Technical Capability Standard for Radiation Portal Monitor Systems with Energy Analysis Capability – 2019

Countering Weapons of Mass Destruction

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Technical Capability Standard for Radiation Portal Monitor Systems with Energy Analysis Capability

1 Overview

1.1 Introduction

A Technical Capability Standard (TCS) is a government-unique standard that establishes targeted performance requirements for radiation detection and non-intrusive inspection systems. The purpose of the TCS is to establish, where practical, requirements and applicable test methods that are based on threat-informed unclassified source materials and test configurations that are not addressed in consensus standards. Threat-informed source materials and configurations are based on a realistic threat interpretation as agreed to by the Technical Capability Standard Working Group (TCSWG). In support of this effort, unclassified detection capability benchmarks were established that do not compromise nuclear weapon design information.

It is anticipated that after a TCS is developed, the DHS Countering Weapons of Mass Destruction (CWMD) office will work within the consensus standards arena to ensure that future American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) N42 series consensus standards reflect the capabilities described by the TCS benchmarks, where applicable.

Technical Capability Standards are developed by an inter-agency TCSWG. Membership of the TCSWG includes representatives from the Department of Homeland Security's Countering Weapons of Mass Destruction Office (CWMD), U.S. Customs and Border Protection (CBP), and Science and Technology Directorate (S&T); the Department of Commerce's National Institute of Standards and Technology (NIST); the Nuclear Regulatory Commission (NRC); the Department of Justice's Federal Bureau of Investigation (FBI); the Department of Defense's Defense Threat Reduction Agency (DTRA); and from the Department of Energy's National Nuclear Security Administration (NNSA) Office of Counterterrorism and Counterproliferation, (NA-80), the Office of Defense Nuclear Nonproliferation, and several DOE national laboratories (Los Alamos National Laboratory [LANL], Oak Ridge National Laboratory [ORNL], Sandia National Laboratories [SNL], Savannah River National Laboratory [SRNL], and Pacific Northwest National Laboratory [PNNL]).

1.2 Scope

This TCS supplements ANSI N42.35, *American National Standard for Evaluation and Performance of Radiation Detection Portal Monitors for Use in Homeland Security*. The Radiation Portal Monitor (RPM) TCS establishes performance requirements for systems with energy analysis capabilities. Radiation detection performance requirements, as well as mechanical, environmental, and electromagnetic performance requirements for RPM systems are covered by ANSI N42.35 [1].

This TCS addresses the mandate in the Security and Accountability For Every (SAFE) Port Act (Pub. L 109-347 §121 (f) October 13, 2006, 120 Stat. 1898) that states: "The Secretary, acting through the Director for Domestic Nuclear Detection Office and in collaboration with the National Institute of Standards and Technology, shall publish technical capability standards and recommended standard operating procedures for the use of nonintrusive imaging and radiation detection equipment in the United States. Such standards and procedures:

1. should take into account relevant standards and procedures utilized by other Federal departments or agencies as well as those developed by international bodies; and

2. shall not be designed so as to endorse specific companies or create sovereignty conflicts with participating countries."

The Secretary of Homeland Security, pursuant to a reorganization under Section 872 of the Homeland Security Act of 2002, as amended, established the Countering Weapons of Mass Destruction (CWMD) office in December 2017. This reorganization was formally authorized by Congress under the Countering Weapons of Mass Destruction Act of 2018 (Public Law No. 115-387), signed by the President on December 21, 2018 [15]. The Assistant Secretary for CWMD serves as the Director for the Domestic Nuclear Detection Office, which was subsumed into the broader CWMD Office.

1.3 Purpose

This TCS establishes additional requirements and test methods for RPMs with energy analysis capabilities not covered in the ANSI N42.35 standard. This standard will be used by DHS/CBP to test RPMs prior to operational/field testing or deployments and by DHS to test equipment performance.

This standard establishes requirements and test methods to:

- determine if the RPM correctly categorizes Naturally Occurring Radioactive Material (NORM);
- ensure that the RPM does not categorize non-NORM material as NORM;
- ensure that an RPM has the ability to detect threat sources in the presence of NORM.

This standard applies to double-sided vehicle RPMs as defined in the ANSI N42.35 standard [1].

2 Bibliography

The following documents are either used or referenced in the preparation of this TCS. If a reference doesn't have a date, then the most recent version applies.

[1] ANSI N42.35-2016 American National Standard for Evaluation and Performance of Radiation Detection Portal Monitors for Use in Homeland Security.

[2] U.S. Department of Homeland Security, Radiological and Nuclear Smuggling Security Classification Guide, DHS SCG DNDO-001.3, November 2017.

[3] ANSI N42.42-2012 American National Standard – Data format standard for radiation detectors used for Homeland Security.

[4] SAFE Port Act, Pub. L. No. 109-347, October 13, 2006, 120 Stat 1884.

[5] ANSI N42.22, American National Standard - traceability of radioactive sources to the National Institute of Standards and Technology (NIST) and Associated Instrument Quality Control.

[6] ANSI N42.23, American National Standard measurement and associated instrument quality assurance for radio assay laboratories.

[7] ANSI/HPS N13.11, Criteria for Testing Personnel Dosimetry Performance.

[8] Fundamental quantities and units for ionizing radiation. Journal of the International Commission on Radiation Units and Measurements – ICRU Report 60.

[9] ANSI N42.14, American National Standard for Calibration and Use of Germanium Spectrometers for the Measurement of Gamma-Ray Emission Rates of Radionuclides.

[10] Technical Capability Standards Traceability Memo, Document number 500-DNDO-119600, 2012.

[11] ANSI N42.38 American National Standard for Performance Criteria for Spectroscopy-Based Portal Monitors Used in Homeland Security.

[12] PNNL-28185. Design and Characterization of NORM Commerce Surrogates.

[13] Nationwide Statistics of Gamma Emission Intensity and Isotopic Composition for Alarming Norm Cargo (CY 2016) in Support of Capability Standard for RPMs With Norm Categorization Capabilities. Tom Carnahan, Emma Taylor, and Jason Wetstone. CBP report number CBP/LSSD/DAC-TER-2017-017(532). April 2017.

[14] Gamma- and X-ray Spectrometry with Semiconductor Detectors. K. Debertin and R.G. Helmer. Editor North-Holland. 1998 Edition.

[15] Countering Weapons of Mass Destruction Act of 2018, Public Law No. 115-387, One Hundred Fifteenth Congress of the United States of America, at second session 2018.

3 Definitions and Abbreviations

3.1 Definitions

3.1.1 alarm: An audible, visual, or other signal activated when the instrument reading or response exceeds a preset value or falls outside a preset range.

3.1.2 categorization: Placing RPM detections into groups of radioactive material classes, such as NORM, Industrial, Medical, Threat.

3.1.3 coverage factor: Numerical factor (k) used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty (ISO GUM: 1995).

3.1.4 detection assembly: Enclosure of the installed radiation portal monitor system that contains the detectors and associated electronic devices.

3.1.5 detection zone: The region either located between opposing detection assemblies or adjacent to a detection assembly over which a source can be detected.

3.1.6 detector: A device or component designed to produce a quantifiable response to ionizing radiation normally measured electronically.

3.1.7 energy analysis: Analysis based on the distribution of energies deposited in a detector from photon events.

3.1.8 evaluation distances: The distance between an evaluation test source and the exterior face(s) of the portal monitor unit(s), which corresponds to the surface of the detection assembly, during a trial.

3.1.9 exposure: A measure of ionization produced in air by X- or gamma-ray radiation. The special unit of exposure rate is the Roentgen per hour, abbreviated in this standard as R/h.

3.1.10 false negative: A lack of indication by the instrument of a radioactive source that is present.

3.1.11 false positive: An indication by the instrument that a radioactive source is present when the source is not present.

3.1.12 fluence: The *fluence*, Φ, is the quotient of dN by da, where dN is the number of particles incident on a sphere of cross-sectional area da. The unit of fluence is m^{-2}. (ICRU Report 60 [8])

3.1.13 fluence rate: The *fluence rate,* $\dot{\Phi}$, is the quotient of $d\Phi$ by dt, where $d\Phi$ is the increment of the fluence in the time interval dt, thus $\dot{\Phi} = \frac{d\Phi}{dt}$. The unit of fluence rate is $m^{-2}s^{-1}$. (ICRU Report 60 [8])

3.1.14 flux: The flux, $\dot{N}$, is the quotient of dN by dt, where dN is the increment of the particle number in the time interval dt. The unit of flux is s^{-1}. (ICRU Report 60 [8])

3.1.15 influence quantity: Quantity that may have a bearing on the result of a measurement without being the subject of the measurement.

3.1.16 instrument: A complete system consisting of one or more assemblies designed to quantify one or more characteristics of ionizing radiation or radioactive material.

3.1.17 masking ratio: Radiation emission rate of the masking source(s) compared to the emission rate of the target source.

3.1.18 occupancy: When the detection zone is occupied with a vehicle that is being monitored and the system switches from a background measurement mode to a foreground measurement mode**.**

3.1.19 point of measurement: Place at which the conventionally true values are determined and at which the reference point of the instrument is placed for test purposes.

3.1.20 special nuclear material (SNM): The term "special nuclear material" means plutonium, uranium enriched in the isotope 233 or in the isotope 235, but does not include uranium and thorium ores or any other material which is determined by the NRC pursuant to the provisions of Section 61 to be source material. (Atomic Energy Act of 1954, as amended)

3.1.21 standard test conditions: The range of values of a set of influence quantities under which a calibration or a measurement of response is carried out.

3.1.22 uncertainty: The estimated bounds of the deviation from the conventionally true value, generally expressed as a percent of the mean, ordinarily taken as the square root of the sum of the square of two components: 1) Random errors that are evaluated by statistical means; and 2) systematic errors that are evaluated by other means.

3.2 Abbreviations and Acronyms

ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials

CBP	Customs and Border Protection
cps	counts per second
CWMD	Countering Weapons of Mass Destruction
DHS	Department of Homeland Security
DOE	Department of Energy
DTRA	Defense Threat Reduction Agency
DU	Depleted Uranium
FBI	Federal Bureau of Investigation
GADRAS	Gamma Detector Response and Analysis Software
HDPE	High Density Polyethylene
HEU	Highly Enriched Uranium
HPGe	High Purity Germanium
ICRU	International Commission on Radiation Units and Measurement
IEEE	Institute of Electrical and Electronics Engineers
IMCC	Intermodal Cargo Container
LANL	Los Alamos National Laboratory
NIST	National Institute of Standards and Technology
NORM	Naturally Occurring Radioactive Material
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PMMA	Polymethyl Methacrylate
PNNL	Pacific Northwest National Laboratory
RPM	Radiation Portal Monitor
SI	International System of Units
SNL	Sandia National Laboratories
SNM	Special Nuclear Material
SRNL	Savannah River National Laboratory
TCS	Technical Capability Standard
TCSWG	Technical Capability Standard Working Group
US	United States
WGPu	Weapons Grade Plutonium

4 General considerations

4.1 Test conditions

Except where otherwise specified, the tests in this standard should be carried out under the standard test conditions shown in Table 1.

If the system response is known for the temperature and humidity ranges specified in the ANSI N42.35 standard, then testing ranges in Table 1 can be extended based on the test results.

If testing is carried out in an uncontrolled environment (e.g., outdoors) the temperature, humidity, atmospheric pressure, and weather conditions (e.g., rain, snow) shall be recorded hourly throughout the duration of the tests. In addition, the RPM stability over the duration of the test period shall be measured as described in Section 5.7.

Table 1: Standard test conditions

Influence quantity	Standard test conditions
Stabilization time	As stated by the manufacturer.
Ambient temperature	18 °C to 25 °C
Relative humidity	≤ 75%
Atmospheric pressure	70 kPa to 106.6 kPa (525 to 800 mm of mercury at 0 °C)
Magnetic induction of external origin	Less than twice the value of the induction due to earth's magnetic field
Gamma background radiation (ambient photon exposure rate)	≤ 10 μR/h
Neutron background radiation	Natural conditions without the presence of man-made emitters

4.2 Uncertainties and units

4.2.1 Uncertainties

Unless otherwise specified, the total combined uncertainty for any measurable quantity (e.g., radiation field), shall be documented and should not exceed 10% with a coverage factor, k, of 1. This does not apply to background radiation measurements, as such low uncertainty might not be possible to achieve. The uncertainty of the measured background shall be recorded.

4.2.2 Units

This standard uses the International System of Units (SI). Multiples and submultiples of SI units will be used, when practical, according to the SI system.

This standard also uses the following non-SI units:

- Energy: kilo-electron-volt (symbol: keV), 1 keV = 1.602 x 10^{-16} J, and mega-electron-volt (symbol: MeV), 1 MeV = 1.602 x 10^{-13} J.
- Exposure: Roentgen (symbol: R), 1 R = 2.58×10^{-4} Coulomb per kilogram (symbol: C/kg).
- Exposure rate: Roentgen per hour (symbol: R/h), 1 R/h = 2.58×10^{-4} C/kg/h.

4.3 Special word usage

The following word usage applies:

- "Shall" signifies a mandatory requirement (where appropriate a qualifying statement is included to indicate that there may be an allowable exception).
- "Should" signifies a recommended specification or method.
- "May" signifies an acceptable method or an example of good practice.

5 General characteristics

5.1 General

RPMs addressed by this standard are used for cargo screening. These RPMs shall be equipped with occupancy sensors and shall have energy-based discrimination analysis. The energy analysis capability is used to categorize radioactive sources including discriminating NORM.

The goal of energy-based discrimination analysis is to reduce the probability of NORM-induced alarms without reducing the RPM performance for items of interest (e.g., highly enriched uranium (HEU), weapons grade plutonium (WGPu) and depleted uranium (DU)).

The manufacturer shall specify the type of energy analysis capability used by the RPM.

The manufacturer shall specify the expected categorization for each of the test sources listed in Table 2. The RPM can either have two categories defined as NORM and Non-NORM or it can provide additional categories such as NORM, Medical, Industrial, Special Nuclear Material (SNM), etc. For the purpose of RPM response evaluation against this standard, if the RPM provides additional categories, all categories other than NORM shall be considered as Non-NORM.

It shall be possible to configure the RPM in such a way that NORM material will generate an alarm and classify the alarm as NORM rather than simply cancel the alarm.

The manufacturer shall provide a replay tool that allows the reanalysis of the acquired RPM data.

5.2 Testing parameters requirements

The setup or evaluation distance for the double-sided vehicle RPMs (includes containerized cargo) is 5 m (with a tolerance of ±10%) [1]; this distance is between the detection assemblies and it is measured from the external face of the RPM detection assembly (or panel) to the external face of the opposing assembly.

The sources shall be placed at a distance of 2.5 m from the detection assemblies (i.e., centered in the detection zone), the occupancy times shall be 5 s (this only applies to the false alarm test), and passage or transit speed shall be 2.2 m/s; the time and speed values are for evaluation purposes only and have a tolerance of ±10% (allow a ±20% tolerance when testing with trucks). For the false alarm test, the occupancy times shall be 5 s. If installation requires distances other than those tested, further testing may be required to determine that performance requirements are met.

For testing, the source height (except for NORM sources), measured from the ground, is 1.5 m. The bare and non-bulk sources should be mounted on a linear motion system (i.e., trolley on a straight line or track) in order to have control of the testing speed. NORM sources should be placed on a flatbed truck. NORM tests are performed with bulk material that will cause the background to be suppressed.

NOTE - Background suppression is not tested specifically in this standard.

NOTE - When used in the field, the alarm threshold settings may be adjusted based on the stream of commerce and the measured background.

NOTE – The 1 alarm per 1000 occupancies is the minimum requirement. The desired false alarm rate is fewer than 1 alarm in 10,000 occupancies to enable remote operations.

5.3 Radiation sources

Sources used for testing the RPMs shall be traceable to NIST (or another equivalent national metrology institute) [5]. Source activities required for testing are listed in Table 2.

Source activities listed in Table 2 are based on photons emitted by stainless steel (0.25 mm thick) encapsulated sources. The specified activities are determined by the desired source emission rate.

The activities of the medical sources (i.e., 99mTc, 131I) are based on photons emitted by stainless steel (0.25 mm thick) encapsulated sources placed inside a 7.5 cm thick polymethyl methacrylate (PMMA) container. The PMMA thickness is consistent with the half thickness of the phantom used in the ANSI/HPS N13.11 standard [7]. The equivalent fluence rates (measured without the PMMA container) at 2.5 m are given in Table 3.

If the source is of a different construction, it is required to have the same apparent activity (i.e., emission rate) for the main photon energy for the source listed in Table 2. The required emission rate outside the source encapsulation for the main photon energy is also listed in Table 2, for additional information see Appendix B.4.

SNM and DU fluence rates required for testing are listed in Table 4 (see Section 5.8.2).

Table 2: Gamma-ray source activities

Radionuclide	Category	Source activity	Main photon energy (keV)	Required emission rate outside encapsulation (s^{-1})
^{241}Am	Industrial	47 µCi (1.74 MBq)	59.5	1.659×10^7
^{57}Co	Industrial	5 µCi (185 kBq)	122.1	1.494×10^5
^{133}Ba	Industrial	14 µCi (222 kBq)	356.0	1.352×10^5
^{137}Cs	Industrial	16 µCi (592 kBq)	661.7	4.959×10^5
^{60}Co	Industrial	7 µCi (259 kBq)	1173.2	2.557×10^5
^{226}Ra	NORM	14 µCi (518 kBq)	609.3	2.321×10^5
^{232}Th	NORM	8 µCi (296 kBq)	238.6	1.250×10^5
^{99m}Tc	Medical	127 µCi (4.70 MBq)	140.5	1.188×10^8
^{131}I	Medical	23 µCi (851 kBq)	364.5	6.783×10^5
DU	Uranium	See Table 4	1001	-
HEU	Threat	See Table 4	186	-
WGPu	Threat	See Table 4	375	-
Zircon sand	NORM	See 5.8.3	-	-
Ice Melt	NORM	See 5.8.3	-	-

NOTE 1— The actual activity of each gamma source at the time of testing shall be within (-10%, +20%) of the value shown in this table. The uncertainty in the actual activity value shall be less than or equal to ±5% (1σ) for the gamma-ray sources.

NOTE 2— Units: 1 µCi = 37000 Bq.

NOTE 3— These activity levels are for testing only and are not indicative of the alarm set point or overall sensitivity of the RPM system, which are established based on the ambient background and acceptable false alarm rate.

NOTE 4— Gamma-ray source activities are based on encapsulation in 0.25 mm wall thickness 316 stainless steel, as specified in the ANSI N42.35 standard [1].

NOTE 5— The medical sources are placed inside a 7.5 cm thick PMMA container to simulate in-vivo measurements, as specified in the ANSI N42.38 standard [11].

Table 3: Medical sources' fluence rates

Radionuclide	Category	Fluence rate (photons/s/cm^2)	Photon energy (keV)
^{99m}Tc	Medical	0.137	140.5
^{131}I	Medical	0.0234	364.5

5.4 Scoring and measurement requirements

5.4.1 Test Replication

All tests shall consist of 20 trials unless otherwise specified in a specific test method.

5.4.2 Compliance with the requirement

For detection, an RPM complies with a requirement when a detection occurs in 19 out of 20 trials unless otherwise specified in a particular test (corresponds to a probability of approximately p = 0.79, with a 95% confidence, or a probability p = 0.88 with an 80% confidence level, using the Agresti and Coull method).

For categorization or energy-based discrimination analysis, an RPM complies with a requirement when the categorization or energy-based discrimination analysis results are acceptable in 19 out of 20 trials.

5.4.3 Test scoring

The appropriate instrument response depends on the type of target source measured. The response is correct when the instrument correctly categorizes or performs the correct energy-based discrimination analysis of the target source. See Appendix A for the scoring criteria that applies to this TCS.

For NORM sources (i.e., no target sources present, only NORM sources are present), the RPM shall categorize them as NORM.

5.5 Test reporting

The test results, including displayed information, shall be recorded and saved in addition to any output document (e.g., data file) provided by the RPM.

All spectral files acquired during the testing shall be saved so they could be replayed if needed to verify the system response using different setting parameters (e.g., actual field settings).

The ANSI N42.35 standard provides requirements for the data file format. The data format shall comply with ANSI N42.42 format and should validate against the N42 schema [3].

5.6 Test facility and equipment

5.6.1 Test Facility

When possible, the test facility shall maintain the standard test conditions as stated in Table 1 (see Section 4.1). Radiation sources that are not part of the tests defined here should be removed from the testing area. If it is not possible to remove the sources during testing, the sources shall be shielded and verified not to affect the radiation background.

Instrumentation shall be available to monitor the environmental conditions as well as the ambient gamma and neutron background levels. For gamma rays, a calibrated High Purity Germanium (HPGe) detector [9] shall be available for spectral measurements and a gamma ray detector (e.g., ionization chamber) for determination of the ambient background exposure rate. The background measurement time (i.e., spectrum live-time) shall be at least 30 min.

The calibration of all monitoring instrumentation, including those devices used to monitor meteorological conditions, shall be traceable to NIST or equivalent national metrology institute.

5.6.2 Test Equipment - HPGe

The testing laboratory shall be equipped with a calibrated HPGe detector (i.e., known efficiency as a function of photon energy for a given source geometry). This HPGe detector shall be used for:

1. Determining the fluence rates of the sources used during testing.
2. Measuring the fluence rates used to determine masking ratios and shielding thicknesses.
3. Measuring the radiation background at the test location.
4. Checking for gamma-ray emitting impurities that could be present in the sources to be used for the tests; the impurity measurements will be used to update the scoring logic in Table 6. Radionuclides that could potentially be categorized based on peaks observed in the source spectra (e.g., peaks due to scattering caused by the source configuration) may be considered in Table 6.

The energy response of the HPGe detector shall be measured prior to performing the radiation background measurements (see reference [9]). The radiation background calculation shall be computed within an energy range from 60 keV to 3 MeV.

Sources used for calibration of HPGe detectors shall be traceable to NIST (or equivalent national metrology institute, see [5], [6]) and should cover an energy range no smaller than 60 keV to 2.6 MeV. The calibration should be performed as described in ANSI N42.14 [9]. Information about calculating fluence rate is provided in Appendix B.

5.6.3 Test Equipment – Gamma Ray Detector

A calibrated pressurized ionization chamber or energy compensated Geiger-Muller (GM) detector shall be used to provide a measurement of the ambient exposure rate at the test area and to monitor for changes in radiation level while tests are being performed. The energy response of the gamma ray detector from 60 keV to 1.33 MeV shall be known. The gamma ray detector calibration shall be traceable to NIST or equivalent national metrology institute.

5.6.4 Neutron Background Radiation

Neutron emitting sources or radiation fields should not be present at the test area throughout the duration of the test.

5.6.5 General Test Process

For each test, record the ambient meteorological conditions (temperature, relative humidity, and atmospheric pressure and weather conditions), background exposure rate (mean and standard deviation) and gamma spectrum, at the test location together with the corresponding units.

Verify that when the sources are placed away from the RPM panels that the RPM total count rate does not exceed 3-sigma above background (e.g., sources may be shielded at the end of the linear motion system or trolley track for the dynamic measurements, sources may be placed at a faraway distance).

5.7 RPM stability measurements

The temperature shall be constantly monitored throughout the duration of the test. If testing is performed in an uncontrolled environment (i.e., no temperature or humidity control or weather protection), a stability measurement shall be carried out to record any changes in the RPM response if the temperature varies by more than ±10°C from the measured temperature range at the start of the test. The RPM response shall be recorded when the temperature is outside this pre-determined range.

The temperature range is determined from a full day of temperature measurements performed prior to the start of the test (refer to as pre-test). With the ^{57}Co and ^{60}Co sources, listed in Table 2, placed on a tripod (or similar mounting fixture without shielding each other) centered in front of the RPM detection assembly, at 2.5 m from the front face of RPM panel, and 2.25 m from the floor, monitor the RPM count rate over the course of the day. Changes in the RPM count rate should be less than ±20%. Record the minimum and maximum temperatures for the day as the temperature range.

If the temperature is outside the pre-determined range, the RPM response is verified by placing the ^{57}Co and ^{60}Co sources (together as in the pre-test), listed in Table 2, on a tripod (or similar mounting fixture) centered in front of the RPM detection assembly at a distance of 2.25 m from the floor. Acquire a 5-minute static source measurement by measuring the count rate; calculate the mean count rate and standard deviation. Remove the sources and acquire a 5-minute RPM background by measuring the count rate; calculate the mean count rate and standard deviation. Record these values. The RPM response shall be within ±20% of the average response recorded when the temperature range was established.

If spectral data are collected by the RPM, these data shall be recorded for the background and source measurements described above.

5.8 Source configuration requirements

5.8.1 ^{241}Am Emissions from WGPu Sources

The amount of ^{241}Am present varies widely for different WGPu sources. There is a need to limit the amount of low-energy gamma-ray emissions from ^{241}Am to ensure that test results are comparable when tests are performed using different WGPu sources.

In order to provide comparable results, the emission rate (i.e., net peak area divided by the HGPe full-energy peak efficiency, see Appendix B) of the 60 keV line from ^{241}Am shall be no more than 10 times greater than that of the emission rate of the 375 keV line for ^{239}Pu (e.g., if the emission rate for the 375 keV line for ^{239}Pu is 100 s^{-1} then the emission rate for the 60 keV line for ^{241}Am shall not exceed 1,000 s^{-1}). Copper listed in the American Society for Testing and Materials (ASTM) B152 with more than 99.9% Cu content should be used as the shielding material to reduce these low-energy emissions [10]. The source should be fully surrounded by the shielding material.

NOTE – Other materials such as cadmium or tin may be used to shield the source.

5.8.2 SNM and DU sources

The fluence rates for the HEU, WGPu and DU sources are calculated based on the assumptions described in Appendix B.

Different source masses and shapes may be used for testing. The HEU, WGPu, and DU sources used for the bare test cases shall conform to those listed in Table 4. The fluence rates are based on the 186 keV gamma-ray line for HEU, the 375 keV gamma-ray line for WGPu, and the 1001 keV gamma-ray line for DU.

In order to obtain the required fluence rate, steel may be added. The steel thickness should be adjusted to obtain the required fluence rate.

NOTE – Validation testing showed that the spectral shape is not changed when steel was added to the source.

For each source configuration listed in Table 4, take a spectrum using the HPGe detector to determine the fluence rate at a distance from the source where the front face of the RPM panels will be located during testing (point of measurement, 2.5 m from the RPM panel), see Section 5.2 and Appendix B.

Table 4: HEU, WGPu and DU bare sources

Source	Fluence rate of the source at the detection assembly at 2.5 m (photons/s/cm^2)*
HEU	0.31
WGPu	0.06
DU	0.08

* The actual fluence rate of each gamma source at the time of testing shall be within (-0%, +20%) of the value shown in this table. The uncertainty in the fluence rate should be within ±10% with a coverage factor, k, of 1 (± 1-sigma).

For this TCS, the isotopic composition for the SNM and DU sources shall meet the following conditions:

- HEU shall have at least 90% ^{235}U and no more than 250 ppt ^{232}U,
- DU shall have no more than 0.2% ^{235}U,
- WGPu shall have no more than 6.5% ^{240}Pu and no less than 93% ^{239}Pu.

5.8.3 NORM sources

NORM sources shall be bulk material in order to have an extended source as encountered in commerce. Testing with NORM sources shall be carried out using a flatbed truck that is at least 90 cm high. The NORM should fill at least 1 m in height and 1 m in length of the flatbed truck. The NORM dimensions within the flatbed truck shall be recorded.

The NORM containers used for testing RPMs against this TCS shall be those designed by PNNL [12], see Appendix C.

The NORM containers were designed based on the NORM distribution measured over by RPMs at US ports of entry. The NORM quantity is based on the count rates measured by currently deployed RPMs. Three count rate values from zircon sand and ice melt were selected for testing the RPMs against this TCS, which corresponds to a total of six NORM sources.

For testing purposes, for each type of NORM (i.e., zircon sand and ice melt), the net count rates summed over the four panels in the currently deployed RPM used to design the NORM sources are:

- NORM configuration 1: 2500 cps (± 20%)
- NORM configuration 2: 12500 cps (± 20%)
- NORM configuration 3: 32500 cps (± 20%)

The average absolute efficiency of the RSPs used to determine the strength of the NORM containers is listed in Table 7 in Appendix C.

Identical NORM source containers could be built following the PNNL design specifications [12]. If the RPM used to build identical NORM containers has a different efficiency (as that listed in Table 7), then the count rates should be adjusted based on the RSP efficiencies. If identical NORM source containers are built, the isotopic composition and activity of different NORM materials shall be measured, as the composition of zircon and ice melt may vary from sample to sample. Therefore, a spectrum of each NORM source shall be acquired at a source-to-detector distance for which the detector efficiency is known. This information shall be saved.

5.8.4 Masking using NORM sources

The target source-NORM masking combinations shall be made up of the HEU and WGPu sources listed in Table 4 and each of the six NORM quantities listed in 5.8.3 (three KCl (ice melt) NORMs and three zircon sand NORMs). This corresponds to a total of 12 target source-NORM configurations.

For all measurements, the target and the masking sources shall be collocated, with the target source on top of the masking source. The target sources shall be placed at the distance defined in Section 5.2. The masking source shall not shield the target source.

6 Radiological tests

The procedure for performing the radiological tests of the RPM involves first performing the False Alarm Test, followed by radionuclide categorization and detection tests for gamma rays.

6.1 False alarm test

This test is conducted to verify the operability at different test locations and confirm parameter settings.

6.1.1 Requirements

When tested in an area with a stable background (only natural fluctuations) at the levels stated in Table 1, the false alarm rate shall be less than 1 alarm per 1000 occupancies.

6.1.2 Test method

1) Set up the RPM as required by the manufacturer specifications and in accordance with Section 5.2.
2) Verify that the RPM is working correctly by passing the ^{137}Cs source listed in Table 2 through the detection zone at the test speed of 2.2 m/s and a height of 1.5 m from the floor (see Section 5.2) and verifying that it alarms in 10 out of 10 trials.
3) Determine the process required to cause a 5 s occupancy as described in Section 5.2.
4) Perform 1000 occupancies with a 10 s minimum delay between occupancies.
5) Observe the RPM during the test and record any alarm and categorization that occurred.
6) Results are acceptable when no more than 1 alarm (gamma or neutron) occurs during the false alarm test.
7) When complete, verify that the RPM is functional by repeating step 2).
8) If there is more than 1 alarm during the false alarm test, the alarm threshold should be adjusted so that there are fewer than 1:1000 false alarms. The false alarm test shall be repeated using the new alarm threshold. After adjusting the alarm threshold, it should remain fixed for all the tests in this standard.

NOTE – the requirement and associated test method are not intended to verify the statistically-based false alarm rates as used by the RPM and they do not carry any statistical significance for field operations. In order to statistically verify the 1:1000 false alarm rate with a 95% upper confidence bound (for a Binomial distribution) for RPMs with occupancy sensors, approximately 4500 trials with 1 failure would be required.

6.2 Single radionuclide detection and categorization

6.2.1 Requirements

The RPM shall detect and correctly categorize the single sources listed in Table 2 and Table 4 using the measurement speed listed in Section 5.2.

6.2.2 Test method

1) Set up the RPM as required by the manufacturer specifications and in accordance with Sections 5.2 and 6.1.

2) Using a linear motion system (or similar device), pass the ^{241}Am source from Table 2, horizontally through the detection zone at the required test speed of 2.2 m/s and a height of 1.5 m from the floor as described in Section 5.2.
3) Perform 20 trials and record the alarms and source categorization for each trial. There shall be a minimum 10 s delay between trials.
4) The RPM response is acceptable when 19 gamma ray alarms occur in 20 trials and when there are 19 correct categorizations in the 20 trials. See Appendix A.
5) Repeat step 2) through 4) for the ^{137}Cs, ^{60}Co, ^{133}Ba, ^{57}Co, ^{99m}Tc, ^{131}I, ^{226}Ra, ^{232}Th, DU, HEU, and WGPu sources listed in Table 2 and Table 4.

The test source shall start from a position where the RPM is not able to detect the source and then go past the RPM to a position where it is again not detected (i.e., instrument reading at background level). This can be achieved by distance or by the placement of shielding at the end of source travel.

A linear motion system (or similar device) shall be used when testing with the medical, industrial, SNM, and DU sources. Testing with NORM sources shall be carried out using a flatbed truck.

6.3 Empty cargo container

6.3.1 Requirement

The RPM shall not alarm when an empty Intermodal Cargo Container passes through the detection zone.

6.3.2 Test Method

1) Set up the RPM as required by the manufacturer specifications and in accordance with Sections 5.2 and 6.1.
2) Use an empty 20 ft. Intermodal Cargo Container (IMCC) mounted on a flatbed truck or standard chassis.
3) Drive the empty 20 ft. IMCC through the detection zone at the required test speed of 2.2 m/s as stated in Section 5.2.
4) Perform 20 trials and record the alarms and source categorization for each trial. There shall be a minimum 10 s delay between trials.
5) The RPM response is acceptable when no alarms occur in 19 trials and when there are no radionuclide categorizations in the 19 trials. See Appendix A.

6.4 False positive categorization produced by NORM sources

6.4.1 Requirement

The RPM shall detect and correctly categorize the NORM configurations 1 and 2 sources described in Section 5.8.3. The RPM should detect and categorize the NORM configuration 3 sources described in 5.8.3.

6.4.2 Test Method

1) Set up the RPM as required by the manufacturer specifications and in accordance with Sections 5.2 and 6.1.
2) Mount the first NORM source from 5.8.3 on a flatbed truck.
3) Drive the truck containing the NORM source through the detection zone at the required test speed of 2.2 m/s as stated in Section 5.2.
4) Perform 20 trials and record the alarms and source categorization for each trial. There shall be a minimum 10 s delay between trials.
5) The RPM response for the NORMs with net count rates of NORM configurations 1 and 2 sources is acceptable when 19 gamma-ray NORM alarms or no alarms (if the system is setup to produce no alarms if NORM is categorized) occur in 20 trials and when there are 19 correct categorizations in the 20 trials. See Appendix A.
6) The RPM response for the NORMs with net count rates of NORM configuration 3 sources is used to characterize the instrument response. There is no pass/fail for the categorization criteria for this level of NORM. The RPM shall alarm in 20 out of 20 trials.
7) Repeat step 2) through 6) for all NORM sources listed in 5.8.3.

The test source shall start from a position where the RPM is not able to detect the source and then go past the RPM to a position where it is again not detected (i.e., instrument reading at background level).

6.5 Simultaneous radionuclide categorization - Masking

6.5.1 Requirement

The RPM should detect and correctly categorize the HEU and WGPu target sources described in Section 5.8.2 when masked by the NORM sources described in 5.8.3. The results of this test will be used to characterize the instrument performance. There is no pass/fail criteria for masking.

6.5.2 Test method

1) Set up the RPM as required by the manufacturer specifications and in accordance with Sections 5.2 and 6.1.
2) Mount the first source combination described in Section 5.8.4 on a flatbed truck; ensure that the NORM does not shield the target source (other than the inherent shielding in the presence of the NORM boxes). The target source shall be placed centered on top of the NORM container, see Appendix C for additional information.
3) Drive the truck containing the source combination through the detection zone at the required test speed as stated in Section 5.2.
4) Perform 20 trials and record the alarms and source categorization for each trial. There shall be a minimum 10 s delay between trials.
5) The RPM response shall be recorded and analyzed according to scoring criteria in Appendix A.
6) Repeat step 2) through 5) for all source combinations.
7) In addition, repeat steps 2 through 5 with each of the SNM sources placed on the flatbed truck without NORM container(s) present (i.e., one SNM source at a time).

The test source shall start from a position where the RPM is not able to detect the source and then go past the RPM to a position where it is again not detected (i.e., instrument reading at background level).

7 Documentation

7.1 Certificate

Documentation shall be provided as required in the ANSI N42.35 standard.

7.2 Operation and maintenance manual

Each RPM shall be supplied with operating instructions and maintenance and technical documentation.

Appendix A Scoring Definitions

For this TCS, the alarm scoring logic listed in Table 5 shall be used.

Table 5: Detection system alarm response scoring logic

Source	Detection System Alarm Response (Gamma Only)	Detection System Alarm Response (Neutron Only)	Detection System Alarm Response (Gamma & Neutron)	Detection System Alarm Response (None)
^{241}Am	Correct	False Positive	False Positive	False Negative
^{137}Cs	Correct	False Positive	False Positive	False Negative
^{60}Co	Correct	False Positive	False Positive	False Negative
^{133}Ba	Correct	False Positive	False Positive	False Negative
^{57}Co	Correct	False Positive	False Positive	False Negative
WGPu	Correct	Correct	Correct	False Negative
DU	Correct	False Positive	False Positive	False Negative
HEU	Correct	False Positive	False Positive	False Negative
^{99m}Tc	Correct	False Positive	False Positive	False Negative
^{131}I	Correct	False Positive	False Positive	False Negative
HEU + NORM	Correct	False Positive	False Positive	False Negative
WGPu + NORM	Correct	Correct	Correct	False Negative
DU + NORM	Correct	False Positive	False Positive	False Negative
No source	False Positive	False Positive	False Positive	Correct

Table 6 provides a summary of the required categorization scoring logic.

Table 6: Detection system radionuclide categorization scoring logic

Source	Detection System Categorization Response (NORM)	Detection System Categorization Response (Non-NORM)	Detection System Categorization Response (None)
NORM	Correct	False Positive	False Negative
^{241}Am	False Positive	Correct	False Negative
^{137}Cs	False Positive	Correct	False Negative
^{60}Co	False Positive	Correct	False Negative
^{133}Ba	False Positive	Correct	False Negative
^{57}Co	False Positive	Correct	False Negative
WGPu	False Positive	Correct	False Negative

Source	Detection System Categorization Response (NORM)	Detection System Categorization Response (Non-NORM)	Detection System Categorization Response (None)
DU	False Positive	Correct	False Negative
HEU	False Positive	Correct	False Negative
^{99m}Tc	False Positive	Correct	False Negative
^{131}I	False Positive	Correct	False Negative
HEU + NORM	False Negative	Correct	False Negative
WGPu + NORM	False Negative	Correct	False Negative
DU + NORM	False Negative	Correct	False Negative
No source	False Positive	False Positive	Correct

Appendix B Additional Calculations

The following provides a means to determine fluence rate at the test position or point of measurement.

B.1 Summary of fluence rate calculations

Radiation from an X-ray generator or a radioactive source consists of a beam of photons, usually with a variety of energies. If we consider that the beam is monoenergetic, then one way to describe the beam would be to specify the number of photons, dN, that would cross an area, da, taken at right angles to the beam. The ratio of these would yield what the International Commission of Radiological Units and Measurements (ICRU) has called fluence or photon fluence represented by the capital Greek letter phi.

$$\Phi = \frac{\mathrm{dN}}{\mathrm{da}} \qquad \text{(B.1)}$$

At times, one may be interested in the number of photons that pass through unit area per unit time. This is called the fluence rate and it is represented by the lower case Greek letter phi, thus:

$$\dot{\phi} = \frac{d\Phi}{dt} = \frac{dN}{da\,dt} \qquad \text{(B.2)}$$

When the emission of a point source is isotropic, and we integrate equation (B.2), the fluence rate at a radius, *r*, from the source can be expressed as:

$$\dot{\phi} = \frac{R}{4\pi r^2} \qquad \text{(B.3)}$$

where R is the number of photons per second emitted from the source. For a point source the number of photons per second emitted from the source is equal to the source activity times the emission probability of a gamma ray at energy *E*.

$$R = A * p(E) \qquad \text{(B.4)}$$

If the source is encapsulated in a material, *R* can be express as a function of the source activity, *A* (expressed in Becquerel), as:

$$R = A * p(E) * \exp[-(\mu/\rho)\, x\, \rho] * B \qquad \text{(B.5)}$$

where *p(E)* is the emission probability of a gamma ray at energy *E*, and the source is encapsulated by layer of material with thickness, *x* (expressed in cm), densityρ (expressed in g/cm^3), B is the build-up factor and μ/ρ is the mass attenuation coefficient of the material (expressed in units of cm^2/g). Then the fluence rate at a radius, *r*, from the source can be expressed as:

$$\dot{\phi} = \frac{A*p(E)*B*exp[-(\mu/\rho)\, x\, \rho]}{4\pi r^2} \qquad \text{(B.6)}$$

If the source emits gamma rays at different energies, then the fluence rate can be expressed as:

$$\dot{\phi} = \frac{A}{4\pi r^2} \sum_i p(E_i)\, B_i \exp\left[-\left({}^{\mu}/_{\rho}\right)_i x\, \rho\right] \qquad \text{(B.7)}$$

Note that the fluence rate value obtained using equations (B.6 and B.7) will depend on the cutoff energy used in the calculation. Most radiation detection instruments have difficulties detecting gamma rays with energies lower than 30 keV.

The emission probabilities listed in the Evaluated Nuclear Structure Data File (ENSDF) shall be used for these calculations. These data can be obtained from: http://www.nndc.bnl.gov/. If the required data are not available in ENSDF a list of the photo peaks and emission probabilities used in the calculation shall be provided as part of the support documentation.

If the source is a point source of unknown activity (i.e., isotropic emission), the fluence rate for a single gamma-ray line of energy, *E*, can be measured using a gamma-ray spectrometer equipped with a HPGe or NaI(Tl) detector. In this case the fluence rate can be expressed as:

$$\dot{\phi} = \frac{Area_{net}}{T_{live} * \epsilon(E) * 4\pi r^2} \qquad \text{(B.8)}$$

where $Area_{net}$ is the net photo-peak area of the gamma line of energy *E*, $\varepsilon(E)$ is the detector full-energy peak efficiency for the gamma ray of energy *E*, and T_{live} is the live time of the measurement (expressed in seconds) [Ref. B1]. This calculation assumes that the sources used for the detector efficiency calibration have the same encapsulation and they are measured in the same geometry and distance as the unknown sources. If this is not the case, the necessary corrections shall be applied to the measurements.

Several corrections to the detector full-energy peak efficiency and/or net photopeak area may be needed depending on the measurement conditions. These corrections may include the decay of the source during the measurement time, the source self-attenuation, attenuation and build-up factor through air from the source location to the detector location, attenuation through shielding material, build-up factor of shielding material, pile-up correction, coincidence summing correction and differences in source geometry (e.g., differences of HPGe calibration to measurement geometries).

B.2 Calculations of fluence rates for the SNM, DU, and NORM sources

Most TCS make use of HEU and WGPu source emissions that are based on a 1 kg and 400 g sphere, respectively, as defined in the TCS traceability memo. The DU emission is based on a 2.5 kg plate with a surface area of approximately 400 cm^2 and a thickness of 0.3175 cm. If these quantities are used for the RPM TCS it would be required that these sources are detected at a distance of 2.5 m. Initial validation measurements were performed to assess the suitability of these sources for testing the RPMs. These measurements showed that the emissions from these sources were too large, producing large count rates at the RPMs, so a different approach was used to determine the required fluence rates.

NOTE – these are the International Atomic Energy Agency (IAEA) category III quantities.

Calculations of fluence rates for the HEU, WGPu, and DU sources were based on count rates measured by a 4-panel RPM-8 system. In addition, the HEU and WGPu fluence rates were compared to the ANSI N42.35 standard requirements for ^{133}Ba and ^{57}Co sources. In the ANSI N42.35 standard the activity of the ^{133}Ba is 14 µCi and of the ^{57}Co is 5 µCi. The total fluence rate for these two sources (using a cut-off energy of 40 keV) at 2.5 m as specified in Table 2, are 0.38 photons/s/cm^2 and 0.23 photons/s/cm^2, respectively. For the 383 keV gamma-ray line of ^{133}Ba the fluence rate is equal to 0.058 photons/s/cm^2.

The calculations for NORM are based on the distribution of NORM measured by RPMs throughout the US. This distribution is based on the count rates measured by the RPMs for different types of NORM cargo, see Nationwide Statistics of Gamma Emission Intensity and Isotopic Composition for Alarming Norm Cargo (CY 2016), see reference [13].

B.3 Full-Energy-Peak Efficiency Calculations

The full-energy-peak efficiency is determined for a fixed source geometry (i.e., source-to-detector distance, source height, and source encapsulation) can be determined from gamma-ray lines in the gamma-ray spectrum by:

$$\epsilon(E) = \frac{Area_{net}}{A \times T_{live} \times P_{\gamma}} \qquad \text{(B.9)}$$

where the $Area_{net}$ is the net photo-peak area of the gamma-ray of energy E, A is the source activity at the time of the measurement, T_{live} is the measurement live time, and P_{γ} is the emission probability of the gamma-ray of energy E.

Correction coefficients to account for the source encapsulation and measurement distance shall be applied to the efficiency if the efficiency measurements and the source measurements are performed using different source geometries. Several corrections to the detector full-energy peak efficiency and/or net photopeak area may be needed depending on the measurement conditions. These corrections may include the decay of the source during the measurement time, the source self-attenuation, attenuation and build-up factor through air from the source location to the detector location, attenuation through shielding material, build-up factor of shielding material, pile-up correction, coincidence summing correction and differences in source geometry (e.g., differences of HPGe calibration to measurement geometries), see reference [14].

B.4 Emission probabilities of main gamma-ray line

In order to calculate the emission rate for the main gamma-ray peaks outside source encapsulation the following emission probabilities were used:

Table 7: Emission probabilities for main gamma-ray lines

Radionuclide	Energy (keV)	Emission probability	Uncertainty emission probability
^{241}Am	59.5409	0.3592	0.0017
^{57}Co	122.06065	0.8549	0.0014
^{133}Ba	356.0129	0.6205	0.0019
^{137}Cs	661.657	0.8499	0.002
^{60}Co	1173.228	0.9985	0.0003
^{226}Ra	609.312	0.4549	0.0005

^{232}Th	238.632	0.433	0.0005
^{99m}Tc	140.511	0.885	0.002
^{131}I	364.489	0.812	0.005

These values were obtained from the LNHB website, see http://www.lnhb.fr/nuclear-data/nuclear-data-table/.

The source emission rates listed in Table 2 were determined using the following equation:

$$R = A * p(E) * \exp[-(\mu/\rho)\, x\, \rho] \qquad \text{(B-10)}$$

where A is the source activity (expressed in Becquerel), $p(E)$ is the emission probability of a gamma ray at energy E, and the source is encapsulated by layer of material with thickness x (expressed in cm), density ρ (expressed in g/cm^3) and μ/ρ is the mass attenuation coefficient of the material (expressed in units of cm^2/g). For 0.025 cm wall thickness 316 stainless steel encapsulation the following parameters were used:

- ρ = 7.99 g/cm^3
- Fractional composition by weight (normalized to 1):

  Mn – 0.01
  Cr – 0.17
  Ni – 0.12
  Mo – 0.025
  Fe – 0.675
- XCOM was used for the mass attenuation coefficient (with coherent scattering) calculations (https://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html)

The total mass attenuation coefficients for 316 stainless steel and iron for the main photon energies are listed in Table 8.

Table 8: Total mass attenuation coefficients (with coherent scattering) for 316 stainless steel and iron for the main photon energies

Radionuclide	Energy (keV)	μ/ρ 316 stainless steel (cm^2/g)	μ/ρ iron (cm^2/g)
^{241}Am	59.5409	1.289059257	1.213937592
^{57}Co	122.06065	0.289115752	0.265678200
^{133}Ba	356.0129	0.095638403	0.099213948
^{137}Cs	661.657	0.073530140	0.073927904
^{60}Co	1173.228	0.057487661	0.055665745
^{226}Ra	609.312	0.075832714	0.076831689
^{232}Th	238.632	0.126008638	0.126905308
^{99m}Tc	140.511	0.232177613	0.216872855
^{131}I	364.489	0.094442912	0.098014235

Appendix C NORM Configuration Information

The bins containing the NORM are made out of plastic (4 ft × 4 ft × 4 ft ProBin 48-S polypropylene bins). Additional information can be found in reference [12].

The zircon sand used to make the NORM containers was procured from Continental Minerals Inc. as "Richard's Bay Prime", a mixture of ZrO_2 and SiO_2 that contained up to 500 ppm of Th and U (from Continental Minerals site, http://www.continentalmineral.com/granular.html).

Due to the relatively high bulk density of zircon sand, gamma-ray emissions from material in the center of a NORM container have a high probability of being self-absorbed before escaping. The computer simulation MCNP6 was used to optimize container design that allowed the highest count rate efficiency with the lowest amount of zircon sand. The containers that held the zircon sand NORM were specially designed to provide the thickness of NORM at which point adding additional material would not substantially increase the count rate. The design of the containers consisted of a 15 cm slab of zircon sand (filled to varying amounts depending on the desired count rates) held up by a 1.9 cm thick plywood frame inside the center of the bin. Figure 1 shows the plywood structure prior to being filled with zircon sand.

Figure 1: The plywood frame inside the zircon sand container used to hold up a 15 cm slab of sand.

The ice melt was procured from Wilbur Ellis Co. as muriate of potash fertilizer. Ice melt and muriate of potash fertilizer are the same chemical, KCl, which contains a large amount of the radioisotope ^{40}K. The bins of ice melt each contained roughly 3,000 lbs (1,360 kg) of KCl, with the exception of "bin 78", which was filled with approximately 450 lbs of KCl.

The required NORM count rate values in the RPM are based on an RPM system composed of 4 radiation sensor panels (RSPs), see Figure 2, with the average absolute efficiency values obtained from the 4 RSPs when the sources are placed in the center of each RSP at a distance of 2.4 m from the front face of the RSP as listed in Table 9.

Table 9: Average absolute efficiency of the RSPs used to determine strength of NORM containers

Source	Absolute efficiency	Tolerance
^{137}Cs	3.34×10^{-3}	± 20%
^{60}Co	6.75×10^{-3}	± 20%
^{232}U	6.54×10^{-3}	± 20%

The absolute efficiency is defined as:

$$Absolute\ efficiency = \frac{Net\ count\ rate\ of\ RSP}{Source\ activity\ in\ Bq}$$

The source activity in this formula accounts for the photon intensity attenuation through the source encapsulation; it is the apparent source activity.

The NORM configurations are as follows:

One bin

- Ice melt - 2,500 cps
- Ice melt - 12,500 cps
- Zircon sand - 2,500 cps
- Zircon sand - 12,500 cps

Two bins

- Zircon sand - 32,500 cps

Three bins

- Ice melt - 32,500 cps

Figure 2: Configuration in which a single bin of NORM was utilized.

Figure 3: Configuration in which two bins of NORM were utilized.

Figure 4: Configuration in which three bins of NORM were utilized.

Table 10. Description of NORM used in testing

NORM	Count Rate (above BG)	Bin(s)	Bin Configuration	NORM Dimensions (cm) (length x width x height)
Zircon Sand	2500	78		Slab: 51 x 10 x 15
Zircon Sand	12500	74		Slab: 51 x 10 x 61
Zircon Sand	32500	74,75		51 x 10 x 107
Ice Melt	2500	19		Full bin
Ice Melt	12500	69		Full bin
Ice Melt	32500	66,67,69		Full bin