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Mission Analysis for Using Preventive Radiological/Nuclear Detection Equipment for Consequence Management

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Background

The overall objective of this project is to research, evaluate, and test first responder preventive radiological/nuclear detection (PRND) equipment to provide state and local agencies with scientific guidance on how to effectively use this equipment for response after a radiological/nuclear release or detonation. While the equipment being tested in this effort has been specifically designed by technology manufacturers and purchased by responders for preventive detection and source interdiction operations, the fleet of PRND equipment can help fill critical needs for radiological instrumentation should a consequence management (CM) response take place, as it is currently the most widely available and fielded radiological instrumentation by state and local agencies. This effort will provide scientific guidance on the most effective way to utilize this class of equipment for consequence management missions. Gaining a better understanding of how PRND equipment can operate and perform for these missions will allow for recommendations on the tactical approach responders can use for consequence management operations.

PRND equipment has been placed into service by federal, state, and local agencies throughout the nation. If the equipment capability and limitations are taken into account, this large inventory can be leveraged to support the emergency response in the aftermath of a radiological or nuclear event.

With several hundred makes and models of PRND equipment, often with significantly different detection capabilities that do not align with their nominal PRND equipment type, development of a streamlined categorization scheme with respect to consequence management missions was the first step to identifying safe and effective uses of PRND equipment for radiological/nuclear incident

response. Integrated PRND and response-based equipment categories were defined in the document ***Preventive Radiological/Nuclear Detection Equipment Categorization for Consequence Management***, LLNL-TR-732941, and are summarized in Table 1.

Table 1: Summary of Equipment Categorization

	Category	Defining Characteristics	Mission Applicability
Body worn	Personal Radiation Detector (PRD)	• Highly sensitive, can detect small changes from background. • Alarming, body worn device capable of passing low exposure rate tests of ANSI N42.32. • Typically uses scintillation detectors.	PRND: Detection of low level radiation for contraband investigation. CM: Environmental and personnel contamination surveys in Cold Zone
	Spectroscopic Personal Radiation Detector (SPRD)	• Highly sensitive, can detect and identify low levels of radiation. • Alarming, body worn device capable of passing low exposure rate tests of ANSI N42.48. • Typically uses scintillation detectors.	PRND: Detection and identification of low level radiation for contraband investigation. CM: Environmental and personnel contamination surveys in Cold Zone, Radionuclide ID.
	Extended Range Personal Radiation Detector (ER-PRD)	• Highly sensitive, can detect small changes from background. • Alarming, body worn device capable of passing low exposure rate tests of ANSI N42.32, • Extended range, with the capability to measure up to 10 R/h or more.	PRND: Detection of low level radiation for contraband investigation. CM: Cold and Hot Zone Survey and responder exposure control.
	Personal Emergency Radiation Detectors (PERD) & Monitors	• High range, alarming, body worn device capable of operating above 10 R/h, potentially up to 1,000 R/h (ANSI N42.49A) • Capable of operating in harsh environments.	CM: Detection and entry into Hot Zone, Exposure control and possibly dose monitoring tool.
	Electronic Personal Dosimeter (EPD)	• High range, alarming, body worn device for occupational workers to measure personal dose equivalence for regulatory compliance. • Performance requirements can be found in ANSI N42.20.	CM: Hot Zone detection, responder exposure control and dose monitoring tool if ruggedized

	Category	Defining Characteristics	Mission Applicability
Human Carried	Radio-Isotope Identification Device (RIID)	• Low range, hand-held radiation detector with gamma spectroscopic capabilities. • The device should be capable of passing the radiological performance tests indicated in ANSI N42.34.	Identification of the type of radioactive material to support: PRND: LE investigation. CM: Public safety, Environmental and personnel contamination surveys in Cold Zone[1]
	Hand-Held Survey Meter (Low Range)	• Hand-held devices that detect low levels of radiation up to 10 milliR per hour (mR/h) or more. • PRND mission related performance requirements in ANSI N42.33 • Other requirements in N42.17A (normal conditions) and N42.17C (extreme conditions)	PRND: Detection of low level radiation for contraband investigation. CM: Workplace or public safety. Can be used to find contamination or hotline.
	Hand-Held Survey Meter (High Range)	• Hand-held devices that measure high radiation levels to 10 R/h. • Requirements can be found in N42.17A (normal conditions) and N42.17C (extreme conditions)	CM: Detection and entry into Hot Zone and responder exposure control
	Human-Portable Detector (Backpack)	• Very sensitive radiation detectors. • Large (backpack or suitcase sized). • Capable of passing radiological performance tests indicated in ANSI N42.43	PRND: Detection of low level radiation for contraband investigation. CM: Environmental and personal contamination surveys in Cold Zone
Other	Vehicle Mounted Detection System	• Extremely sensitive radiation detectors. • Large systems that can be mounted on a car, boat, or aircraft • Capable of passing radiological performance tests indicated in ANSI N42.43	PRND: Detection of low level radiation for contraband investigation. CM: Environmental and personal contamination surveys in Cold Zone
	Radiation Portal Monitors	• Fixed or transportable detectors. • Used as a non-intrusive means to screen people, vehicles, or other objects. • Performance tests indicated in ANSI N42.35 (PRND) and FEMA-REP-21 (CM).	PRND: Detection of low level radiation on people or vehicles for contraband investigation. CM: Personal / object contamination monitoring.

Consequence Management Mission Areas

This report defines key mission areas of interest to consequence management and provides an initial assessment of how the integrated PRND/response equipment categories may be able to support the consequence management missions.

[1] The Cold Zone is the area outside of the Hot Zone. There may be some contamination and elevated radiation in this area, but it is below the levels indicated for controlled access. e.g. a Hot Line. The Hot Zone boundary is defined by exposure rate levels > 10 mR h^{-1} (NCRP 2010). The Dangerous Radiation Zone (DRZ) is where exposure rate exceeds 10 R h^{-1} (10,000 mR h^{-1}), within which, actions taken should be restricted to time-sensitive, mission-critical activities, such as lifesaving. (NCRP, 2010)

Description of Radiological Events

The Federal Radiological Monitoring and Assessment Center (FRMAC) Mission Analysis (FMA, Volume One – Revision 3 Emergency (Early) Phase September 2009) document is focused on the federal resource requirements activated to provide rapid support to nuclear/ radiological monitoring and dose assessment activities at a radiological incident site. An analysis of the potential event scenarios was performed to determine the required numbers and types of responders as well as the procedures and equipment necessary for performing the monitoring and dose assessment activities through the Emergency (Early) phase of the incident. All scenarios considered were addressed as single events and are designed to be the foundation for the development of national preparedness standards from which homeland security capabilities can be measured. The following scenarios are identified in the FMA and were considered for this document.

Domestic Nuclear Explosion (DNE)

A low-technology, low-yield (~10 kilotons) nuclear device detonated near ground level in a major U.S. metropolitan area would be catastrophic due to the combined effects of blast, heat, and radiation. This scenario is certainly the bounding event of this document and requires more resources than have currently been identified or evaluated. The focus in this report is not the effects of the blast, heat and prompt radiation at detonation but on the residual radiation that may extend hundreds to thousands of kilometers downwind. Focus of the response shifts from preventing long-term health concerns to reducing the near-term deaths and injuries caused by the highly radioactive fallout. Rescue and lifesaving activities can subject responders to significant doses of radiation. Addressing exposure concerns and decontamination needs will overwhelm the available radiological measurement capabilities.

Nuclear Power Plant Incident or Event Involving Significant Release

In addition to design-basis accidents (accident without containment failure), a terrorist action causing a loss of reactor containment, coupled with a Loss of Coolant Accident (LOCA) event, was evaluated. The significant concerns are the long-term health effects and large areas of contamination (hundreds to thousands of square kilometers). Addressing exposure concerns and decontamination needs will challenge the available radiological measurement capabilities.

Alpha Radiological Dispersal Devise (α-RDD)/Failed Improvised Nuclear Device (IND)

The alpha-particle emitting radionuclides in nuclear weapons can have long-term dose consequences if inhaled or ingested. If a nuclear weapon explodes without initiating nuclear detonation (non-performing nuclear weapon), some of the special nuclear material (alpha emitters such as Plutonium) would be aerosolized and drift downwind, contaminating the landscape and causing an internal dose hazard. Such a release could also happen if alpha-emitting industrial-use radionuclides (such as Americium, Radium, and Polonium) are used in an RDD. The major risk is inhalation; the external radiation exposure levels will not be as extensive as in the other events. External exposure levels may be low but within the range of detection for some PRND equipment depending on the radionuclide. If the RDD source is primarily an alpha emitter (e.g., a Polonium source), PRND equipment may not be as valuable in this scenario.

Beta-Gamma Radiological Dispersal Device (β-γ RDD)

A terrorist detonation of a device with radioactive material that emits beta-gamma radiation or a transportation accident involving beta-gamma material has different risks and exposure modes than the alpha radiation dispersal device. Few fatalities from radiation exposure are expected, though long-term public health concerns and area contamination may be significant issues. The major risk is inhalation and external exposure levels. This event could result in a large "Hot Zone" that exceeds the four-day evacuation PAG for both external exposure and inhalation dose. External exposure levels may be high and result in dangerous levels near ground zero.

Description of Key Zones

A key parameter of radiological detection equipment is its ***Operational Range***[2], which determines the level of radiation that is appropriate for equipment to attempt to monitor. Areas potentially impacted by a radiological/nuclear incident are zoned according to their radiation level. Although there is no universally accepted definition of radiation hazard zones in an emergency response, the following definitions are used by this document:

Cold Zone

The Cold Zone is the area outside of the Hot Zone. There may be some contamination and elevated radiation in the Cold Zone, but it is below the levels defined for controlling access. For a large incident, the Cold Zone may include areas where protective measures are in place such as agricultural embargo. There may also be a ***Warm Zone*** used by response agencies as a transition area between Hot and Cold Zones.

Hot Zone

The National Council on Radiation Protection and Measurement (NCRP) identifies the hot zone[3] boundary if any of the following exposure rate or surface contamination levels are exceeded:

- 10 mR/h exposure rate,
- 60,000 dpm/cm2 beta/gamma surface contamination; or
- 6,000 dpm/cm2 for alpha surface contamination.

10 mR/h is also used by ASTM E2601-15 (for radiation emergencies including RDDs) and IAEA (2006) to define the Hot Zone. The Planning Guidance for Response to a Nuclear Detonation (EOP, 2010) uses this value to define when additional responder controls are required. The Conference of Radiation Control Program Directors refer to this area as the "Low Radiation Zone" (CRCPD, 2006)

[2] This parameter was defined in ***Preventive Radiological/Nuclear Detection Equipment Categorization for Consequence Management***, LLNL-TR-683757

[3] ASTM E2601-08 (for radiation emergencies including RDDs); IAEA 2006; NCRP Report 165, 2010

Dangerous Radiation Zone

NCRP also defines a Dangerous Radiation Zone (DRZ) where exposure rates exceed 10 R/h (10,000 mR/h), within which actions taken should be restricted to time-sensitive, mission-critical activities such as lifesaving.

A similar zone was defined in the Planning Guidance for Response to a Nuclear Detonation (EOP, 2010) called the Dangerous Fallout Zone:

> "The area covered by fallout that impacts responder life-saving operations and/or has acute radiation injury potential to the population is known as the dangerous fallout zone (DFZ). Unlike the LDZ, MDZ, and SDZ[4], the DFZ is distinguished not by structural damage, but by radiation levels. A radiation exposure rate of 10 R/h is used to bound this zone, and the DFZ may span across both the LDZ and MDZ."

Mission Area Requirements

This report has identified several key radiological emergency response mission areas and the detection needs and properties to support response activities in each area.

"Appropriate" and "Marginal" detection capabilities are identified for each mission area:

- Appropriate (■): Detection capabilities that *fully* meet the mission area monitoring needs.
- Marginal (○): Detection capabilities that meet *minimum* mission area monitoring needs. Devices with the specified marginal capabilities can provide useful and relevant data in support of the designated mission or task, but with modification to the normal mode of employment. In addition, its use may create a potentially unsafe condition to the user of the device. This implies a need for understanding the device limitations and care in the interpretation of the data produced by such a device under the circumstances.

Extensive PRND equipment make and model detection specifications were collected and reviewed to screen equipment capabilities against CM mission application requirements. The detailed equipment capability data has been compiled into an extended, cross referenced database. Device capabilities are summarized herein with respect to the mission areas. The detailed database will be maintained by the Domestic Nuclear Detection Office's (DNDO's) Data Mining, Analysis and Modeling Cell (DMAMC).

Cold Zone Missions

Worker Exposure Control

The key property is warning the worker that they are approaching the Hot Line (10 mR/h) for photon energies most likely to be encountered in an emergency. To perform this mission, the equipment should have the following capabilities:

[4] Light Damage Zone (LDZ), Moderate Damage Zone (MDZ) and Severe Damage Zone (SDZ)

Appropriate Capabilities	*Marginal Capabilities*
(■) 0.1 – 10 mR/h effective rate range	(○) 0.1 – 2 mR/h effective rate range
(■) 60-1,250 keV Energy Range	
(■) Audible Alarm	(○) No audible alarm
(■) Readout in exposure rate or dose rate	(○) Does not Readout in exposure rate or dose rate (i.e., 1 -9)

Worker Dose Monitoring

The key property is measuring a worker's accumulated exposure or dose.

Appropriate Capabilities	*Marginal Capabilities*
(■) 1 – 10 mR/h effective rate range	
(■) 60-1,250 keV Energy Range	
(■) 1 – 100,000 mR or mrem minimum integrated exposure or dose range	

The integrated exposure/dose capability is not required for the PRND mission (though it is required for other response devices, like EPDs or PERDs). Per this project's equipment specification review, currently this feature is on:

- 16% of PRD/SPRDs (5 out of 32)
- 44% of ER-PRDs (4 out of 9)
- 34% of RIIDs (21 out of 62)
- 100% of EPDs (Required by definition)
- 100% of PERDs (Required by definition)

Radiation Survey

There are several missions that might be able to use PRND equipment to identify environmental contamination or radiation levels to help inform appropriate protective action decisions. In emergency response activities, projected exposures that warrant protective measures can be used to develop pre-established operational intervention levels (OILs) for taking protective actions and other response actions. These OILS are measurable quantities of environmental contamination that would indicate action is warranted, and are determined by state and federal response staff.

In some cases, areas that may warrant public protective measures such as shelter, evacuation, or relocation can be correlated to ambient exposure rates measurable on PRND equipment. Of course, the specific reading that may be used as a trigger for action will be highly dependent on many factors such as the radionuclide (or mixture of radionuclides), the type of event, and the time post-incident that the measurement is made.

As an example, in the aftermath of a Cesium-137 (Cs-137) based RDD, a measurement of > 0.25 mR/h may indicate that relocation should be considered because the annual exposure rate in that area could exceed 2 rem in the first year after the event.

Although PRND equipment may not always be as accurate as health physics survey equipment and may not be immediately integrated into more formal monitoring efforts (such as those performed by the Federal Radiological Monitoring and Assessment Center (FRMAC)), it can provide decision makers with indicators to support initial, time sensitive decisions.

PRND equipment is generally sensitive enough to provide an indication that a particular OIL may have been exceeded, or support initial estimates that an OIL has not been exceeded and that potentially hazardous protective actions (such as evacuation) are not required.

The key property is detecting low levels of photon radiation with energies most likely to be encountered in an emergency. To perform the Radiation Survey mission, the equipment should have the following capabilities:

Appropriate Capabilities	*Marginal Capabilities*
(■) 0.05 – 10 mR/h effective rate range	(○) 0.05 – 2 mR/h effective rate range
(■) 60 -1,250 keV Energy Range	
(■) Readout in exposure rate or dose rate	

The ability to readout in exposure or dose rate is required for this mission. This feature is not required for PRND missions (though it is required for other devices, like EPDs or PERDs). Instead, some PRND equipment provide a relative number scale or read out in counts per second rather than dose or exposure rate. Currently the dose/exposure rate readout feature is found on:

- 75% of PRD/SPRDs (24 out of 32)
- 89% of ER-PRDs (8 out of 9)
- 82% of RIIDs (51 out of 62)
- 100% of EPDs (Required by definition)
- 100% of PERDs (Required by definition)

Person/Object External Contamination Detection (γ)

Surveys conducted to determine if the contamination on a person or object exceeds predetermined criteria are needed during the aftermath of a radiological/nuclear incident. For this mission, detection sensitivity is important as the device should be able to detect low levels of contamination on a person or object. In a large-scale event, an initial screening level of 1 microcurie (μCi) of Cs-137 spot contamination is considered acceptable[5]. Equipment that could effectively detect 0.05 mR/h could also be used to initially screen for higher contamination levels, but this would be considered marginal.

[5] Screening level identified in National Council on Radiation Protection and Measurement. (2011), "Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers". Report No. 165, ISBN 978-0-9823843-3-6, December 31, 2010. This is also the "Fixed + Loose" contamination screening level found in ***Background Information on Fema-Rep-22: Contamination Monitoring Guidance for Portable Instruments Used for Radiological Emergency Response to Nuclear Power Plant Accidents.*** See Appendix 2 of ***Mission Analysis for Using Preventive Rad/Nuc Detection Equipment for Consequence Management*** report for more information.

Testing at Brookhaven National Laboratories[i] demonstrated that most PRDs can detect 1 µCi Cs-137 of spot contamination at a distance of 2 inches from the surface of clothing, skin, or object surveying at a speed of 12 inches s^{-1}, although some equipment may need to be used at 6 inches s^{-1}.

Appropriate Capabilities	*Marginal Capabilities*
(■) Reliably Detect 1 µCi Cs-137 of spot contamination	(○) 0.05 mR/h effective detection range

Although a 0.05 mR/h effective detection range is an inherent function for most PRND equipment, some of the equipment identified on the mission analysis table, such as EPDs and PERDs, may not inherently have this capability.

For more information, see the appendix on ***Technical Background on Personal Contamination.***

Isotope Identification

Identifying the radionuclide(s) involved in a consequence management mission is important to provide more specific responder and public protection criteria and to establish appropriate OILs based on the radio-toxicity of the material. Sampling and isotopic analysis would likely be conducted on a tactical basis to characterize the initial post-incident radiation environment. Therefore, spectroscopic capability is not a required element for Cold Zone detection equipment.

Although radionuclide identification is an integral part of RIIDs and SPRDs, these features can sometimes be found on backpacks and portal monitors as well. The ANSI standards that define this instrument's capability are well suited for both prevention and consequence missions and are therefore not an area that requires further evaluation for multiple mission applicability.

Hot Zone Missions

A key Hot Zone mission requirement is that instruments have capability for high range (up to 10 R hr^{-1}) detection to support worker dose monitoring and exposure control. This capability will be inherent in PERDs and ER-PRDs, but not all EPDs or survey instruments have this capability. For more information, see figure 1 in the *Preventive Radiological/Nuclear Detection Equipment Categorization for Consequence Management* technical report.

PRND equipment is made for law enforcement support and is not (typically) a safety system. Because of this, methods of communicating a radiation alert are often subtle, not overt. Although not listed as a requirement, it is preferred that equipment used in the Hot Zone or Dangerous Radiation Zone provide a noticeable, unambiguous alert to the user even if they are operating in a noisy, distracting environment.

Another a highly desirable feature in the Hot and Dangerous Radiation Zones is exposure rate over-range alarm and datalogging capability to track over-range events.

Worker Exposure Control

As with Worker Exposure Control for the Cold Zone mission, the primary function of the equipment is to alert the wearer that they are approaching radiation levels that would require different controls. However, the higher dose rates that may be encountered in the Hot Zone (from 0.01 R/h to 10 R/h) require more proactive equipment to avoid potential overexposure situations.

Appropriate Capabilities	*Marginal Capabilities*
(■) 1 – 10,000 mR/h effective rate range	
(■) 60-1,250 keV Energy Range	
(■) Audible Alarm	
(■) Readout in exposure rate or dose rate	

Worker Dose Monitoring

As with Worker Dose Monitoring for the Cold Zone mission, the primary function of the equipment is to alert the wearer that they are approaching an accumulated dose guideline level where alternate controls may be required. However, the higher dose rates that may be encountered in the Hot Zone (from 0.01 R/h to 10 R/h) require more proactive equipment to avoid potential overexposure situations.

Appropriate Capabilities	*Marginal Capabilities*
(■) 1 – 10,000 mR/h effective rate range	(○) 1 – 1,000 mR/h effective rate range
(■) 60 -1,250 keV Energy Range	
(■) 1 – 100,000 mR or mrem minimum integrated exposure or dose range	
(■) Audible Alarm	(○) No audible alarm

Radiation Survey (Hot Zone Only)

The primary function of the equipment is to make environmental measurements in the hot zone which may have exposure rates from 0.01 R/h to 10 R/h. This is important for early, rough estimates of contamination (such as transecting the contamination footprint from an RDD) to better normalize the model predictions.

Appropriate Capabilities	*Marginal Capabilities*
(■) 0.005 – 10,000 mR/h effective rate range	
(■) 60 -1,250 keV Energy Range	
(■) Readout in exposure rate or dose rate	

Dangerous Radiation Zone Missions

A key requirement is that Instruments have the capability for very high range (up to 1,000 R/h) functionality. Although PERDs must be able to achieve these dose rates, not all ER-PRDs or EPDs can perform up to this level. For more information, see Figure 1 in the *Preventive Radiological/Nuclear Detection Equipment Categorization for Consequence Management* technical report.

Worker Exposure Control and Monitoring

The primary function of the equipment is to alert the wearer that they are approaching radiation levels that would require different controls or have exceeded integrated exposure guidelines. However, the extremely high dose rates that may be encountered in the Dangerous Radiation Zone (> 10 R/h) require the equipment read up to 999 R/h and have more obvious alarms to avoid potential overexposure situations.

Appropriate Capabilities	*Marginal Capabilities*
(■) 1 – 999,000 mR/h effective rate range	(O) 1 – 100,000 mR/h effective rate range
(■) 60-1,250 keV Energy Range	
(■) 1 – 999,000 mR or mrem minimum integrated exposure or dose range	
(■) Audible Alarm for either dose or dose rate	

General Equipment Categories Evaluated Against Mission Analysis

Table 2 summarizes the equipment category capabilities as a function of consequence management mission area. Footnotes on the table identify when common equipment capabilities that exceed baseline category requirements would change the applicability of that instrument for the mission.

Summary Table Legend:

■ Appropriate for the mission,
O Marginal, meets minimum requirement,
⦸ Insufficient for the mission

(1): Instruments with capability to track integrated exposure or dose.
(2): Instruments with capability for low range (down to 0.1 mR/h) exposure monitoring.
(3): Instruments that readout in exposure or dose rate and do not automatically adjust for background.
(4): Instruments with capability for energy spectroscopic analysis
(5): Dosimeter with capability for read out in the field
(6): Instruments with capability for high range (up to 10 R/h) functionality.
(7): Instruments with capability for very high range (up to 999 R/h) functionality
(8): Instruments with loud audible and vibration alarm

Table 2: General Equipment Categories Evaluated Against Mission Analysis

	Mission	Personal Radiation Detector (PRD & SPRD)	Extended Range Personal Radiation Detector (ER-PRD)	Personal Emergency Radiation Detectors (PERD) & Monitors	Electronic Personal Dosimeter (EPD)[E]	Radio-Isotope Identification Device (RIID)	Hand-Held Survey Meter (Low Range)	Hand-Held Survey Meter (High Range)	Human-Portable Detector (Backpack) &Vehicle Mounted	Radiation Portal Monitors (RPM)
Cold Zone (< 10 mR/h)	Worker Exposure Control	■	■	■	■	O	O	O	O	N/A
	Worker Dose Monitoring	⊘ ■ if (1)	⊘ ■ if (1)	■	■	⊘ O if (1)	⊘ O if (1)	⊘ O if (1)	⊘	N/A
	Person/Object External Contamination Detection (γ)	■	■	⊘ Oif (2)	⊘ Oif (2)	■	■	O	■	■
	Radiation Survey (Cold Zone Only)	O ■ if (3)	■	⊘ O if (2)	⊘	■	■	O	■	N/A

■ Appropriate for the mission,

O Marginal, meets minimum requirement,

⊘ Insufficient for the mission

(1) Instruments with capability to track integrated exposure or dose.

(2) Instruments with capability for low range (down to 0.05 mR/h) exposure monitoring.

(3) Instruments that readout in exposure or dose rate and do not automatically adjust for background.

(4) Instruments with capability for energy spectroscopic analysis

(5) dosimeter with capability for read out in the field

(6) Instruments with capability for high range (up to 10 R/h) functionality.

(7) Instruments with capability for very high range (up to 999 R/h) functionality

(8) Instruments with loud audible and vibration alarm

	Mission	Personal Radiation Detector (PRD & SPRD)	Extended Range Personal Radiation Detector (ER-PRD)	Personal Emergency Radiation Detectors (PERD) & Monitors	Alarming Electronic Personal Dosimeter (EPD)	Radio-Isotope Identification Device (RIID)	Hand-Held Survey Meter (Low Range)	Hand-Held Survey Meter (High Range)	Human-Portable Detector (Backpack) &Vehicle Mounted	Radiation Portal Monitors (RPM)
Hot Zone (>10 mR/h)	Worker Exposure Control	⦸	O ■ if (8)	■	O ■ if (8)	⦸	⦸	O	⦸	⦸
	Worker Dose Monitoring	⦸	⦸ ■ if (1), (8)	■	O ■ if (8)	⦸	⦸	⦸ O if (1)	⦸	⦸
	Radiation Survey (Hot Zone Only)	⦸	■	■	⦸	⦸	⦸	■	⦸ ■ if (6)	⦸
DRZ (>10 R/h)	Worker Exposure Control	⦸	⦸ ■ if (7), (8)	■	O ■ if (7), (8)	⦸	⦸	O	⦸	⦸
	Worker Dose Monitoring	⦸	⦸ ■ if (1), (7), (8)	■	O ■ if (7), (8)	⦸	⦸	⦸ O if (1)	⦸	⦸

■ Appropriate for the mission,
O Marginal, meets minimum requirement,
⦸ Insufficient for the mission

(1) Instruments with capability to track integrated exposure or dose.

(3) Instruments that readout in exposure or dose rate and do not automatically adjust for background.
(4) Instruments with capability for energy spectroscopic analysis
(5) dosimeter with capability for read out in the field

(6) Instruments with capability for high range (up to 10 R/h) functionality.
(7) Instruments with capability for very high range (up to 999 R/h) functionality
(8) Instruments with loud audible and vibration alarm

References

(ASTM, 2015) ASTM E2601-15, Standard Practice for Radiological Emergency Response, http://www.astm.org/cgi-bin/resolver.cgi?E2601, ASTM International, West Conshohocken, PA, 2008, www.astm.org.

(CDC, 2014) Centers For Disease Control and Prevention: Population Monitoring in Radiation Emergencies: A Guide for State and Local Public Health Planners, April, 2014.

(CRCPD, 2006) CRCPD Publication 06-6, Handbook for Responding to a Radiological Dispersal Device: First Responders Guide – The First 12 Hours, Conference of Radiation Control Program Directors, September 2006, www.crcpd.org.

(FRMAC,2015) Federal Radiological Monitoring and Assessment Center. (2015). The Federal Manual for Assessing Environmental Data During a Radiological Emergency. Federal Radiological Monitoring and Assessment Center (FRMAC) Assessment Manual; Volume 1: Overview and Methods. SAND2015-2884P.

(IAEA, 2003) International Atomic Energy Agency: "Method for Developing Arrangements for Response to A Nuclear or Radiological Emergency," ISBN 92-0-111503-2, IAEA, 2003.

(IAEA, 2006) International Atomic Energy Agency: "Manual for First Responders to a Radiological Emergency," IAEA, 2006.

(NCRP, 2001) National Council on Radiation Protection and Measurements: "Management of Terrorist Events Involving Radioactive Material," NCRP Report No. 138, ISBN 0-929600-71-1, October 24, 2001, http://www.ncrppublications.org/Reports/138.

(NCRP, 2005) National Council on Radiation Protection and Measurements: "Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism," NCRP Commentary No. 19, ISBN 0-929600-88-6, December 31, 2005, http://www.ncrppublications.org/Commentaries/19.

(NCRP, 2010) National Council on Radiation Protection and Measurement. , “Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers”. Report No. 165, ISBN 978-0-9823843-3-6, December 31, 2010, http://www.ncrppublications.org/Reports/165.

(NCRP, 2010A) National Council on Radiation Protection and Measurements: "Population Monitoring and Radionuclide Decorporation Following a Radiological or Nuclear Incident," NCRP Commentary No. 166, ISBN 978-0-9823843-7-4, December 31, 2010 http://www.ncrppublications.org/Reports/166.

(Musolino, 2013) Musolino, Stephen, Frederick Harper, Brooke Buddemeier, et al. “Updated Emergency Response Guidance For The First 48 H After The Outdoor Detonation Of An Explosive Radiological Dispersal Device,” 2013.

(EPA, 2017) U.S. Environmental Protection Agency: "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," EPA 2017. https://www.epa.gov/radiation/pag-manuals-and-resources

(EOP, 2010) Executive Office of the President Homeland Security Council Interagency Policy Coordination subcommittee for Preparedness and Response to Radiological and Nuclear Threats, Planning Guidance for Response to a Nuclear Detonation (June 2010). Office of Science and Technology Policy, available at www.ostp.gov

Appendix 1: Mission Applicability for Various Equipment

Below are tables summarizing equipment applicability for various missions based on currently available information collected from manufacturer specification sheets, equipment manuals, and manufacture inquiry.

Table Legend:

- ■ Appropriate for the mission,
- O Marginal, meets minimum requirement,
- ⦸ Insufficient for the mission
- ? Indicates that there was insufficient information to make a determination of mission applicability

Each overall Mission rating is based on the lowest rating of all the requirements for the mission. For example, since the D-Tect Mini-RadD received a O for the overall "Worker Exposure Control" mission applicability because it was a O for the exposure readout category even though it was ■ for energy range, exposure rate range, and alarming capability.

Manufacturer	**Model**	**Worker Exposure Control: Cold Zone (overall)**	Exposure Control: Cold Zone: Gamma Dose Rate Range	Exposure Control: Cold Zone: Gamma Energy Range	Exposure Control: Cold Zone: Alarm Type (Audible)	Exposure Control: Cold Zone: Readout (Exposure or Dose Rate)
D-Tect Systems	**miniRad-D**	O	■	■	■	O

Personal Radiation Detector (PRD & SPRD)

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Berkeley Nucleonics Corp	NukAlert 951	N/A	●	○	⊘	⊘	⊘	⊘	⊘	⊘	⊘
D-Tect Systems	miniRad	D	●	○	⊘	⊘	⊘	⊘	⊘	⊘	⊘
D-Tect Systems	miniRad	DX	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Mirion	PDS-100	G	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Mirion	PDS-100	G/ID	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Mirion	PDS-100	GN	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Mirion	PDS-100	GN/ID	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Mirion	PDS-GO		●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Mirion	PDS-ID Vanguard		●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1401	GNA	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1401	GNB	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Polimaster	1401	GN-BT	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1401	MA	●	●	○	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1401	MB	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1703	GN	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1703	GNA	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1703	GNB	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1703	M	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1703	MA	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1703	MB	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1704	A	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1704	A-GN	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Polimaster	1704	GN	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Polimaster	1704	SPRD	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
RAE Systems	Neutron-RAE	II	○	●	●	●	⊘	⊘	⊘	⊘	⊘
Sensor Technology Engineering	HRM	N/A	●	○	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Sensor Technology Engineering	Pager	N/A	●	○	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Sensor Technology Engineering	Pager	S	●	○	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Thermo Electron	Intercep-tor	G	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	RadEye	GN	●	●	●	●	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	RadEye	GN+	●	●	●	●	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	RadEye	PRD	●	●	●	●	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	RadEye	SPRD	●	●	●	●	⊘	⊘	⊘	⊘	⊘

Extended Range Personal Radiation Detector (ER-PRD)

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Polimaster	1703	GNM	●	●	●	⊘	●	●	⊘	●	⊘
Polimaster	1703	MO-1	●	●	●	●	●	●	●	●	●
Polimaster	1703	MO-2	●	●	●	●	●	●	●	⊘	⊘
Polimaster	1704	A-GNM	●	●	●	⊘	●	●	⊘	●	⊘
Polimaster	1704	A-M	●	●	●	⊘	●	●	⊘	●	⊘
Polimaster	1704	M	●	●	●	⊘	●	●	⊘	●	⊘
RAE Systems	Gamma-RAE	IIR	○	●	●	●	●	●	●	○	○
Sensor Technology Engineering	HRM	HR	⊘	○	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	RadEye	PRD-ER	●	●	●	●	●	●	●	⊘	⊘

Personal Emergency Radiation Detectors (PERD) & Monitors

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Canberra	mini-Radiac (Military AN/UDR-13)	N/A	⊘	○	⊘	●	○	○	●	○	○
Canberra	Ultra Radiac-Plus	N/A	⊘	●	⊘	●	●	●	●	○	○
Thermo Scientific	RadEye	G	⊘	●	●	●	●	●	●	⊘	⊘

Alarming Electronic Personal Dosimeter (EPD)

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Mirion	Rad-60		⊘	●	⊘	●	●	●	●	○	○
Mirion	Rad-62		⊘	●	⊘	●	●	●	●	○	○

Radio-Isotope Identification Device (RIID)

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Berkeley Nucleonics Corp	microSAM 950	G	●	●	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Berkeley Nucleonics Corp	microSAM 950	GN	●	●	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Berkeley Nucleonics Corp	microSAM 950	HG	●	●	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Berkeley Nucleonics Corp	microSAM 950	HGN	●	●	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Berkeley Nucleonics Corp	Sam 940	2C	●	●	●	⊘	●	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	Sam 940	2-G	●	●	●	⊘	●	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	Sam 940	2-GN	●	●	●	⊘	●	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	Sam 945	CG	●	●	●	⊘	●	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	Sam 945	CGN	●	●	●	⊘	●	●	⊘	⊘	⊘

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Berkeley Nucleonics Corp	Sam 945	G	●	●	●	⊘	●	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	Sam 945	GN	●	●	●	⊘	●	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	Sam 945	LG	●	●	●	⊘	●	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	Sam 945	LGN	●	●	●	⊘	●	●	⊘	⊘	⊘
Canberra	Falcon 5000	N/A	●	○	●	?	⊘	?	?	⊘	?
Canberra	Inspector 1000	IPROL-1	●	●	●	●	●	●	●	⊘	⊘
Canberra	Inspector 1000	IPROL-1N	●	●	●	●	●	●	●	⊘	⊘
Canberra	Inspector 1000	IPRON-1	●	●	●	●	●	●	●	⊘	⊘
Canberra	Inspector 1000	IPRON-1N	●	●	●	●	●	●	●	⊘	⊘
Defentect	GT4 Sensor	N/A	●	?	?	?	?	?	?	?	?
D-Tect Systems	Rad-ID	G	●	●	●	?	?	?	?	⊘	⊘

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
D-Tect Systems	Rad-ID	GN	●	●	●	?	?	?	?	⊘	⊘
FLIR Radiation Inc.	IdentiFINDER 2	LG	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	LGH	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	NG	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	NGH	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	T1	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	T2	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	ULCS-NG	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	ULCS-NGH	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	ULK-NG	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	ULK-NGH	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	UW-CS-NG	●	●	●	●	⊘	⊘	○	⊘	⊘

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
FLIR Radiation Inc.	Identi-FINDER 2	UW-CS-NGH	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	UW-ULCS-NG	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Identi-FINDER 2	UW-ULCS-NGH	●	●	●	●	⊘	⊘	○	⊘	⊘
FLIR Radiation Inc.	Nano-Raider	ZH	●	●	●	?	⊘	⊘	?	⊘	⊘
FLIR Radiation Inc.	Nano-Raider	Z	●	●	●	?	⊘	⊘	?	⊘	⊘
FLIR Radiation Inc.	Rad-Hunter	ULCS-NG	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
FLIR Radiation Inc.	Rad-Hunter	ULCS-NGH	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
FLIR Radiation Inc.	Rad-Hunter	UL-LG	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
FLIR Radiation Inc.	Rad-Hunter	UL-LGH	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Leidos	GR-135	CN	●	●	●	?	●	●	?	⊘	⊘
Leidos	GR-135	N	●	●	●	?	●	●	?	⊘	⊘

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Leidos	GR-135	Plus	●	●	●	?	●	●	?	⊘	⊘
Mirion	SpiR-ID	LaBr	●	●	●	?	⊘	⊘	?	⊘	⊘
Mirion	SpiR-ID	NaI	●	●	●	?	⊘	⊘	?	⊘	⊘
Ortec	Detective	DX	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Ortec	Detective	DX-100	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Ortec	Detective	EX	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Ortec	Detective	EX-100	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Ortec	Micro-Detective	DX	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Ortec	Micro-Detective	HX	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Ortec	Micro-Detective	N/A	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Ortec	RadEagle	3SG	●	●	●	●	●	●	●	○	○

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Ortec	RadEagle	3SG-H	●	●	●	●	●	●	●	○	○
RadCom	Syclone	N/A	●	●	●	●	●	●	?	⊘	⊘
Radiation Solutions Inc. (RSI)	RS-330	N/A	●	●	○	⊘	⊘	⊘	⊘	⊘	⊘
Radiation Solutions Inc. (RSI)	SR-10 super RIID	N/A	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Smith Detection	Rad-Seeker	CL	●	●	●	?	⊘	⊘	⊘	⊘	⊘
Smith Detection	Rad-Seeker	CS	●	●	●	?	⊘	⊘	⊘	⊘	⊘
Smith Detection	Rad-Seeker	CS-G	●	●	●	?	⊘	⊘	⊘	⊘	⊘
Spectra	MKS	11G	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Spectra	MKS	11GN	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	RIIDEye	X-G	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	RIIDEye	X-GN	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Thermo Scientific	RIIDEye	X-H	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	RIIDEye	X-HN	●	●	●	⊘	⊘	⊘	⊘	⊘	⊘

Human-Portable Detector (Backpack)

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Berkeley Nucleonics Corp	SAM Pack RD-120	2CG	●	●	●	⊘	⊘	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	SAM Pack RD-120	2CGN	●	●	●	⊘	⊘	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	SAM Pack RD-120	CG	●	●	●	⊘	⊘	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	SAM Pack RD-120	CGN	●	●	●	⊘	⊘	●	⊘	⊘	⊘

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Berkeley Nucleonics Corp	SAM Pack RD-120	G	●	●	●	⊘	⊘	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	SAM Pack RD-120	GN	●	●	●	⊘	⊘	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	SAM Pack RD-120	LG	●	●	●	⊘	⊘	●	⊘	⊘	⊘
Berkeley Nucleonics Corp	SAM Pack RD-120	LGN	●	●	●	⊘	⊘	●	⊘	⊘	⊘
Bruker Detection	Sentry	MK II	●	○	○	⊘	⊘	⊘	⊘	⊘	⊘
Bruker Detection	Sentry	N/A	●	○	○	⊘	⊘	⊘	⊘	⊘	⊘
Bubble Technology Industries	FlexSpec Backpack	N/A	●	●	●	⊘	●	●	⊘	○	⊘
Bubble Technology Industries	FlexSpec Backpack	N/A	●	●	●	⊘	●	●	⊘	○	⊘
Environics	Ranid	PRO200	●	?	?	⊘	⊘	⊘	⊘	⊘	⊘
Mirion	SPIR-Pack	G	●	?	?	⊘	?	●	⊘	?	⊘
NucSafe	Guardian Predator	N/A	?	?	?	?	?	?	?	?	?

Manufacturer	Model	Model Variant	Contamination Screening: Cold Zone	Worker Exposure Control: Cold Zone	Exposure Rate Survey: Cold Zone	Integrated Dose: Cold Zone	Worker Exposure Control: Hot Zone	Exposure Rate Survey: Hot Zone	Integrated Dose: Hot Zone	Worker Exposure Control: Dangerous Zone	Integrated Dose: Dangerous Zone
Sensor Technology Engineering	RadPack	MAX	●	○	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Sensor Technology Engineering	RadPack	N/A	●	○	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	FHT-1377 PackEye	N/A	●	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	FHT-1377 PackEye	G	●	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Thermo Scientific	FHT-1377 PackEye	GN-2	●	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘

Appendix 2: Technical Background on Personal Contamination

Although there are several guidelines and references for personal contamination, currently there is no universally agreed on technical criteria for personal contamination. Many guidelines, such as "twice background" (EPA 1992 PAG) provide no method to correlate to actual contamination levels. Others, such as the CRCPD RDD Guidance of 1,000 - 10,000 CPM using a pancake probe 1 inch from the surface, are instrument specific and without knowing the survey speed (how quickly the probe is moving over the person's body surface), cannot be correlated to a specific spot contamination level.

In order to test the performance of PRND equipment for this mission, a specific technical criterion, which can be validated against laboratory experimentation, must be used. For personal and object contamination, the important experimental features are: spot contamination level, widespread contamination level, distance of equipment from body surface, and survey speed. The last item is particularly important as large-scale population monitoring activities become unmanageable if it takes more than a few minutes to survey a person.

For this reason, it is recommended to use similar equipment test methods to those described in ***Background Information on Fema-Rep-22: Contamination Monitoring Guidance for Portable Instruments Used for Radiological Emergency Response to Nuclear Power Plant Accidents.*** Table 3 describes the technical basis for the detection level criteria used in FEMA REP-22.

Table 3: Derived Required Detectable Levels to Avoid Health Effects (FEMA, 2002)

Effect	Assumed Maximum Acceptable Area of the Condition from Undetected Contamination	Spot Contamination		Total Body Contamination	
		(µCi)[a] Loose[b]	(µCi)[a] Fixed[c]	(µCi)[a] Loose[b]	(µCi)[a] Fixed[c]
Acute Exudative Radiodermatitis	0.2 cm^2	0.95	0.10	N.A.[d]	N.A.
Ulceration with Fibrosis	0.2 cm^2	4.3	0.46	N.A.	N.A.
Ulceration from a Hot Particle	N.A.	2.1	N.A.[e]	N.A.	N.A.
Erythema	5 cm^2	9.7	1.0	N.A.	N.A.
Skin Cancer	N.A.	N.A.	N.A.	694	74

a. The Minimum Detectable Levels were derived for each health or radiation effect based on the calculated µCi-h of exposure needed to cause the effect. These values were then divided by the expected hours of exposure (see Section II.D of Background Information on Fema-Rep-22: Contamination Monitoring Guidance for Portable Instruments Used for Radiological Emergency Response to Nuclear Power Plant Accidents).

b. Loose contamination that is not detected by monitoring is assumed to be removed by bathing within 36 hours after its deposition on the skin.

c Fixed contamination is assumed to be removed by natural processes within 336 hours (14 days) after deposition on the skin.

d. N.A. means not applicable.

e. Hot particles are assumed to be removable by bathing (i.e., loose contamination).

The most restrictive detectable amount noted in the table above is for Acute Exudative Radiodermatitis which results in a (rounded) values of:

- **1 µCi Cs-137 for fixed + loose contamination**
- **0.1 µCi Cs-137 for fixed contamination**

The differences between the two values can be attributed to the amount of time required for skin to naturally slough off fixed contamination vs. the assumption that loose contamination would likely be removed through washing and clothing change within 36 hours of the contamination event.

Although these values are established primarily for Nuclear Reactor Accidents, for the purpose of this report, it is assumed that these values will be sufficient for most β/γ emitters that would produce these types of health effects. Although PRND equipment that has the energy range to detect the low energy photons from many alpha emitters, the predominant health effect from alpha emitters would be inhalation or ingestion through cross contamination and alternate technical criteria should be considered.

FEMA REP-22 (Contamination Monitoring Standard for a Portal Monitor Used for Radiological Emergency Response) provides similar guidance for "walk through" portal monitors. For Portal monitors, the standard uses:

- **One or more cesium-137 source(s) with a <u>total activity not exceeding one µCi</u> shall be used for determining compliance with this Standard.**

Surface Contaminated Objects

Releasing potentially contaminated objects is not normally an emergency phase priority, however there may be cases (e.g., vehicles and critical response equipment) where it is warranted. The difficulty is that the standard for such action is often a very conservative criterion. For example, ANSI/HPS N13.12-2013 uses criteria of 1 mrem / yr total effective dose (TED) [see Table 3]. This results in Table 4 are derived contamination limits based on assumptions of subsequent use. Although it is unclear if PRND equipment might be used to evaluate such surface contamination levels, their relative sensitivity might make it possible and it is worth exploring.

Table 4: Screening levels for clearance from ANSI N13.12

Radionuclide groups[7]	SI units[6]	Conventional units	
	Surface (Bq/cm$^{2)}$ Volume (Bq/g)	Surface (dpm/100 cm$^{2)}$	Volume (pCi/g)
Group 1 High-energy gamma, radium, thorium, transuranics, and mobile beta-gamma emitters: ^{22}Na, ^{46}Sc, ^{54}Mn, ^{56}Co, ^{60}Co, ^{65}Zn, ^{94}Nb, ^{106}Ru, ^{110m}Ag, ^{125}Sb, ^{129}I[8], ^{134}Cs, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{182}Ta, ^{207}Bi, ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{229}Th, ^{230}Th, ^{232}Th, ^{232}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{244}Pu, ^{241}Am, ^{243}Am, ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm, ^{249}Cf, ^{251}Cf, ^{254}Es, and associated decay chains[9], and others	0.1	600	3
Group 2 Uranium and selected beta-gamma emitters: ^{14}C, ^{36}Cl, ^{59}Fe, ^{57}Co, ^{75}Se, ^{85}Sr, ^{90}Sr, ^{95}Zr, ^{99}Tc, ^{105}Ag, ^{109}Cd, ^{113}Sn, ^{124}Sb, ^{123m}Te, ^{139}Ce, ^{140}Ba, ^{155}Eu, ^{160}Tb, ^{181}Hf, ^{185}Os, ^{190}Ir, ^{192}Ir, ^{204}Tl, ^{206}Bi, ^{233}U, ^{234}U, ^{235}U, ^{238}U, natural uranium[10], ^{237}Np, ^{236}Pu, ^{243}Cm, ^{244}Cm, ^{248}Cf, ^{250}Cf, ^{252}Cf, ^{254}Cf, and associated decay chains[9], and others	1	6,000	30
Group 3 General beta-gamma emitters: ^{7}Be, ^{74}As, ^{93m}Nb, ^{93}Mo, ^{93}Zr, ^{97}Tc, ^{103}Ru, ^{114m}In, ^{125}Sn, ^{127m}Te, ^{129m}Te, ^{131}I, ^{131}Ba, ^{144}Ce, ^{153}Gd, ^{181}W, ^{203}Hg, ^{202}Tl, ^{225}Ra, ^{230}Pa, ^{233}Pa, ^{236}U, ^{241}Pu, ^{242}Cm, and others	10	60,000	300
Group 4 Low-energy beta-gamma emitters: ^{3}H, ^{35}S, ^{45}Ca, ^{51}Cr, ^{53}Mn, ^{59}Ni, ^{63}Ni, ^{86}Rb, ^{91}Y, ^{97m}Tc, ^{11m}Cd, ^{115m}In, ^{125}I, ^{135}Cs, ^{141}Ce, ^{147}Nd, ^{170}Tm, ^{191}Os, ^{237}Pu, ^{249}Bk, ^{253}Cf, and others	100	600,000	3,000
Group 5 Low-energy beta emitters: ^{55}Fe, ^{73}As, ^{89}Sr, ^{125m}Te, ^{147}Pm, ^{151}Sm, ^{171}Tm, ^{185}W, and others	100 (surface)[11] 1,000 (volume)	600,000[11]	30,000

[6] The screening levels for clearance have been rounded to one significant figure and are assigned to both surface and volume radioactivity (assuming an average surface to mass ratio of 1:1, as discussed in Annex A), unless otherwise noted. Note: regulatory authorities *may* increase all volume and surface screening levels by one order of magnitude when clearing bulk quantities of less than 1 metric ton or 1 m^2.

[7] To determine the specific group for radionuclides not shown, a comparison of the screening factors, by exposure scenario, listed in Tables B.1, C.1, and D.1 of NCRP Report No. 123I (NCRP 1996) for the radionuclides in question and the radionuclides in the general groups above *should* be performed and a determination of the proper group made, as described in Annex A.

[8] Because of potential ground-water concerns, the volume or surface radioactivity values for ^{129}I *should* be lowered by one order of magnitude when disposal to landfills or direct disposal to soil is anticipated.

[9] For decay chains, the screening levels represent the total activity (i.e., the activity of the parent plus the activity of all progeny) present.

[10] The natural uranium screening levels for clearance *shall* be lowered from Group 2 to Group 1 if decay-chain progeny are present (i.e., uranium ore versus process or separated uranium, for example, in the form of yellowcake). The natural uranium activity equals the activity from uranium isotopes (48.9% from ^{238}U, plus 48.9% from ^{234}U, plus 2.2% from ^{235}U). This approach is consistent with summing radionuclide fractions discussed in Section 4.4.

[11] For radioactivity control considerations, surface radioactivity screening levels for Group 5 radionuclides are controlled to the Group 4 surface radioactivity screening levels.