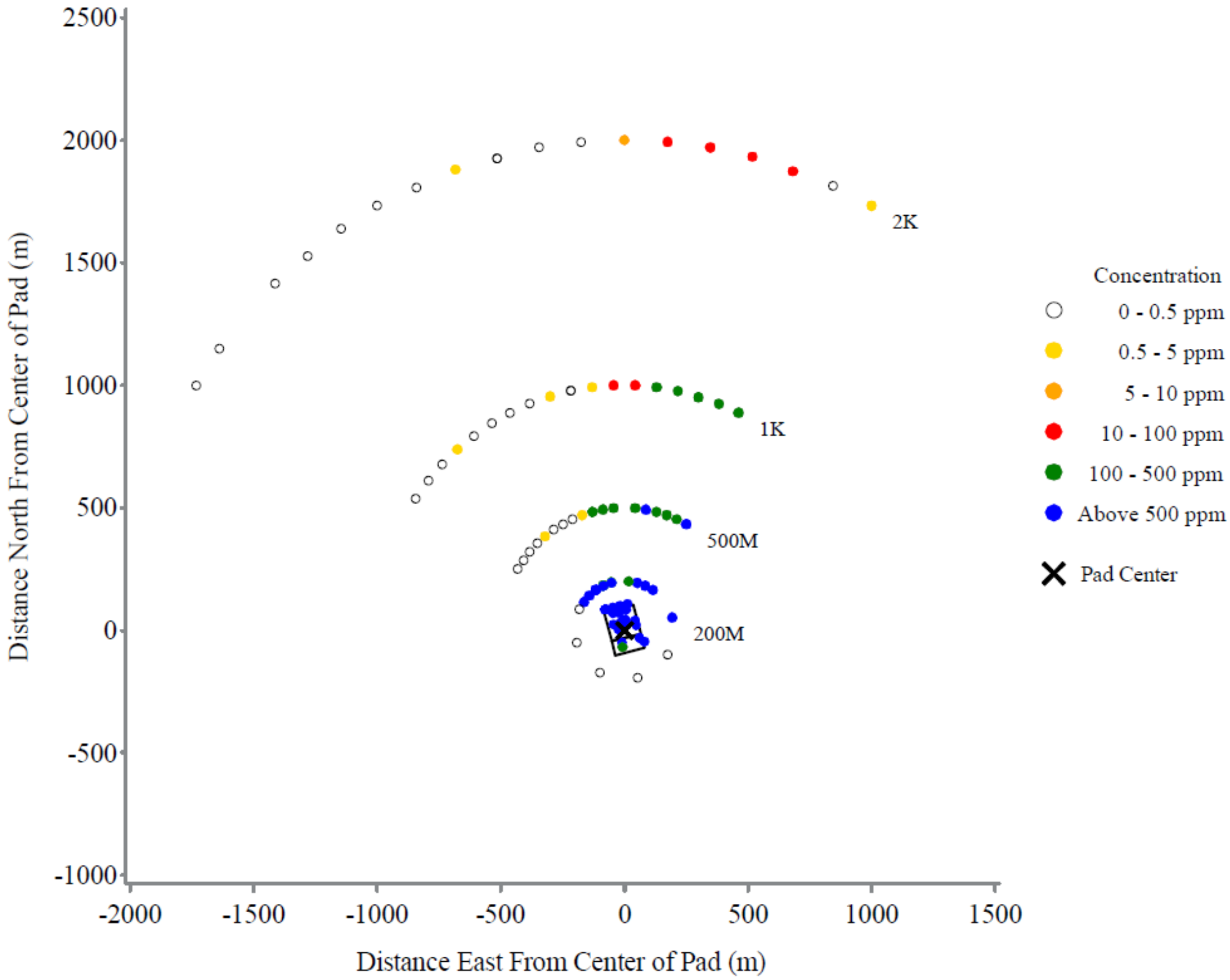


Figure F.2. Trial 4 Far Field Maximum Chlorine Concentrations; JRII.



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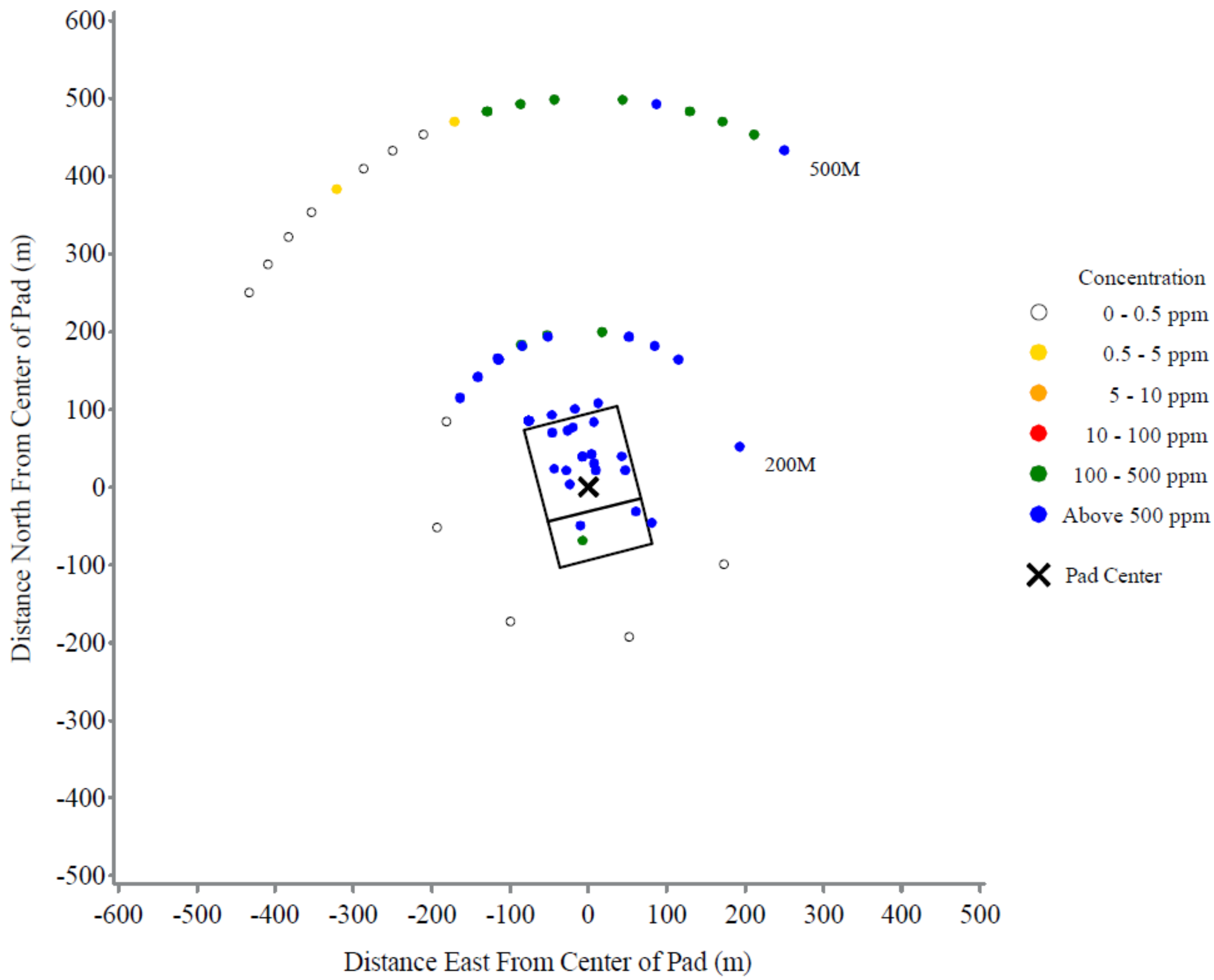
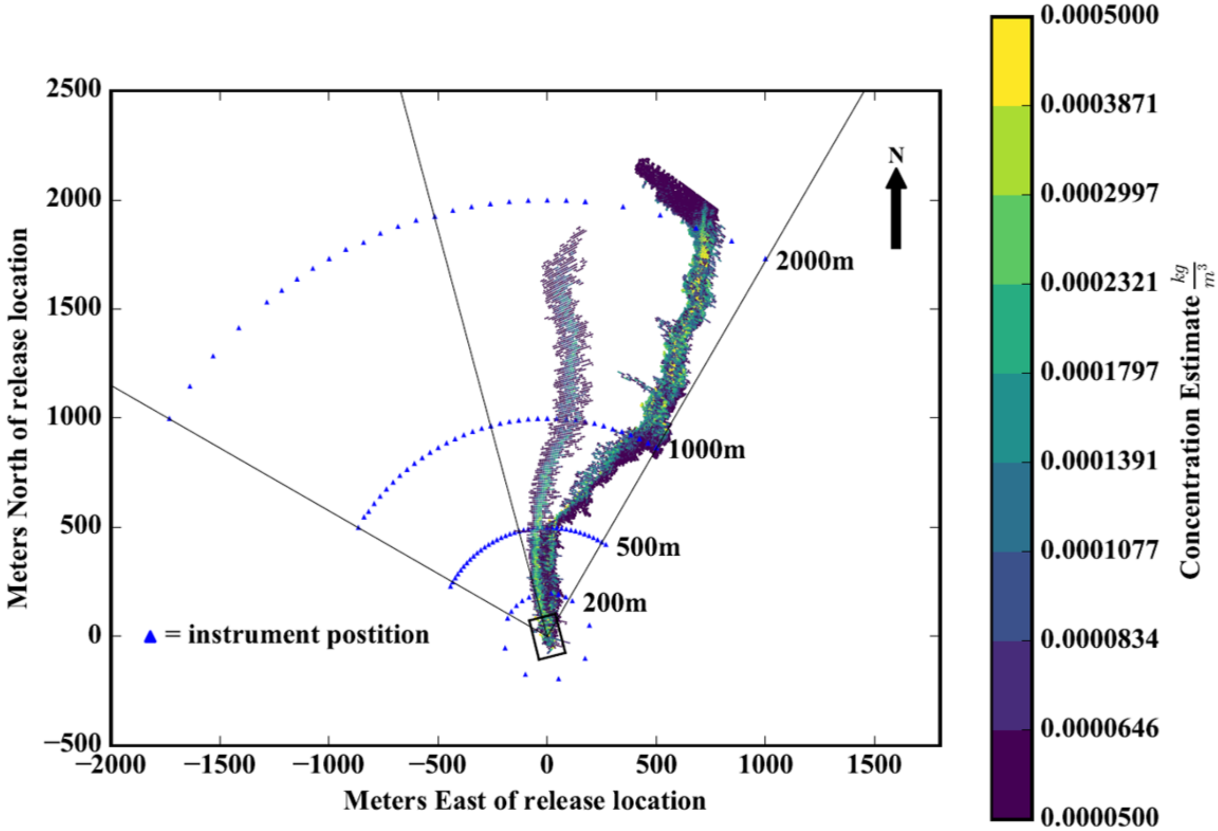


Figure F.4. Trial 4 Near Field Maximum Chlorine Concentrations; JRII.



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2. This figure represents measurements taken of the east and west sides of the chlorine cloud and displays only the outline of the cloud. The UV LIDAR could not penetrate the entire cloud.

Figure F.5. Trial 4 Ultraviolet (UV) Light Detection and Ranging (LIDAR); JRII.

Figure F.6. Trial 4 Representative Photograph of Release; JRII.

APPENDIX G. TRIAL 5 TEST DATA

FIGURE LIST

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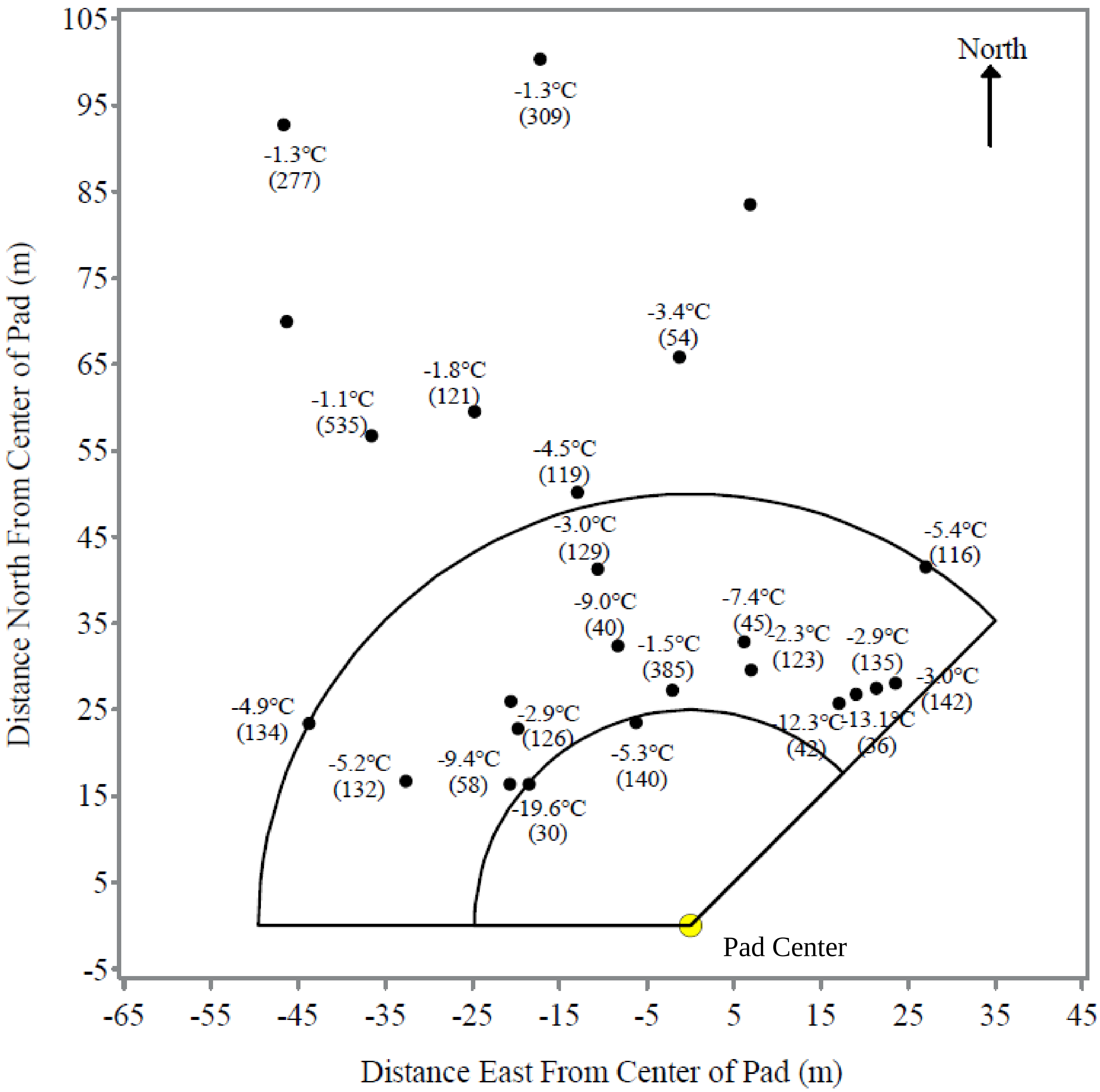


NOTES:
1. Temperature shown is the maximum temperature drop during the trial.
2. Numbers in parenthesis are time to maximum temperature drop in seconds.
3. Only maximum temperature drops less than -0.5°C are shown.

Figure G.1. Trial 5 Meteorological (MET) Thermocouple Data at 60 cm (23.6 in) Height; JRII.

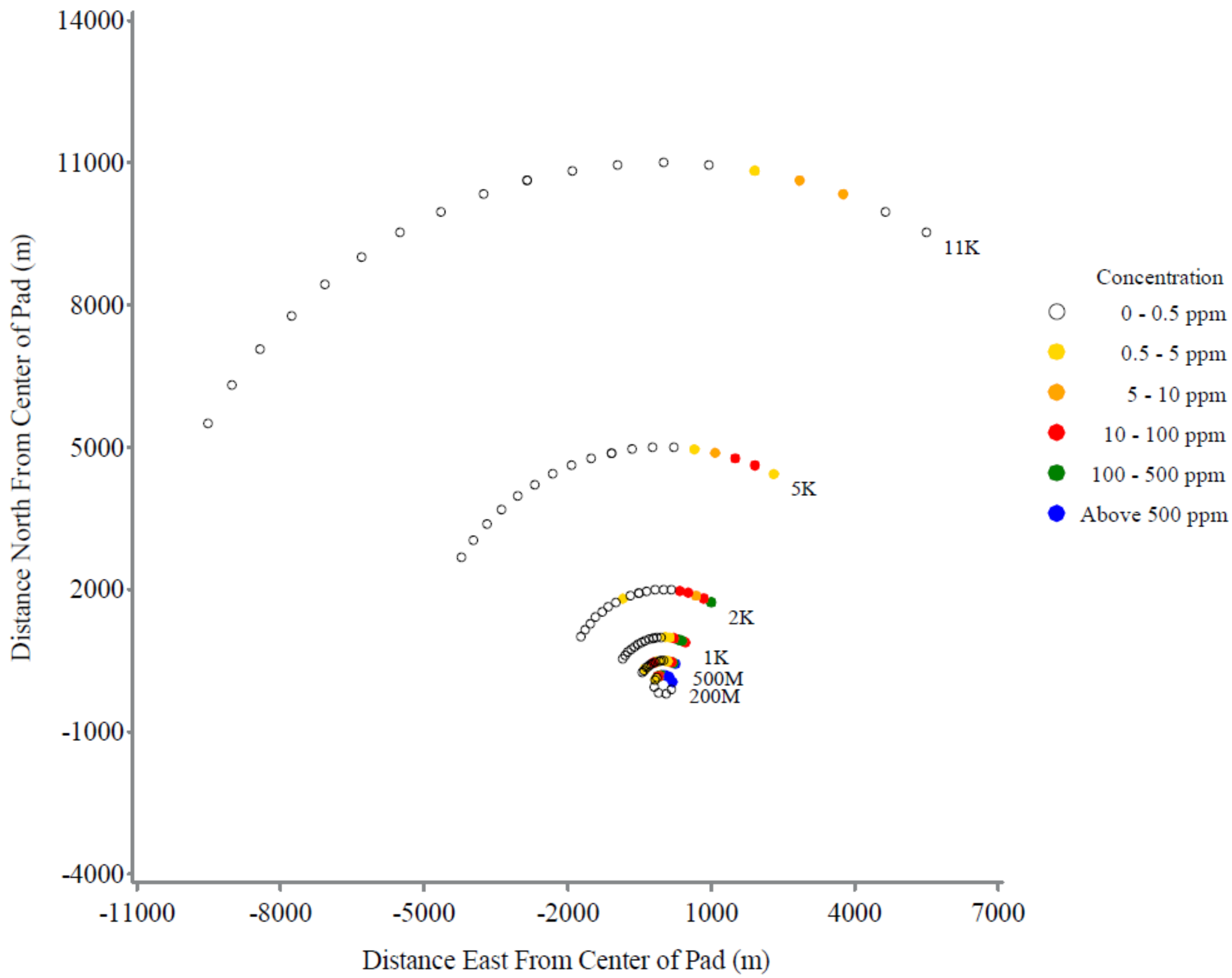


Figure G.2. Trial 5 Far Field Maximum Chlorine Concentrations; JRII.

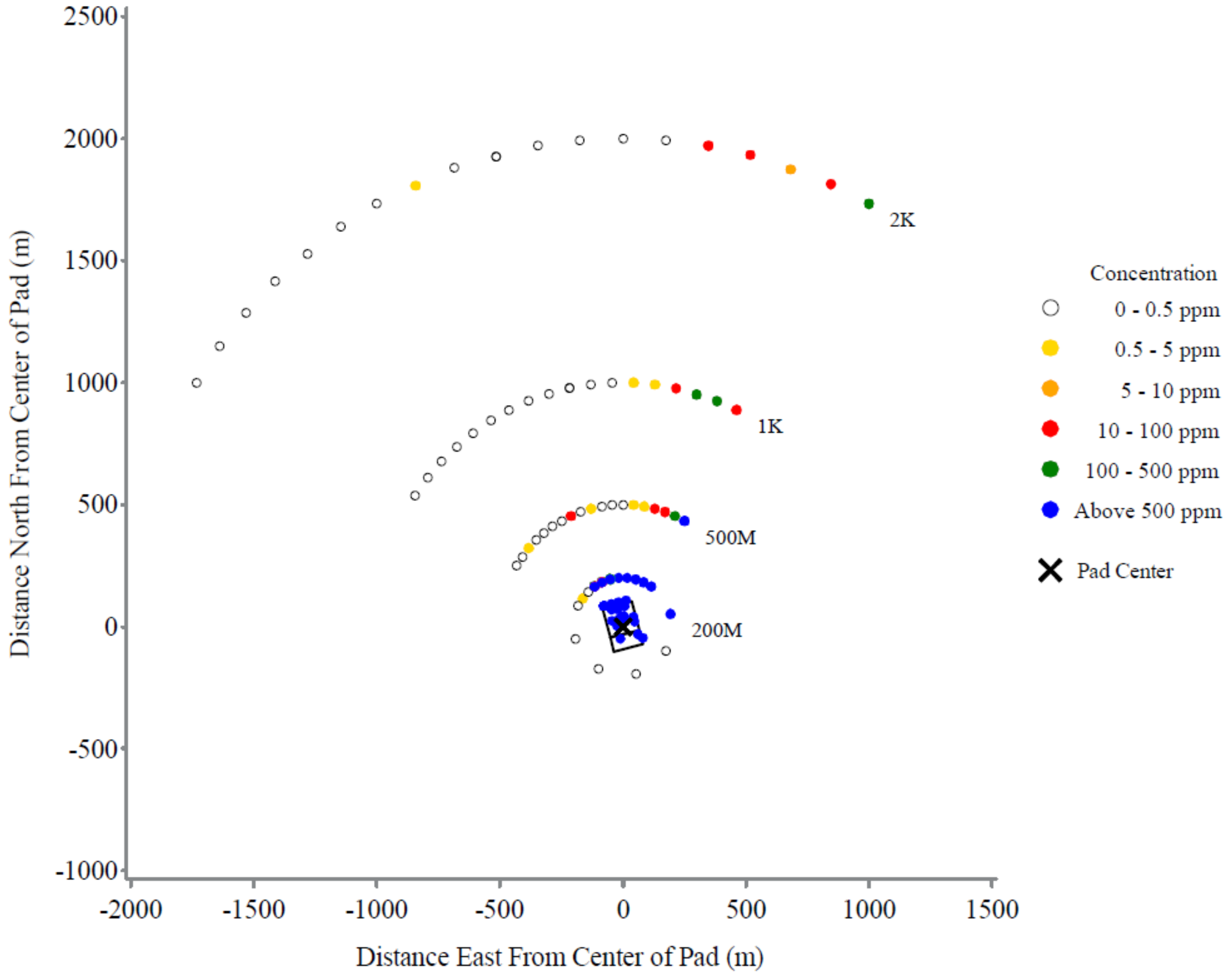
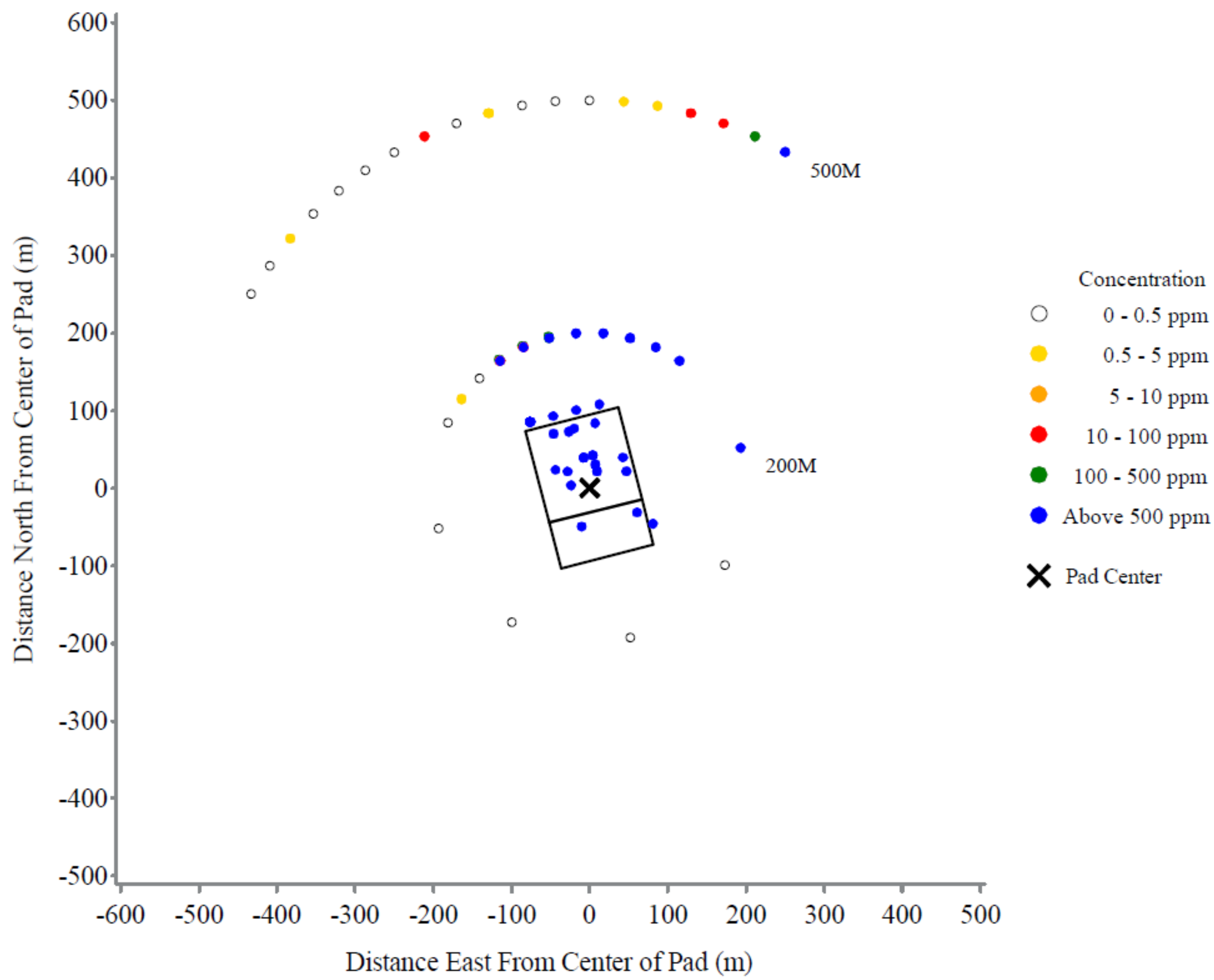


Figure G.3. Trial 5 Mid Field Maximum Chlorine Concentrations; JRII.



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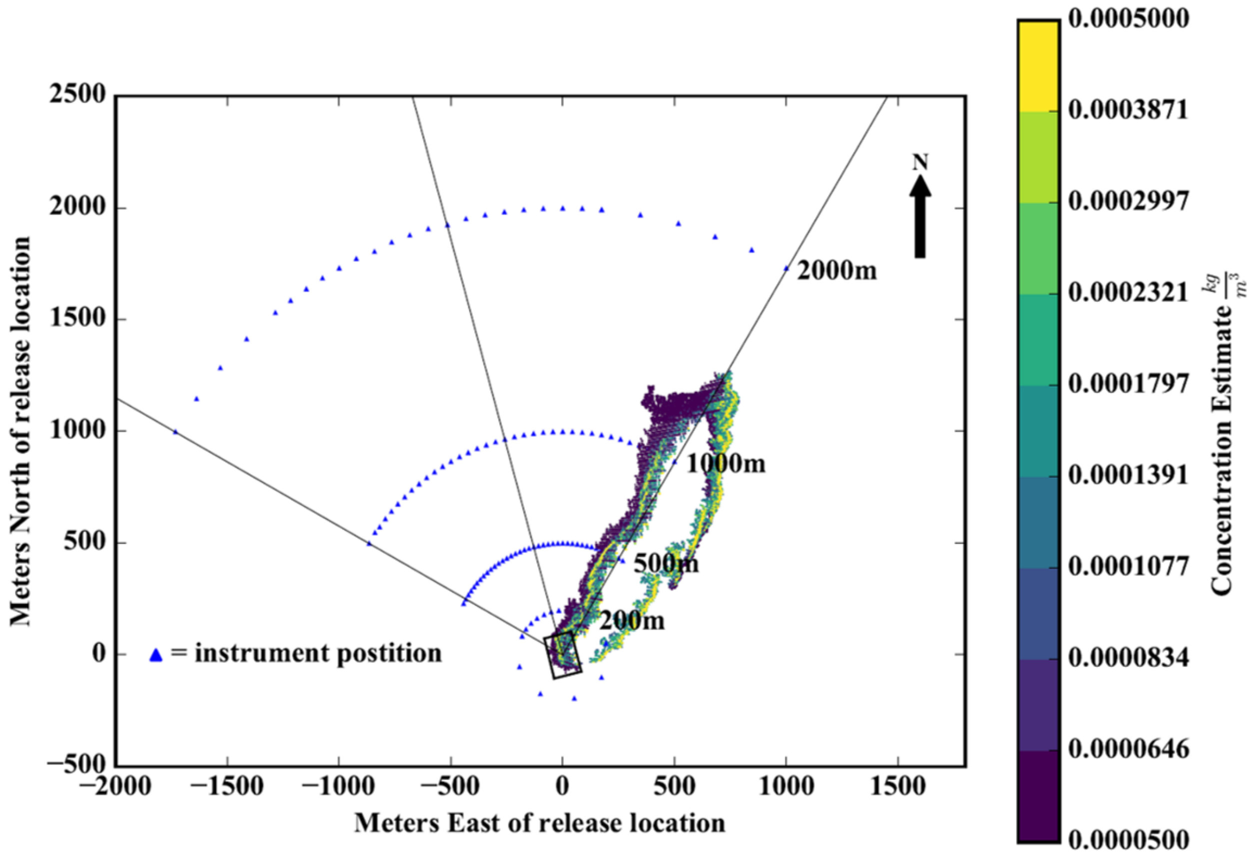


NOTES: 1. Elapsed Time: T+00:07:21 to T+00:07:36.
2. This figure represents measurements taken of the east and west sides of the chlorine cloud and displays only the outline of the cloud. The UV LIDAR could not penetrate the entire cloud.

Figure G.5. Trial 5 Ultraviolet (UV) Light Detection and Ranging (LIDAR); JRII.

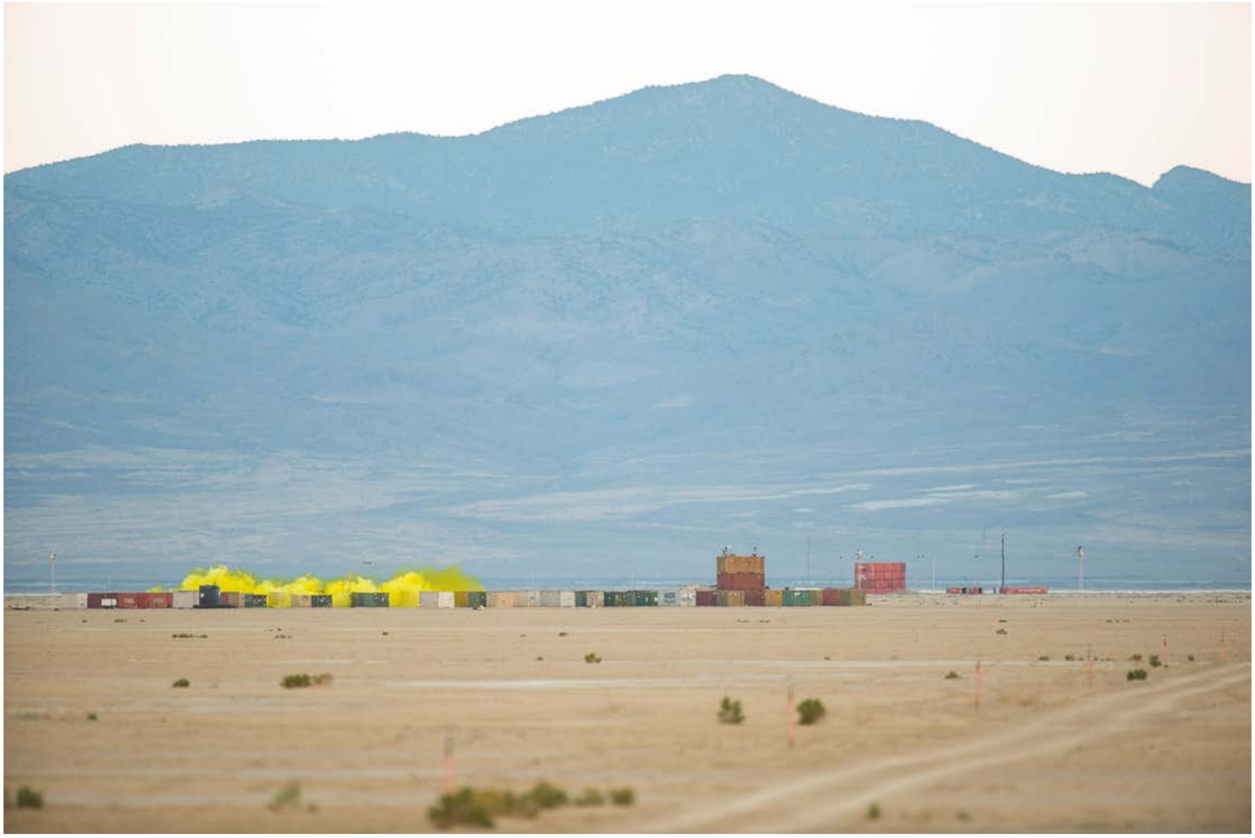
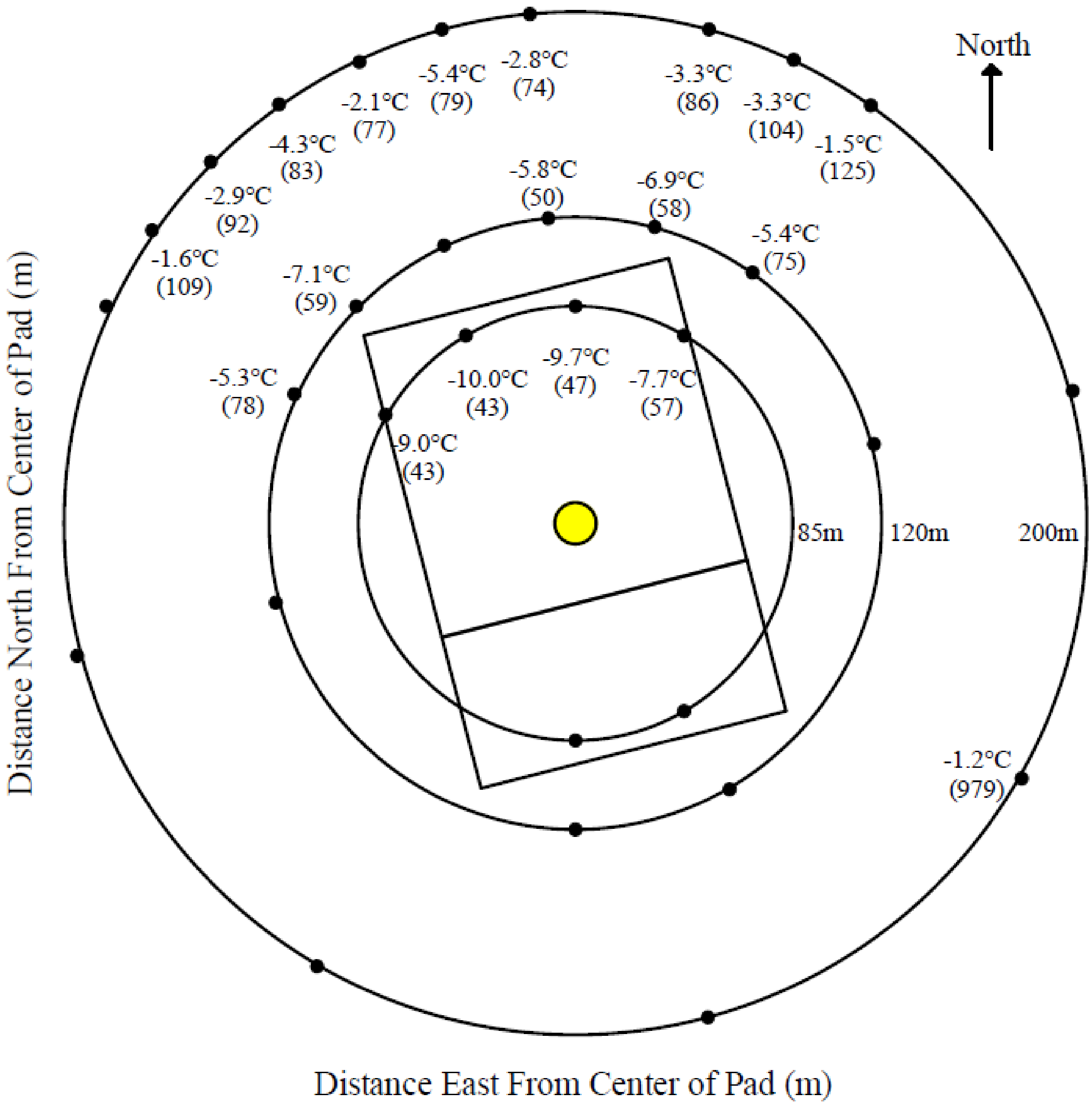


Figure G.6. Trial 5 Representative Photograph of Release; JRII.

APPENDIX H. TRIAL 6 TEST DATA

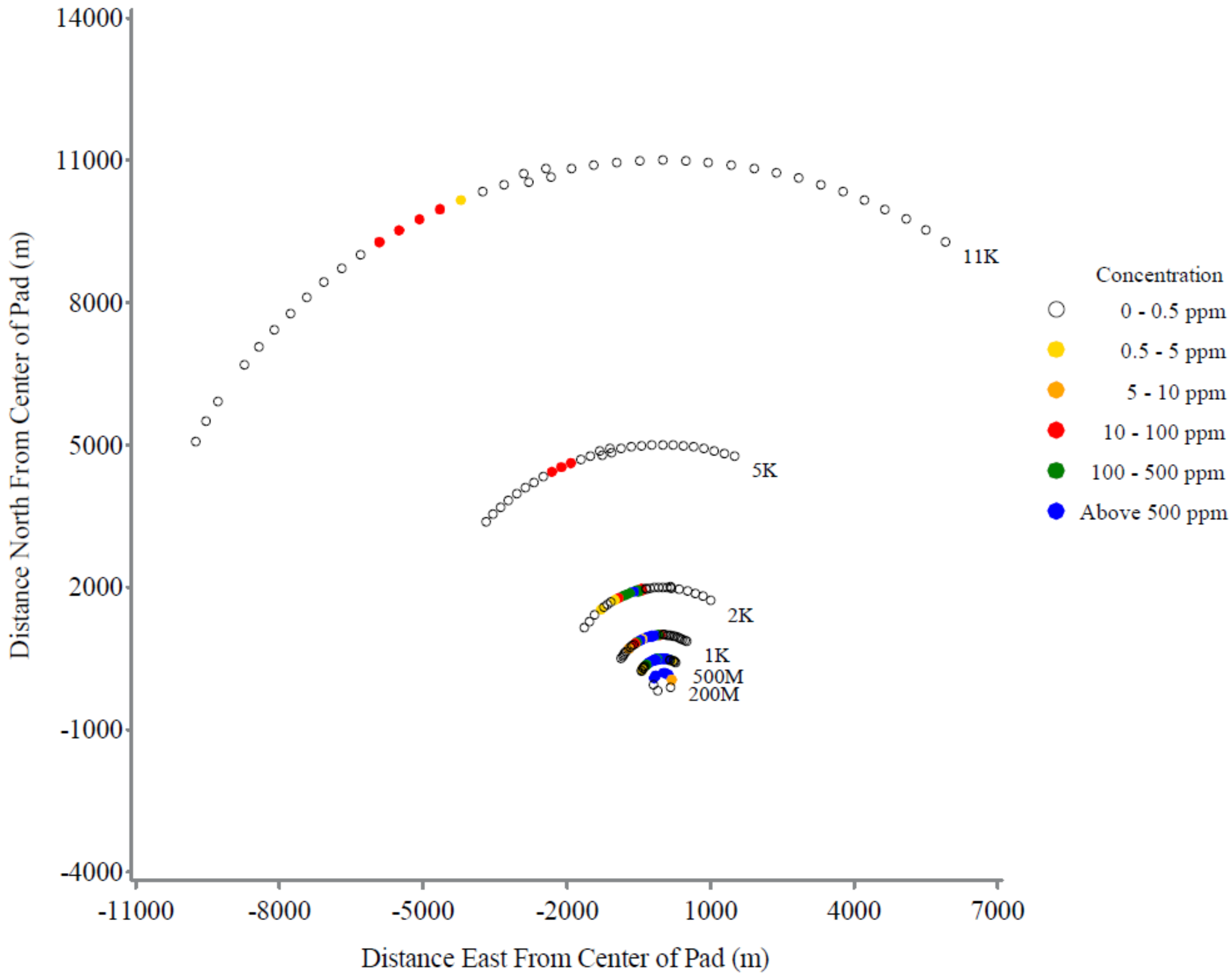
FIGURE LIST

FIGURE PAGE



NOTES: 1. Temperature shown is the maximum temperature drop during the trial.
2. Numbers in parenthesis are time to maximum temperature drop in seconds.
3. Only maximum temperature drops less than -0.5°C are shown.

Figure H.1. Trial 6 Meteorological (MET) Thermocouple Data at 60 cm (23.6 in) height; JRII.



NOTE: Duplicate points represent collocated instruments.

Figure H.2. Trial 6 Far Field Maximum Chlorine Concentrations; JRII.

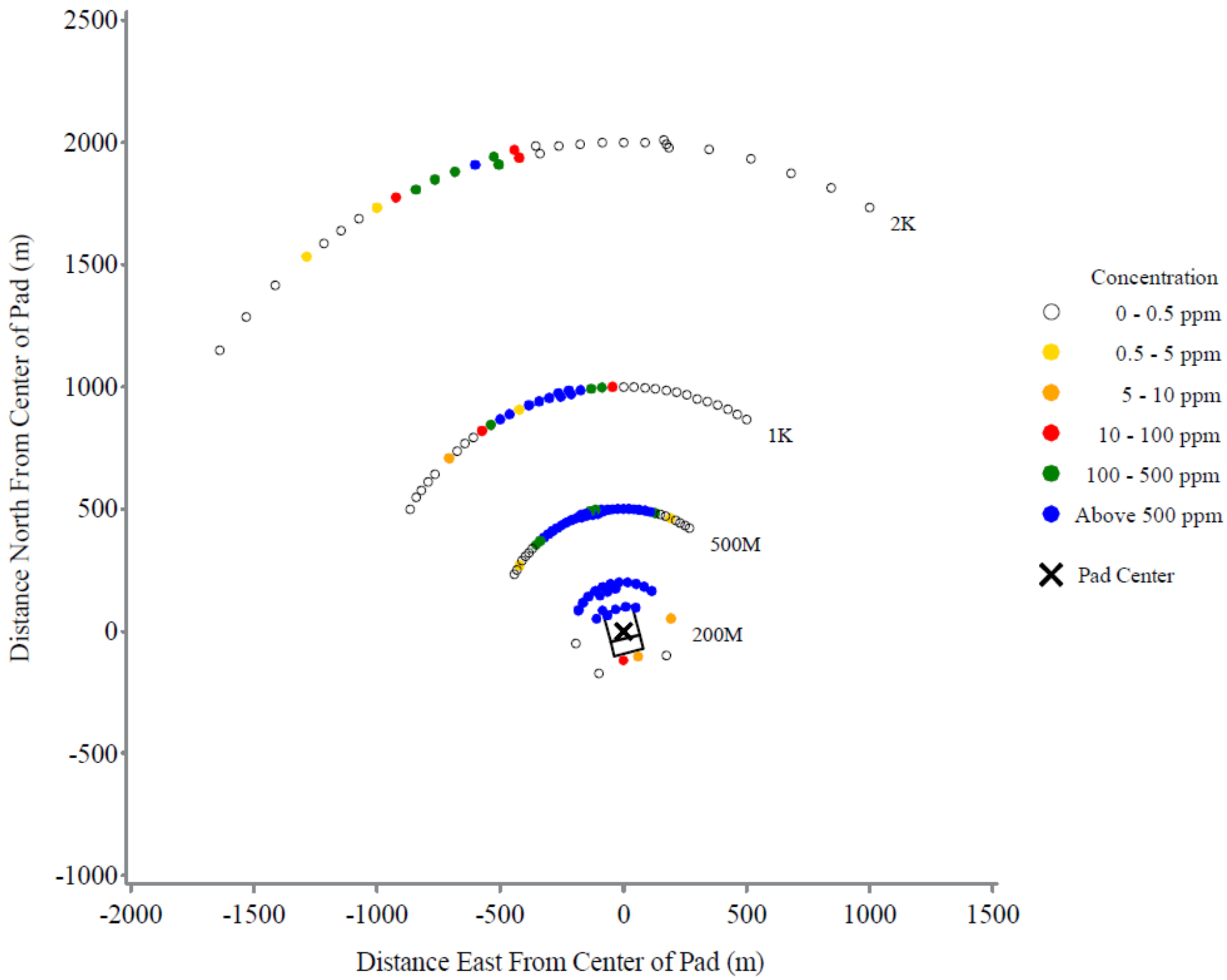


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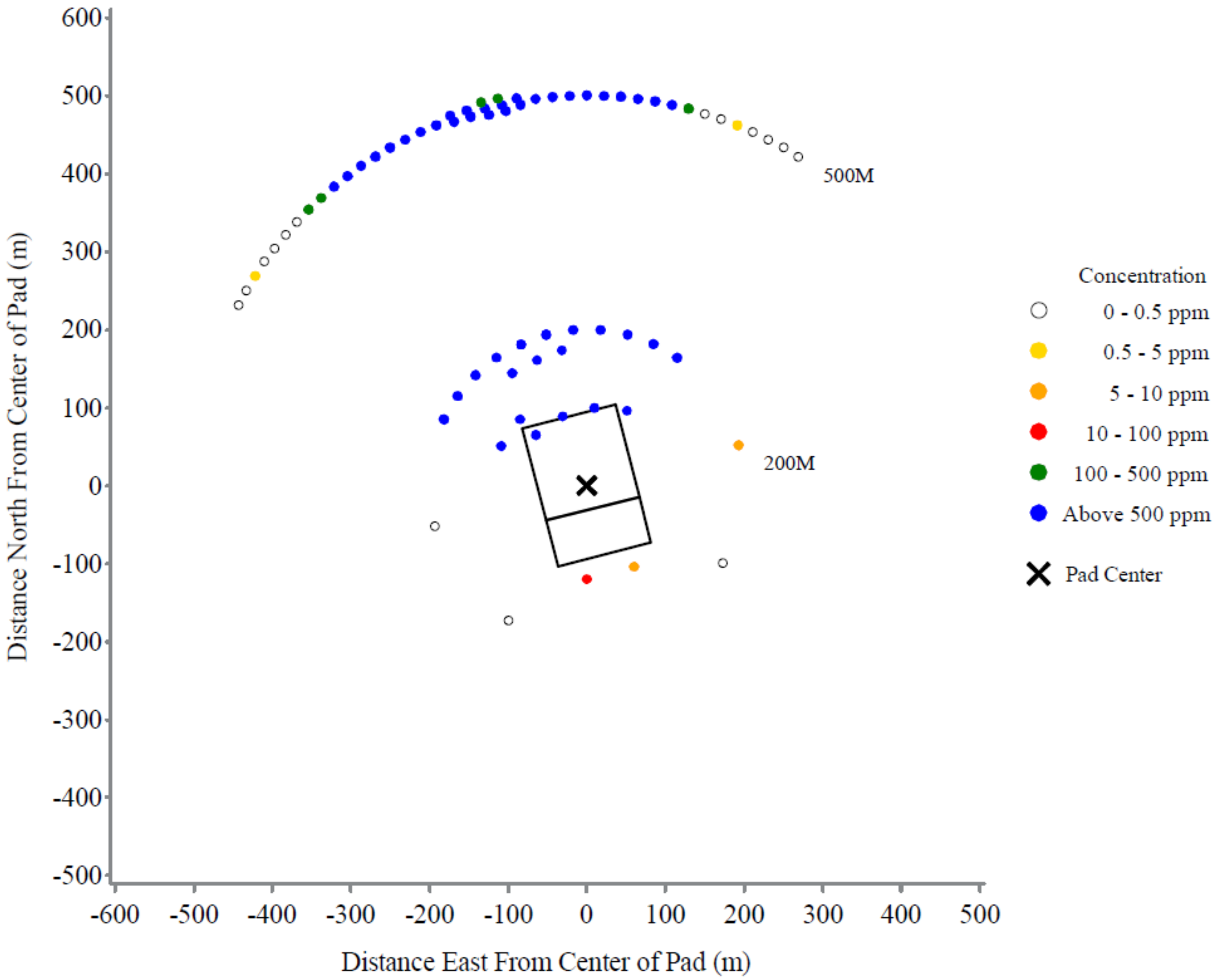
Figure H.3. Trial 6 Mid Field Maximum Chlorine Concentrations; JRII.



NOTE: Duplicate points represent collocated instruments.

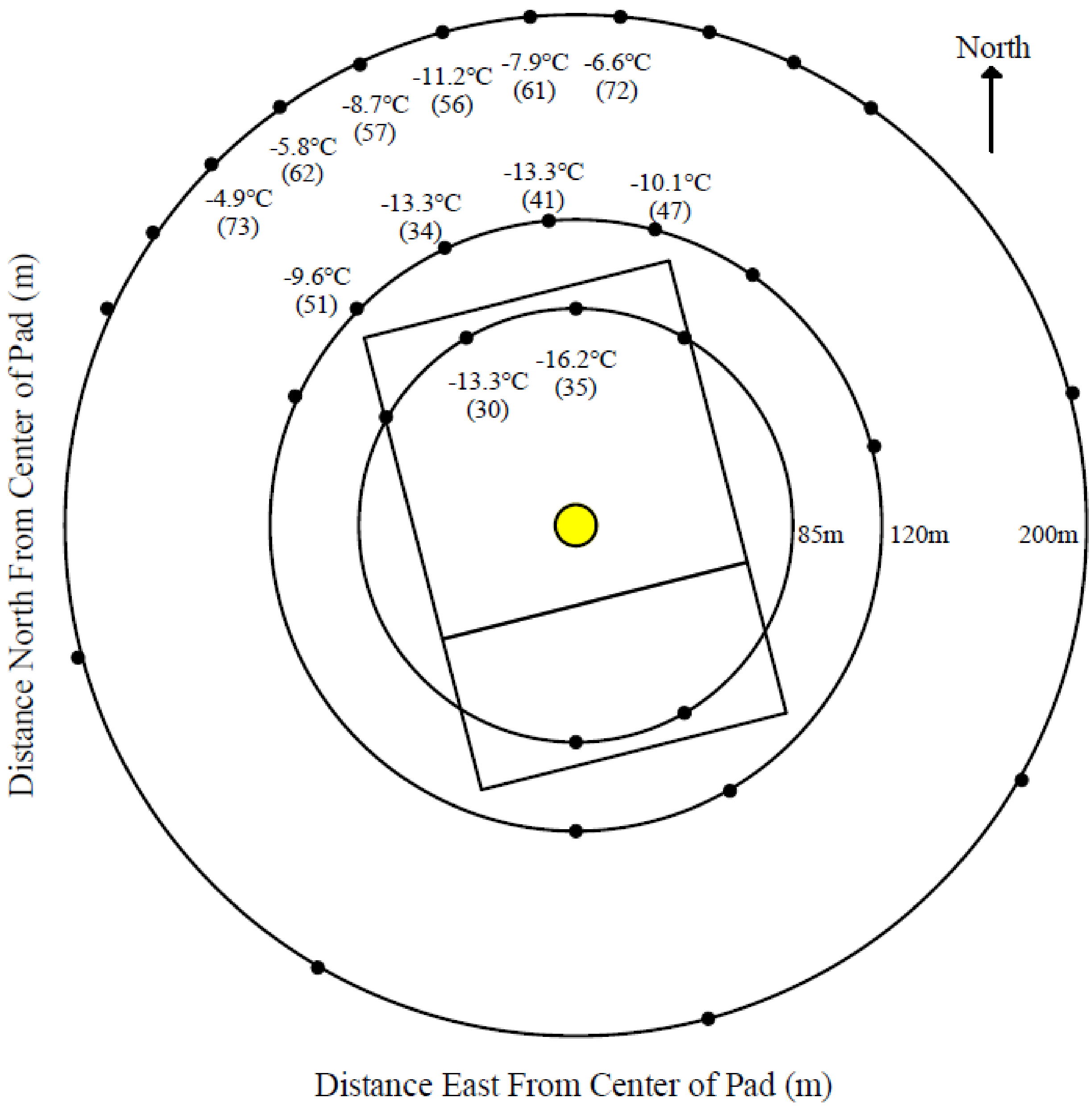
Figure H.4. Trial 6 Near Field Maximum Chlorine Concentrations; JRII.

Figure H.5. Trial 6 Representative Photograph of Release; JRII.

APPENDIX I. TRIAL 7 TEST DATA

FIGURE LIST

FIGURE | PAGE



NOTES:
1. Temperature shown is the maximum temperature drop during the trial.
2. Numbers in parenthesis are time to maximum temperature drop in seconds.
3. Only maximum temperature drops less than -0.5°C are shown.

Figure I.1. Trial 7 Meteorological (MET) Thermocouple Data at 60 cm (23.6 in) height; JRII.

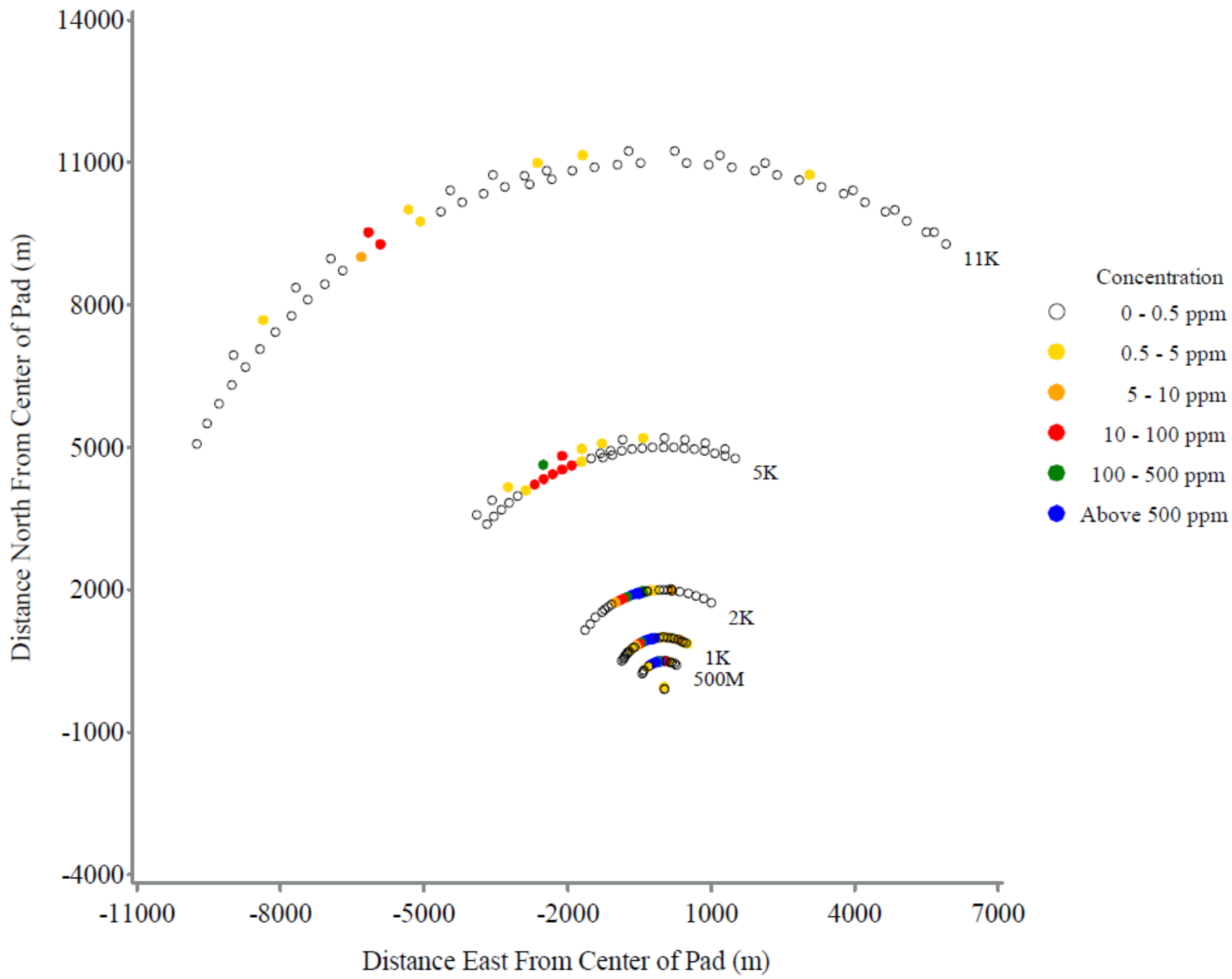


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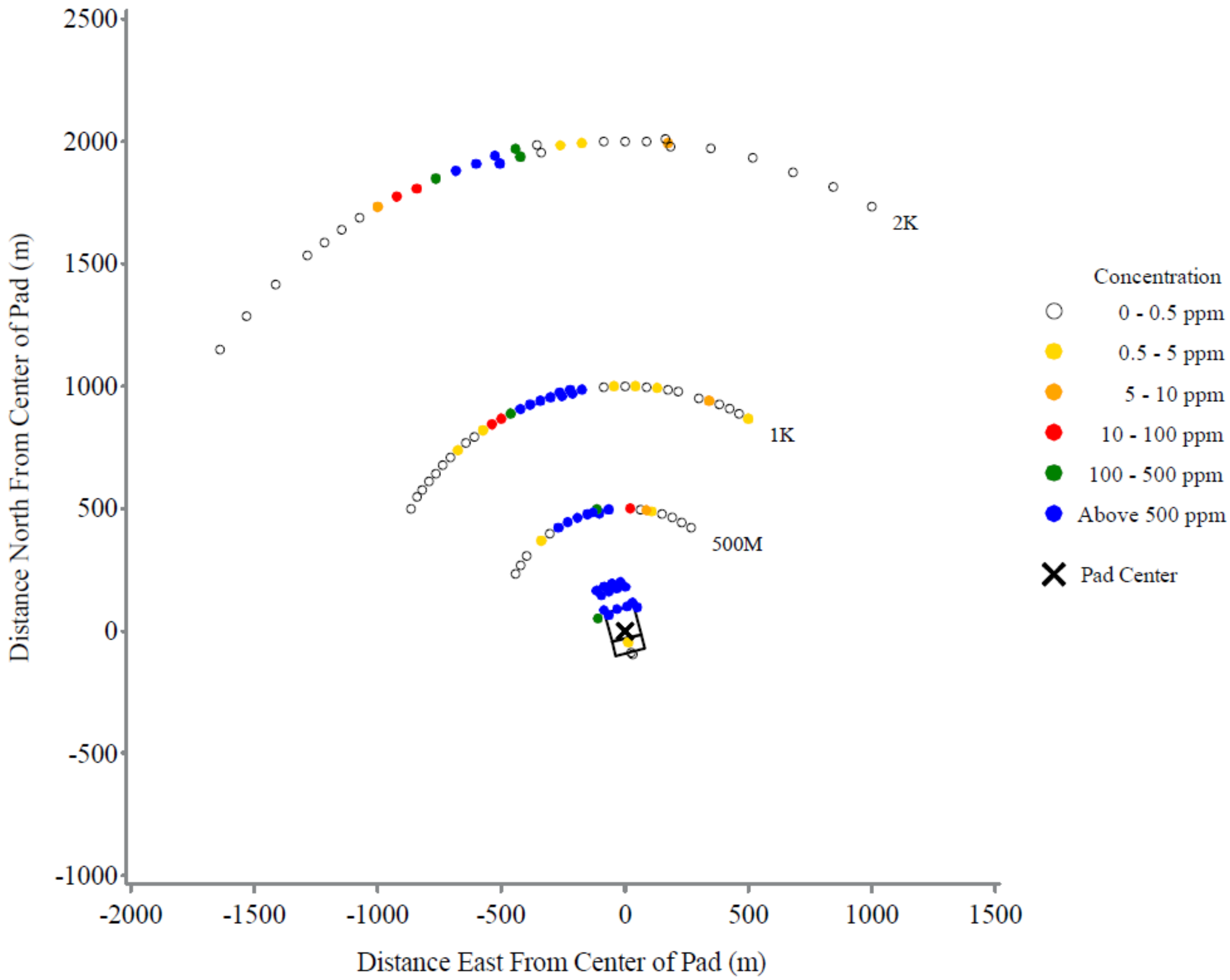
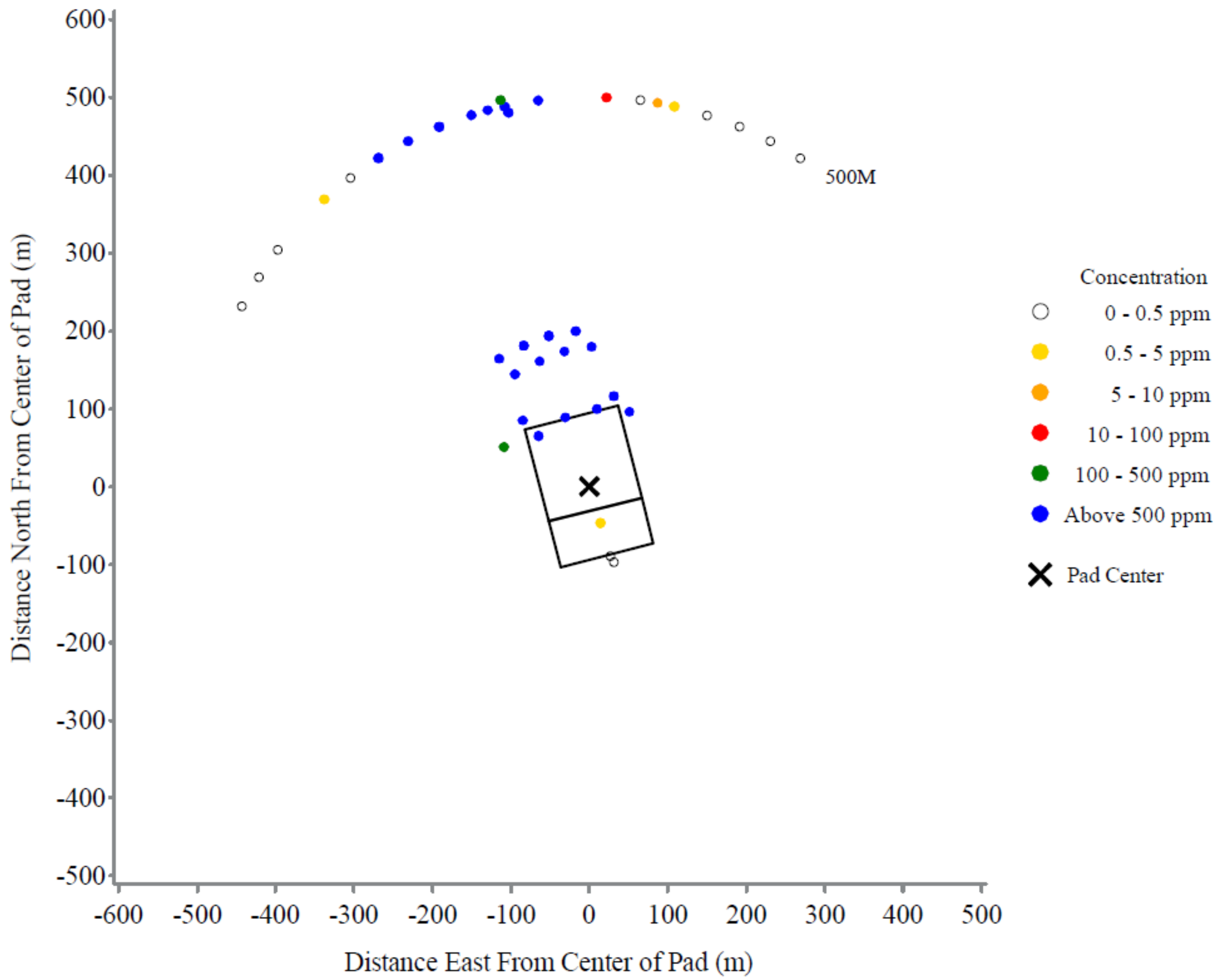
Figure I.2. Trial 7 Far Field Maximum Chlorine Concentrations; JRII.



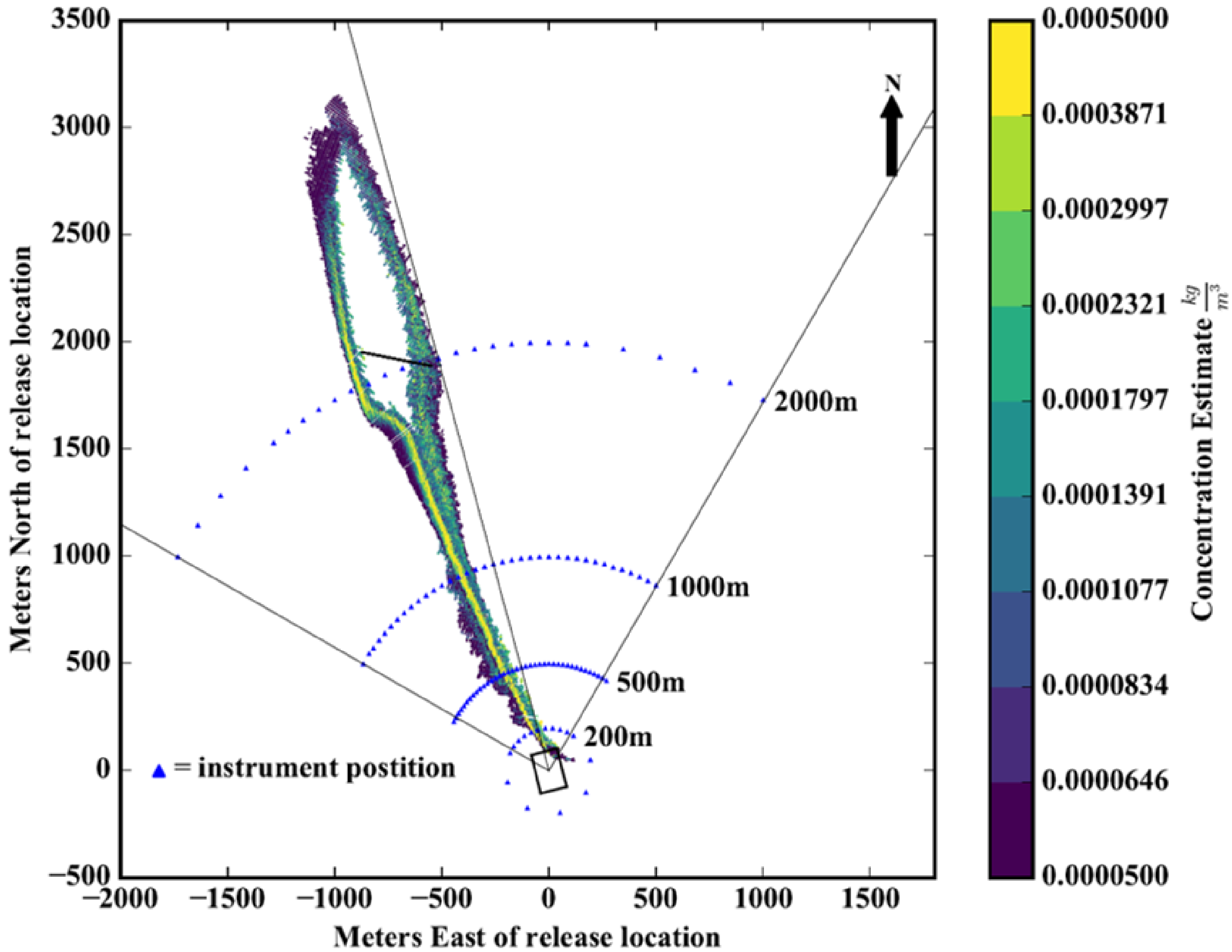
NOTE: Duplicate points represent collocated instruments.

Figure I.3. Trial 7 Mid Field Maximum Chlorine Concentrations; JRII.



NOTE: Duplicate points represent collocated instruments.

Figure I.4. Trial 7 Near Field Maximum Chlorine Concentrations; JRII.



NOTES: 1. Elapsed Time: T+00:07:32 to T+00:07:55.

2. This figure represents measurements taken of the east and west sides of the chlorine cloud and displays only the outline of the cloud. The UV LIDAR could not penetrate the entire cloud.

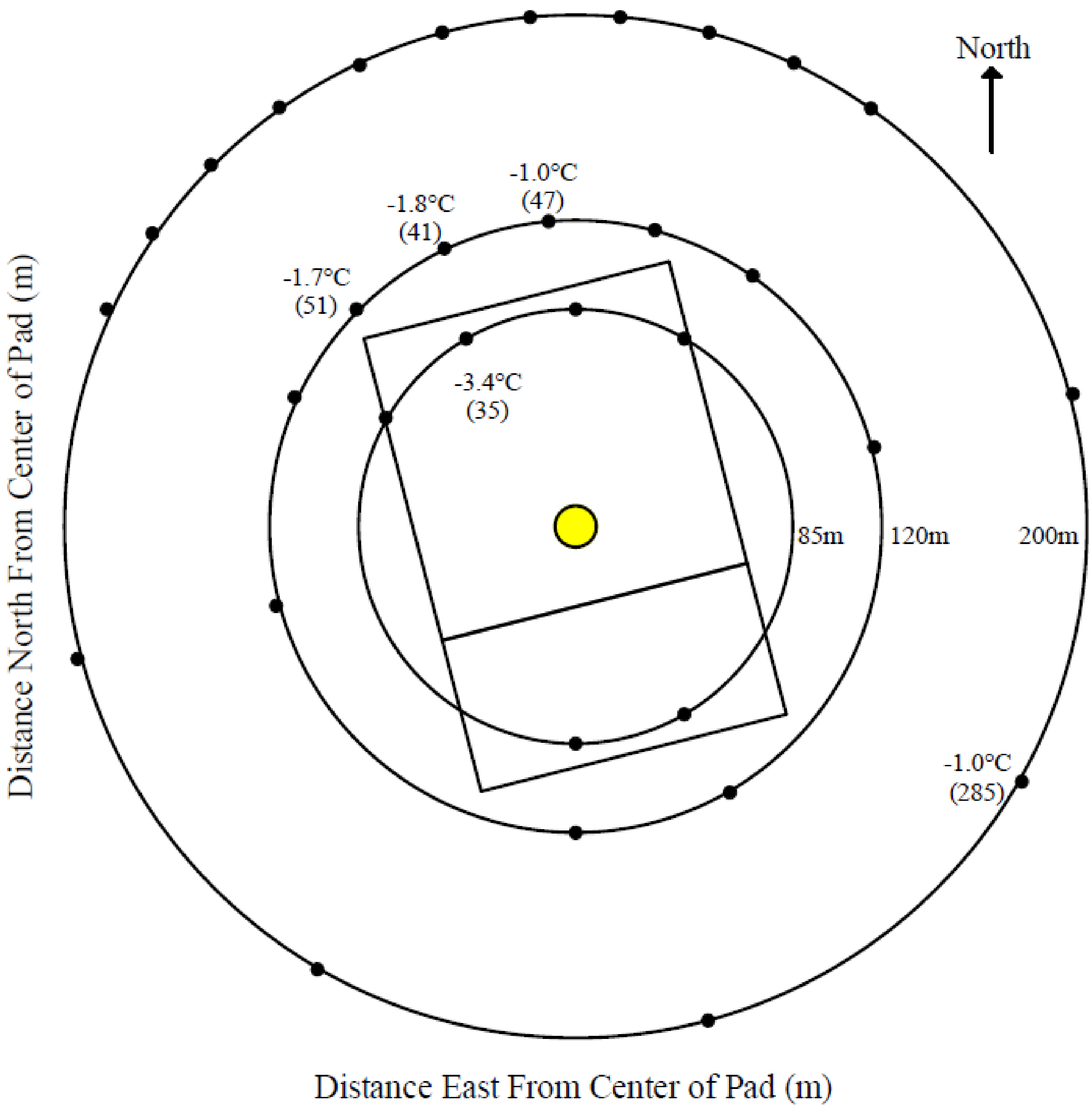
Figure I.5. Trial 7 Ultraviolet (UV) Light Detection and Ranging (LIDAR); JRII.

Figure I.6. Trial 7 Representative Photograph of Release; JRII.

APPENDIX J. TRIAL 8 TEST DATA

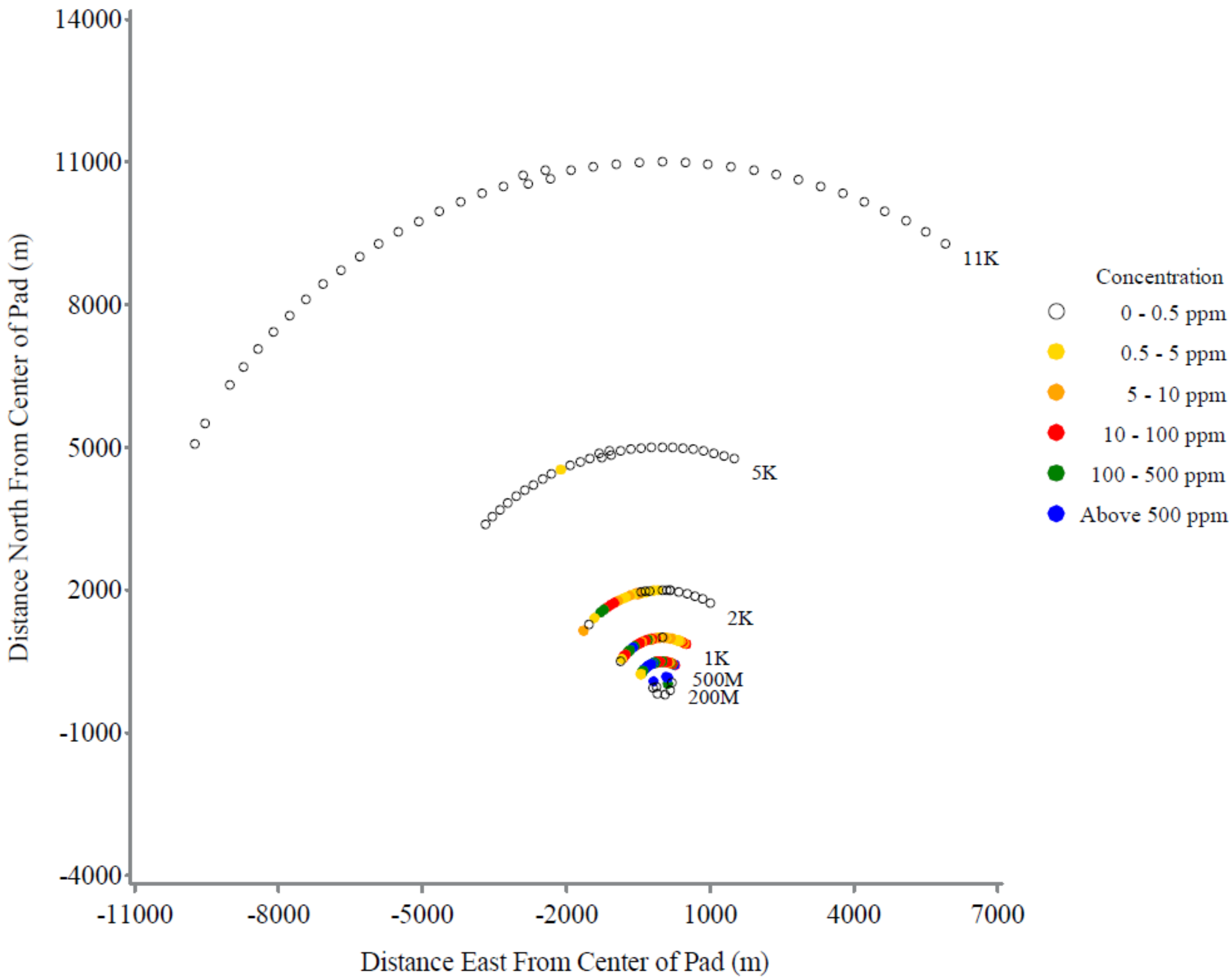
FIGURE LIST

FIGURE | PAGE



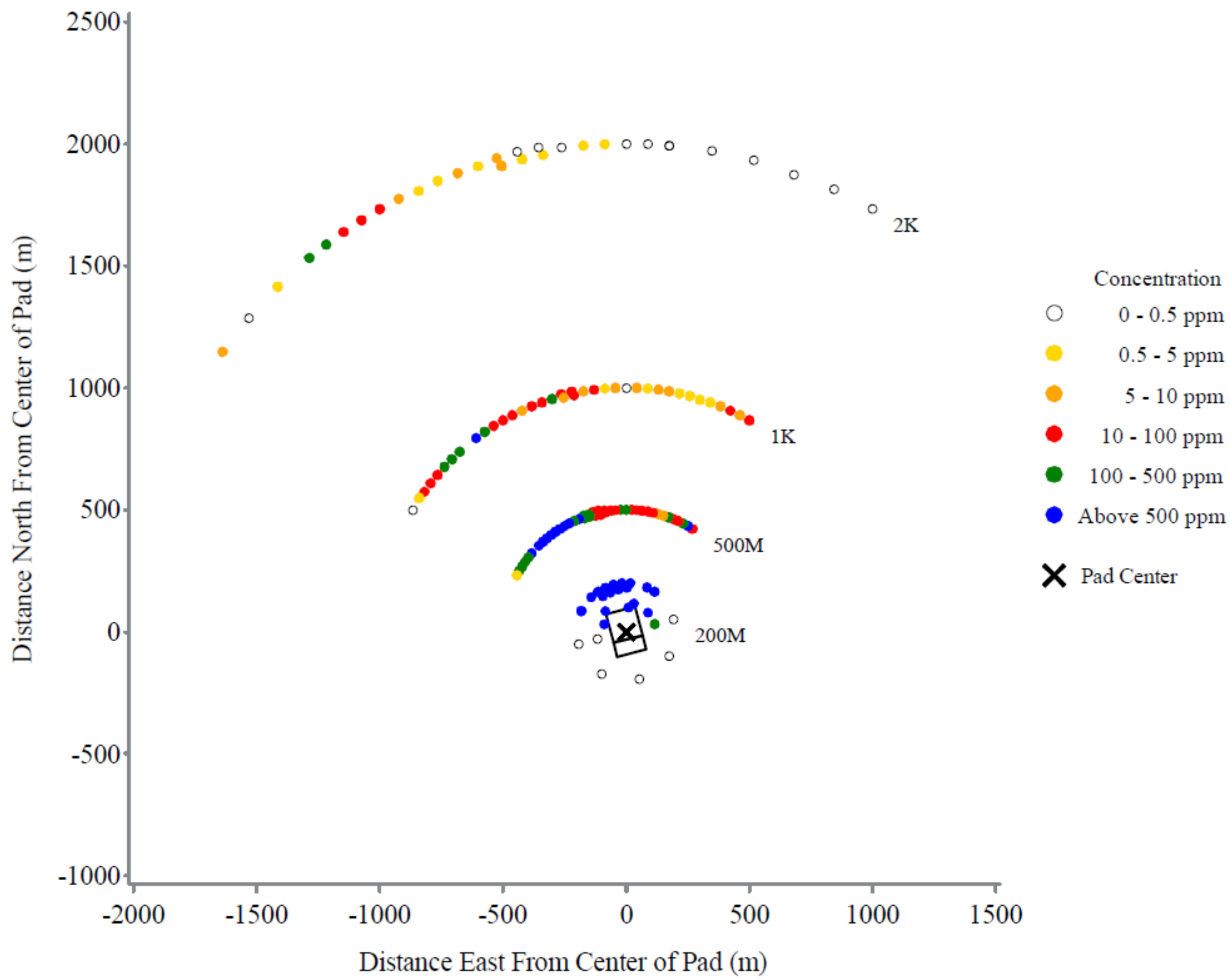
NOTES: 1. Temperature shown is the maximum temperature drop during the trial.
2. Numbers in parenthesis are time to maximum temperature drop in seconds.
3. Only maximum temperature drops less than -0.5°C are shown.

Figure J.1. Trial 8 Meteorological (MET) Thermocouple Data at 60 cm (23.6 in) Height; JRII.



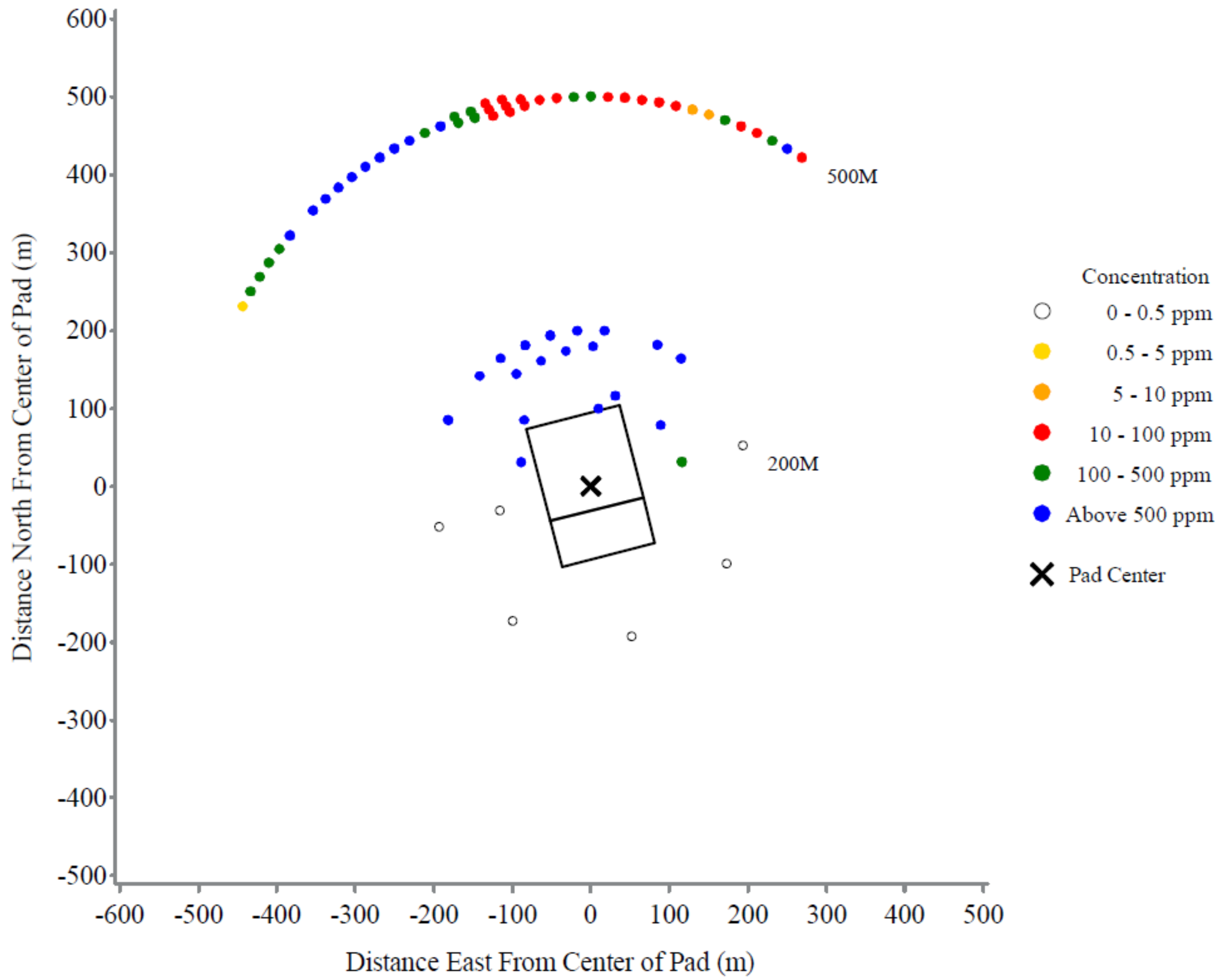
NOTE: Duplicate points represent collocated instruments.

Figure J.2. Trial 8 Far Field Maximum Chlorine Concentrations; JRII.



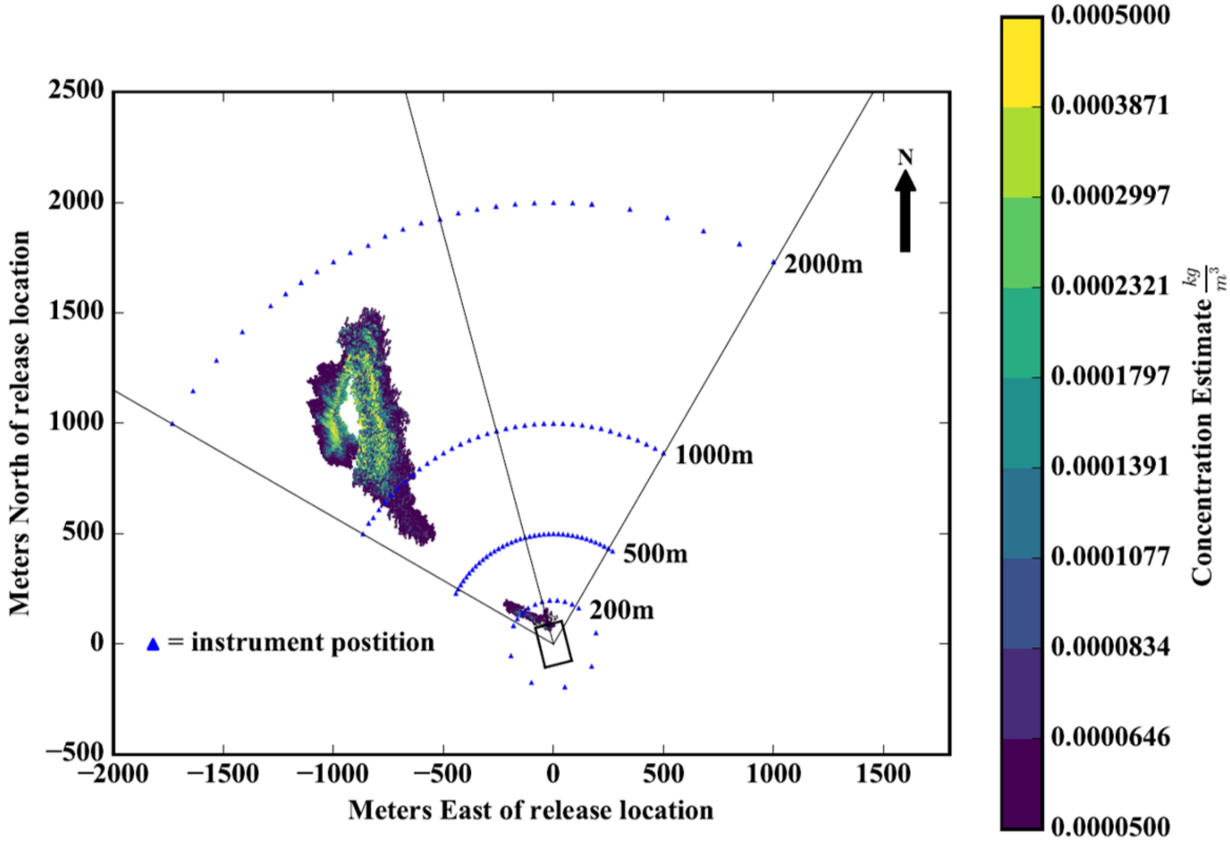
NOTE: Duplicate points represent collocated instruments.

Figure J.3. Trial 8 Mid Field Maximum Chlorine Concentrations; JRII.



NOTE: Duplicate points represent collocated instruments.

Figure J.4. Trial 8 Near Field Maximum Chlorine Concentrations; JRII.



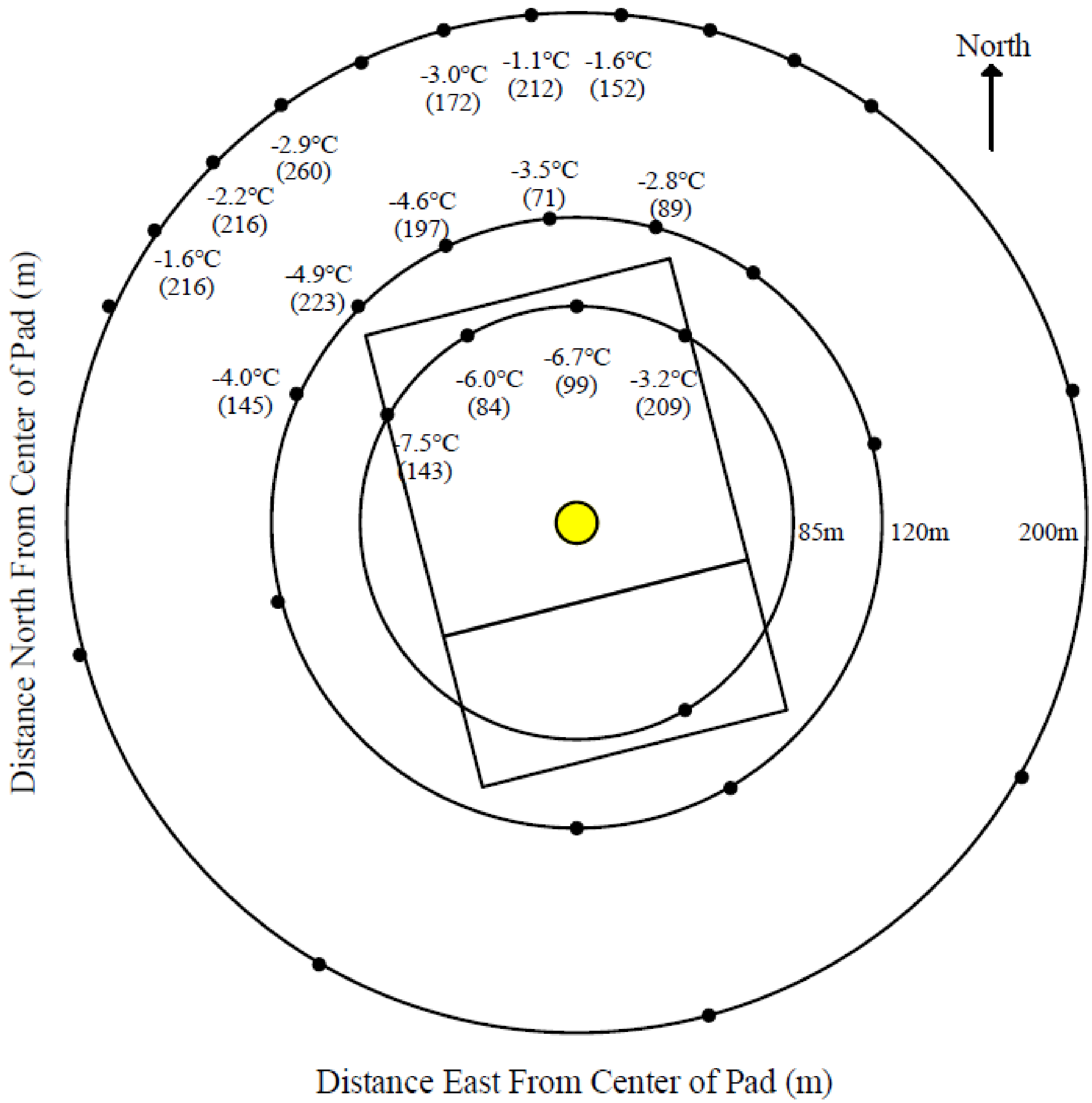
NOTES:
1. Elapsed Time: T+00:10:33 to T+00:10:48.
2. This figure represents measurements taken of the east and west sides of the chlorine cloud and displays only the outline of the cloud. The UV LIDAR could not penetrate the entire cloud.

Figure J.5. Trial 8 Ultraviolet (UV) Light Detection and Ranging (LIDAR); JRII.

Figure J.6. Trial 8 Representative Photograph of Release; JRII.

APPENDIX K. TRIAL 9 TEST DATA

FIGURE LIST



NOTES:
1. Temperature shown is the maximum temperature drop during the trial.
2. Numbers in parenthesis are time to maximum temperature drop in seconds.
3. Only maximum temperature drops less than -0.5°C are shown.

Figure K.1. Trial 9 Meteorological (MET) Thermocouple Data at 60 cm (23.6 in) Height; JRII.

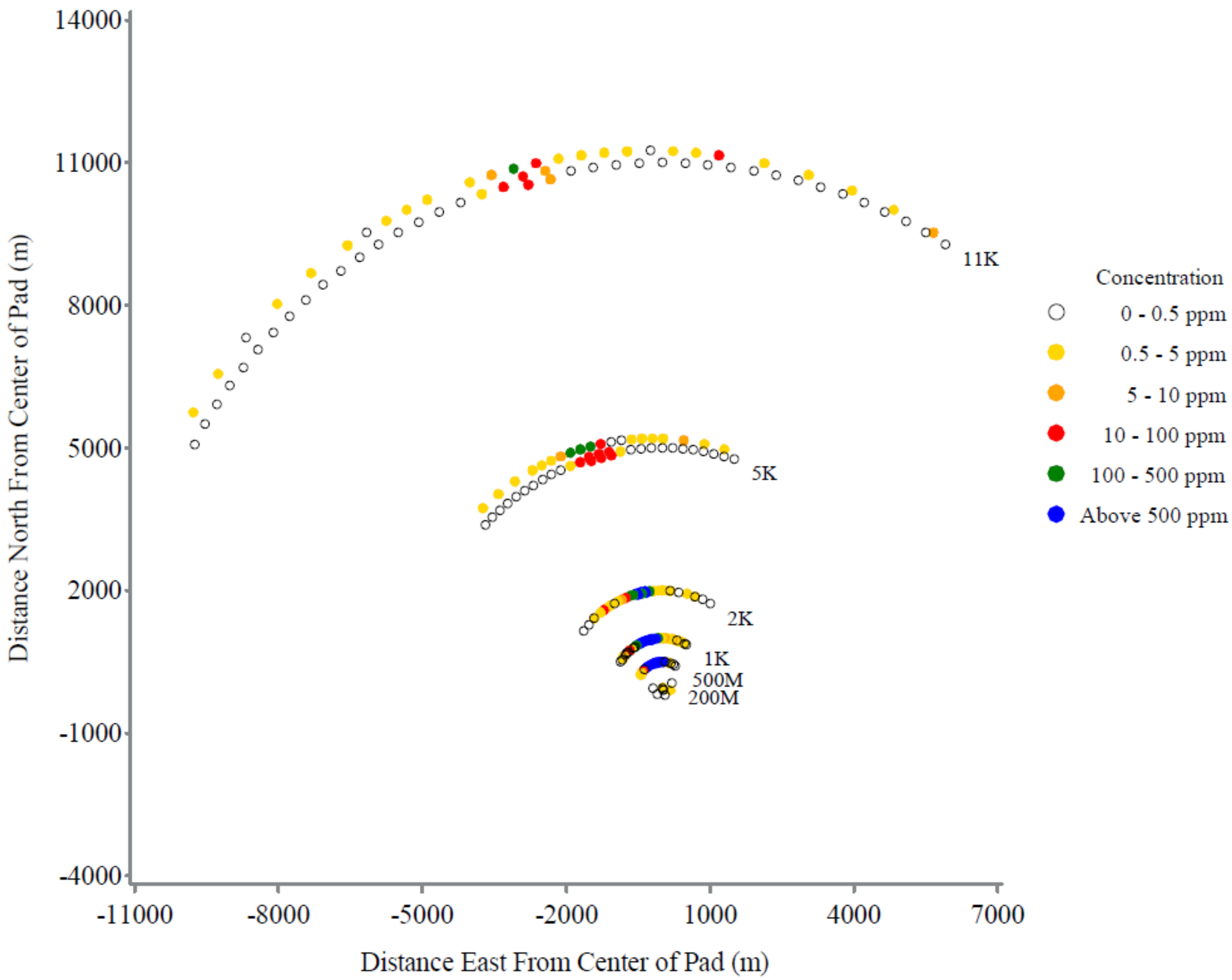


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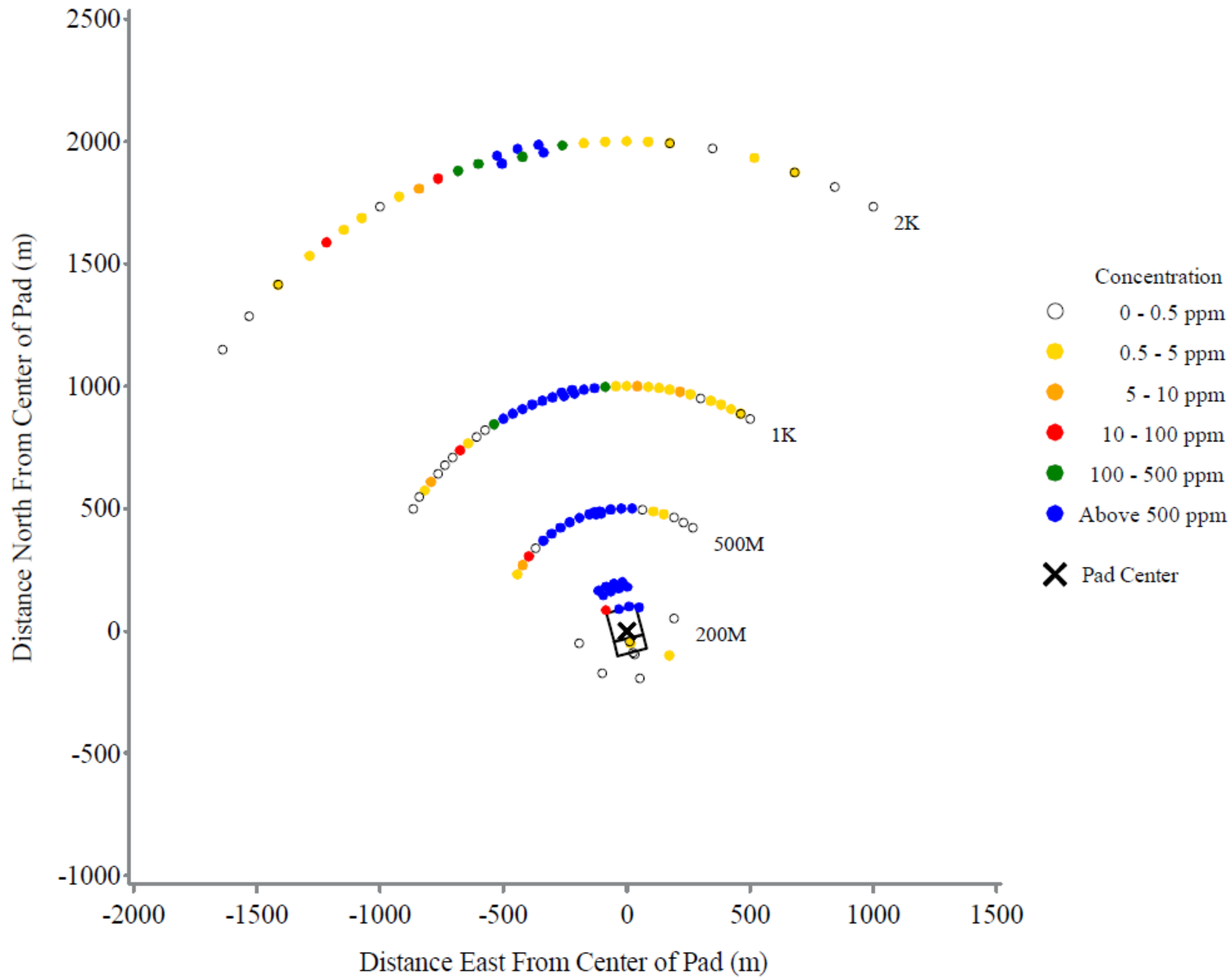
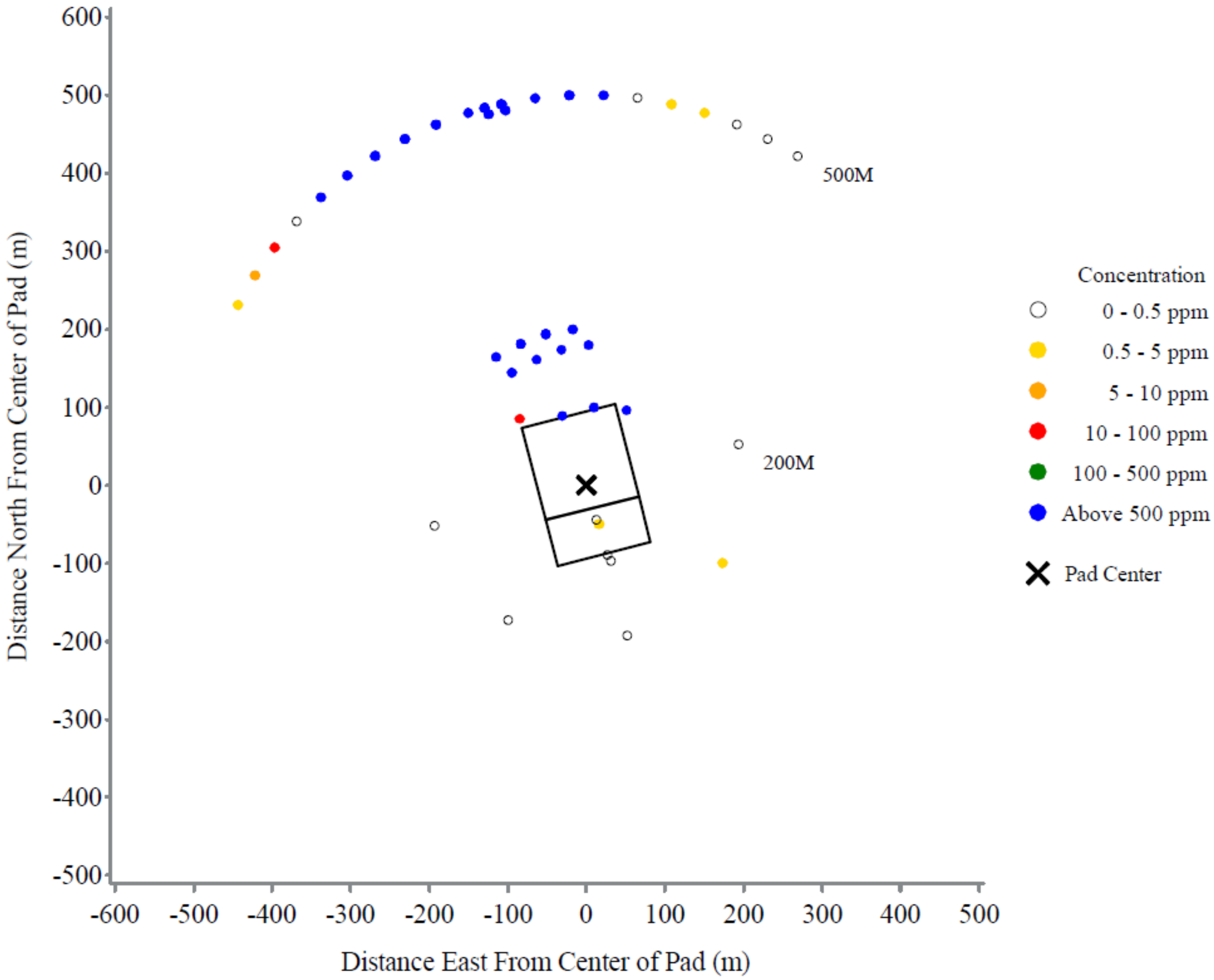
Figure K.2. Trial 9 Far Field Maximum Chlorine Concentrations; JRII.



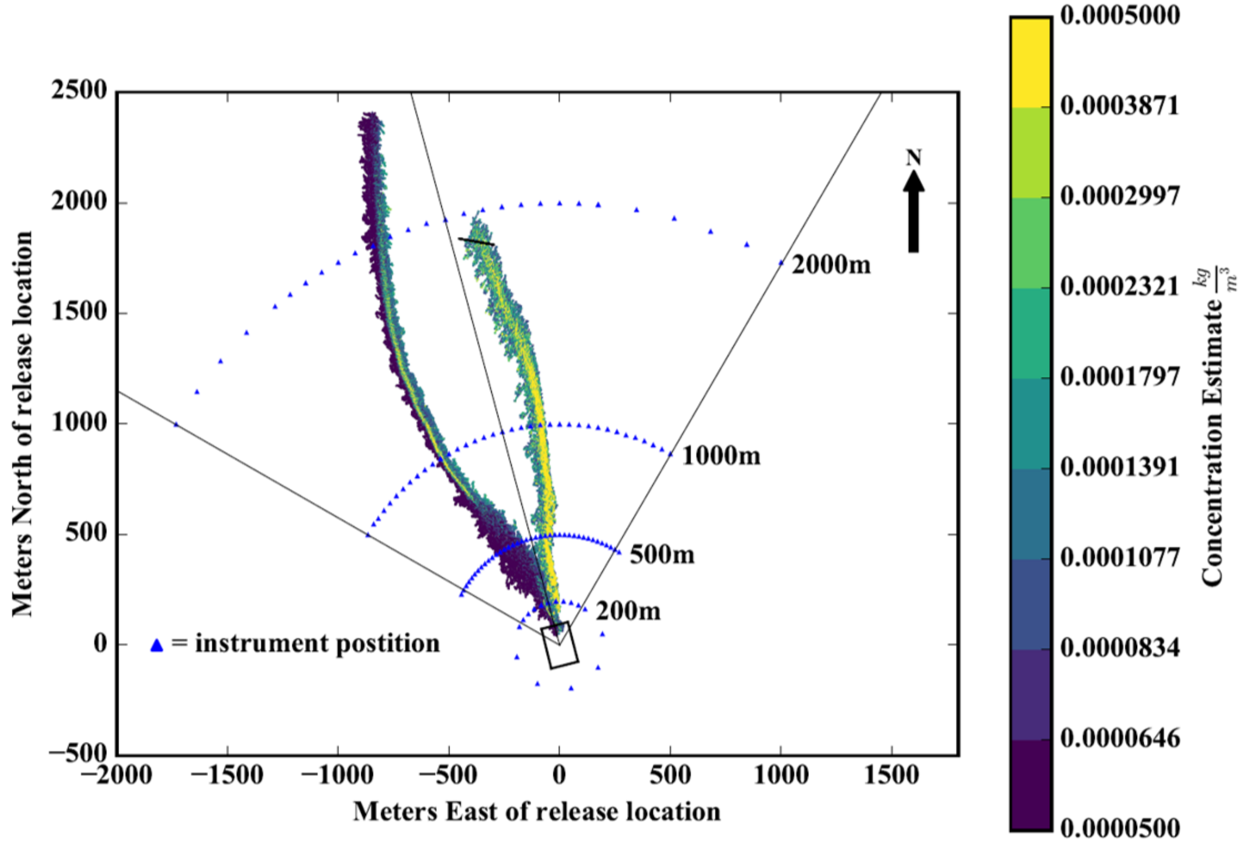
NOTE: Duplicate points represent collocated instruments.

Figure K.3. Trial 9 Mid Field Maximum Chlorine Concentrations; JRII.



NOTE: Duplicate points represent collocated instruments.

Figure K.4. Trial 9 Near Field Maximum Chlorine Concentrations; JRII.



NOTES:
1. Elapsed Time: T+00:10:57 to T+00:11:22.
2. This figure represents measurements taken of the east and west sides of the chlorine cloud and displays only the outline of the cloud. The UV LIDAR could not penetrate the entire cloud.

Figure K.5. Trial 9 Ultraviolet (UV) Light Detection and Ranging (LIDAR); JRII.

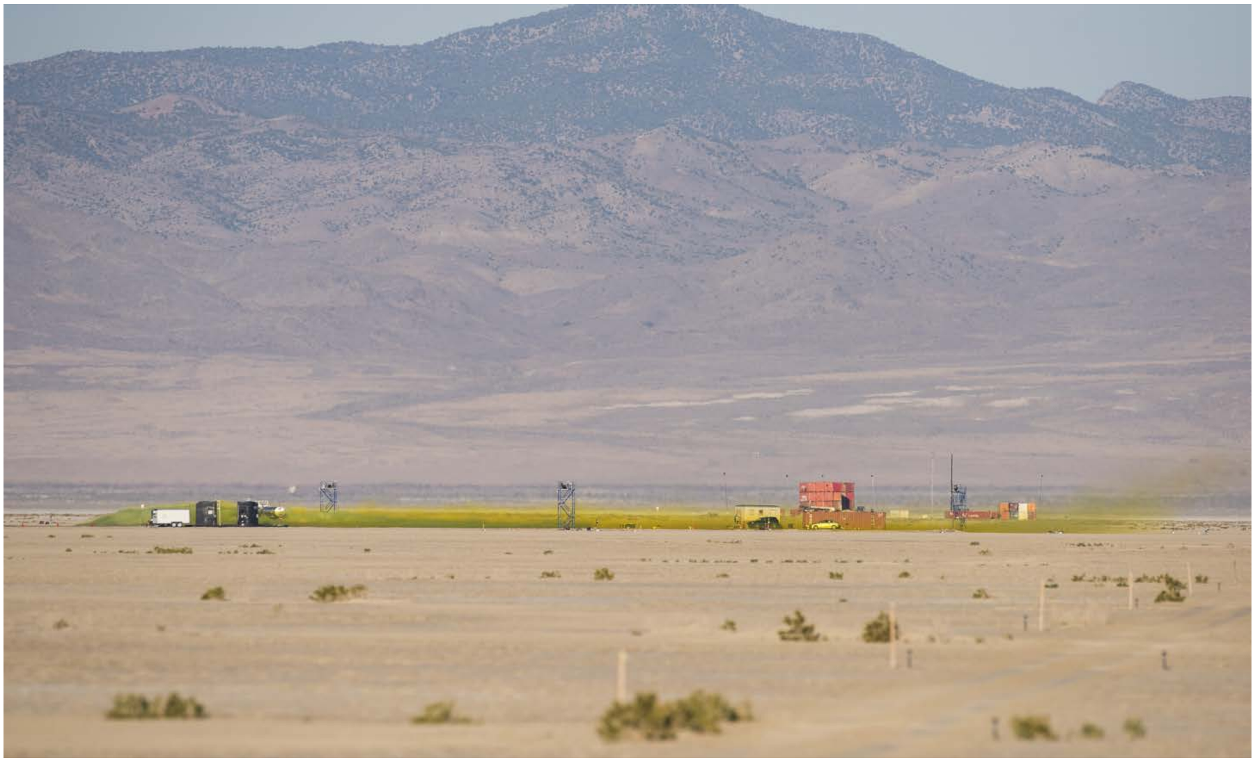


Figure K.6. Trial 9 Representative Photograph of Release; JRII.

APPENDIX L. BIBLIOGRAPHY OF WORKS DERIVED FROM JRII

1. Bohl, D., *Clarkson University Jack Rabbit II Report – Final*, Department of Mechanical and Aeronautical Engineering, Clarkson University, 28 February 2017.

2. DHS FEMA National Fire Acadamy, *Jack Rabbit II Phase 1 Trials: Training Needs Assessment and Analysis, Final Report*, Emmitsburg, MD, 01 August 2016.

3. Hanna S, Chang, J, *Dependence of maximum concentrations from chemical accidents on release duration*. Atmos. Environ. 148:1-7, 2017.

4. Hanna S, Chang, J, Huq P, *Observed chlorine concentrations during Jack Rabbit I and Lyme Bay field experiments*. Atmos. Environ. 125:252-256, 2016.

5. Hanna, S, Chang, J., Mazzola T., 2017, Analysis of variations of concentration with downwind distance and characteristics of dense gas plume rise for Jack Rabbit II chlorine field experiments. 18th Conference on Harmonization of Air Pollution Regulatory Models, Bologna, Italy, 12 October 2017.

6. Hanna, S. et al., 2016, *Preliminary analysis of observations from the JR II 2015 field experiment on dense gas dispersion in a built environment*. Paper H17-186, 17th Conference on Harmonization of Air Pollution Regulatory Models, Budapest, Hungary, 12 May 2016.

7. McKenna, B., Mallafre Garcia, M., Gant, S. McGillivray, Al, Batt, R. Wardman, M., Tucker, H., Tickle, G., Witlox, H., *Jack Rabbit II 2015 trials: preliminary comparison of the experimental results against Drift and Phast dispersion model predictions*. Hazards 27 Conference, ICC Birmingham, UK, 11 May 2017.

8. Noll, G., Byrnes, A., *The Jack Rabbit Tests: Catastrophic Releases of Compressed Liquefied Gases*. Fire Engineering, November 2016.

9. Ponsardin, P., *REVEAL Data Analysis Results from 2016 Jack Rabbit II Field Testing*, DTRA FTR-17-003, Spectral Sensors Solutions, LLC, 25 January 2017.

10. Seebaugh, W. R. and Mazzola T., *Time Synchronization Issues for GRIMM Aerosol Spectrometers During 2016 JRII Trials*, Engility, 31 May 2017.

11. Spicer, T., Feuvrier, A., *Investigating the Reactivity of Chlorine with Environmental Materials in Relevant, Controlled Conditions*. Physmod 2017 – International Workshop on Physical Modelling of Flow and Dispersion Phenomena, Dynamics of Urban and Coastal Atmosphere, École Centrale de Nantes, France, 25 August 2017.

12. Spicer, T., Miller, D., *Quantifying the Mass Release Rate for Flashing Two Phase Releases*. 13th Global Congress on Process Safety, San Antonio, TX, 30 March 2017.

13. Spicer, T., Wallace, S., Tabara, C.E., Sun, S., *Transient Large-Scale Chlorine Releases in the Jack Rabbit II Field Tests: Near Source Release Data and Preliminary Analysis*. American Institute of Chemical Engineers 2016 Spring Meeting, 12th Global Congress on Process Safety, Houston, TX, 12 April 2016.

14. Vik, T., Wingstedt, E., Reif, B., *Preliminary numerical simulation of the dispersion of chlorine vapour in a mock urban environment fot the Jack Rabbit II field trials*. Norwegian Defence Research Establishment, FFI-rapport 2015/01986, 02 February 2016.

15. Whitmire, M., Schneider, J., *Evaluation of Portable X-Ray Fluorescence for the Determination of Chlorine in the Environment After Chlorine Releases at Jack Rabbit II*. Department of Homeland Security, Science & Technology, Chemical Security Analysis Center, CSAC-16-0004, 02 February 2016.

APPENDIX M. REFERENCES

1. US Army Dugway Proving Ground (DPG), Utah, *Final Test Report for the Jack Rabbit Test Program*, US Army Test and Evaluation Command (ATEC) Project Number 2010-DT-DPG-SNIMT-E5835, West Desert Test Center (WDTC) Document Number WDTC-TR-10-059, August 2010.

2. US Department of Transportation, Washington, DC, *2012 Emergency Response Guidebook*, 15 October 2012.

3. Federal Emergency Management Association (FEMA), US Fire Administration, National Fire Academy (NFA), Emmitsburg, Maryland, *Emergency Responder Subject Matter Expert (SME) Input for Jack Rabbit (JR)II Trials*, 30 January 2015.

4. Fox, S., *Jack Rabbit II Project Charter*, Department of Homeland Security, Chemical Security Analysis Center, Aberdeen Proving Ground, MD, 31 July 2014.

5. Homeland Security Studies and Analysis Institute, Falls Church, Virginia, *Four Mock Urban Layout Graphics by Dr. Joseph Chang*, May 2015.

6. US Army Dugway Proving Ground (DPG), Utah, *Detailed Test Plan for the Jack Rabbit II Test Program*, US Army Test and Evaluation Command (ATEC) Project Number 2010-DT-DPG-SNIMT-F9735, West Desert Test Center (WDTC) Document Number WDTC-SPD-DTP-001, August 2016.

7. Homeland Security Information Network (HSIN), Washington, DC, https://hsin.dhs.gov, accessed on 8 August 2017.

8. RAE® Systems, Inc., San Jose, California, *MiniRAE 3000 User's Guide*, Revision D, April 2014.

9. RAE® Systems, Inc., San Jose, California, *ToxiRAE Pro User's Guide*, Rev. C, March 2013.

10. GRIMM Technologies, Inc., Ainring, Bavaria, Germany, *Portable Laser Aerosol Spectrometer and Dust Monitor Model 1.108/1.109*, Undated.

11. State of Utah, Salt Lake City, Utah, Approval Order (AO): *New Jack Rabbit Research and Development Program at Dugway Proving Ground*, AO Number: DAQE-AN107060043-14, 3 December 2014.

12. Teledyne RISI, Tracy, California, *Operator's Manual, Exploding Bridge-Wire (EBW) Firing System, FS-43 Fire Set*, 14 February 2013.

13. US Army Dugway Proving Ground (DPG), Utah, *Methodology Investigation Report (MIR) for the Jack Rabbit (JR) II Dissemination Method Testing*, US Army Test and Evaluation Command (ATEC) Project Number 2010-DT-DPG-SNIMT-F9735, West Desert Test Center (WDTC) Document Number WDTC-SPD-MIR-001, December 2016.

14. US Army Dugway Proving Ground (DPG), Utah, Standing Operating Procedure (SOP) DP-0000-G-139, *Munitions Demilitarization Open Detonation of Explosives and Open Burning Procedures*, Revision 14, 26 June 2011.

15. Lawrence Berkeley National Laboratory, Berkeley, California, *Jack Rabbit II Mock Urban Test Plan Detailed Indoor Study Work Plan*, June 2015.

16. US Army Dugway Proving Ground (DPG), Utah, *Master Execution Plan (MEP) for Jack Rabbit (JR) II*, US Army Test and Evaluation Command (ATEC) Project Number 2010-DT-DPG-SNIMT-F9735, August 2015.

17. US Department of Homeland Security (DHS), Science & Technology, Chemical Security Analysis Center (CSAC), Washington, DC, *Procedures for Chlorine Reactivity and Deposition Experiments*, April 2015.

18. US Army Dugway Proving Ground (DPG), Utah, Letter of Instruction (LOI)-SPD-017, *Letter of Instruction (LOI) for Chlorine Operations*, May 2015 (DRAFT).

19. US Army Dugway Proving Ground (DPG), Utah, *Operations Plan for Jack Rabbit (JR)II Test*, US Army Test and Evaluation Command (ATEC) Project Number 2010-DT-DPG-SNIMT-F9735, West Desert Test Center (WDTC) Document Number WDTC-OP-15-058, May 2015.

APPENDIX N. ABBREVIATIONS

3D – three dimensional

3DCAV – 3D Cloud Analysis Visualization

ADSS – ATEC Decision Support System

AFRL – Air Force Research Laboratory

AGL – above ground level

AO – approval order

APG – Aberdeen Proving Ground

ATEC – US Army Test and Evaluation Command

AWG – American Wire Gauge

CI – Chlorine Institute

Cl_2 – chlorine gas

CP – command post

CSAC – Chemical Security Analysis Center

CSSS – Center for Security Science

DAQ – Division of Air Quality

DHS – Department of Homeland Security

DJI – Dà Jiāng Innovations

DPG – US Army Dugway Proving Ground

DRDC – Defence Research and Development Canada

DSN – Defense Switched Network

DSO – Defense Science Organization

DT – developmental test

DTC – Developmental Test Command

DTCC – Distributed Test Control Center

DTP – detailed test plan

DTRA – Defense Threat Reduction Agency

EA – Environmental Assessment

EBS – Energy Balance Station

EBW – exploding bridge wire

ECBC – Edgewood Chemical Biological Center

EVO – Genisys Evolution

FOV – field of view

fps – frames per second

FTIR – fourier-transform infrared spectrometer

FTR – final test report

GHD – Gutteridge Haskins & Davey

GPS – global positioning satalite

GWR – guided-wave radar

HD – high-definition

HMP – humidity and temperature probe

hPa – hectopascal

HPAC – Hazard Prediction and Assessment Capability

HS – high-speed

HSIN – Homeland Security Information Network

HVAC – heating, ventilating, and air conditioning

Hz – hertz

I – interstate

IAW – in accordance with

IMT – incident management team

IR – infrared

ITOP – International TOP

JPEO – Joint Program Executive Office

JPM CA – Joint Program Project Manager for Contamination Avoidance

JPM P – Joint Program Project Manager for Protection

JR – Jack Rabbit

LIDAR – light detection and ranging

LIF – laser-induced fluorescence

LOI – letter of instruction

MBTA – Migratory Bird Treaty Act

MEP – master execution plan

MET – meteorological

MHz – megahertz

NA – not applicable

NSWC – Naval Surface Warfare Center

OBD – on-board diagnostics

OPSEC – operations security

PAM – pamphlet

PMSS – Parallel Micro Swift Spray

PPE – personal protective equipment

ppm-m – parts per million-meter

PWIDS – Portable Weather Information Display System

RDX – rimethylenetrinitramine

REVEAL – Real-time Eyesafe Visualization Evaluation and Analysis LIDAR

RH – relative humidity

RIAC – Rapid Integration and Acceptance Center

RPT – rapid phase transition

S&T – Science & Technology Directorate

S/V – surface-to-volume

S3 – Spectral Sensor Solutions

SAR – Safety Assessment Report

SCIPUFF – Second-order Closure Integrated Puff

SF_6 – sulfur hexafluoride

SL – surface layer

SODAR – sonic detection and ranging

SOP – standing operating procedure

TCO – test control officer

TIC – toxic industrial chemical

TIH – toxic inhalation hazard

TIM – toxic industrial material

TOP – test operations plan

TP – test plan

TRR – test readiness review

TSA – Transportation Security Administration

UAS – unmanned aerial system

UTC – Coordinated Universal Time

UTG – Urban Test Grid

UV – ultraviolet

DOAS – Differential Optical Absorption Spectroscopy

UVU – Utah Valley University

V – vertical

VIP – very important person

Vis – visible

VISION – Versatile Information Systems Integrated ON-line Nationwide

VNIR – variable and near infrared

VOC – volatile organic compound

WDL – West Desert LIDAR

WDTC – West Desert Test Center

WGS – World Geodetic System

XRF – X-ray fluorescence