System Assessment and Validation for Emergency Responders (SAVER)

Portable Radiological Equipment Technical Guide

July 2012

Homeland Security
Science and Technology

U.S. Department of Homeland Security
SAVER
System Assessment and Validation for Emergency Responders

Prepared by National Urban Security Technology Laboratory

Approved for Public Release

FOREWORD

The U.S. Department of Homeland Security (DHS) established the System Assessment and Validation for Emergency Responders (SAVER) Program to assist emergency responders making procurement decisions. Located within the Science and Technology Directorate (S&T) of DHS, the SAVER Program conducts objective assessments and validations on commercial equipment and systems and provides those results along with other relevant equipment information to the emergency response community in an operationally useful form. SAVER provides information on equipment that falls within the categories listed in the DHS Authorized Equipment List (AEL). The SAVER Program mission includes:

- Conducting impartial, practitioner-relevant, operationally oriented assessments and validations of emergency responder equipment; and
- Providing information that enables decision-makers and responders to better select, procure, use, and maintain emergency responder equipment.

Information provided by the SAVER Program will be shared nationally with the responder community, providing a life- and cost-saving asset to DHS, as well as to Federal, state, and local responders.

The SAVER Program is supported by a network of Technical Agents who perform assessment and validation activities. Further, SAVER focuses primarily on two main questions for the emergency responder community: "What equipment is available?" and "How does it perform?"

As a SAVER Program Technical Agent, the National Urban Security Technology Laboratory (NUSTL) has been tasked to provide expertise and analysis on key subject areas, including radiological instrumentation for interdiction and emergency response. In support of this tasking, NUSTL developed this technical guide to assist emergency responders in determining application-appropriate portable radiological equipment. Portable radiological equipment covered by this guide falls under the following AEL equipment categories and reference numbers:

- Personal Dosimeter 07RD-01-DOSP;
- Self Reading Dosimeter 07RD-01-DOSS;
- Electronic Personal Dosimeter 07RD-01-EPD;
- Handheld Survey Meter 07RD-01-HHSM;
- Alarming Personal Radiation Detector 07RD-01-PDGA; and
- Radionuclide Isotope Identifier 07RD-01-RIID.

Visit the SAVER library at www.dhs.gov/science-and-technology/SAVER for more information on the SAVER Program or to view additional reports on portable radiological equipment or other technologies.

POINTS OF CONTACT

National Urban Security Technology Laboratory
U.S. Department of Homeland Security
Science and Technology Directorate
201 Varick Street
New York, NY 10014-7447

E-mail: NUSTL@hq.dhs.gov

Website:www.dhs.gov/science-and-technology/SAVER

TABLE OF CONTENTS

Foreword i

Points of Contact ii

Executive Summary v

1. INTRODUCTION 1
   - 1.1 Product Category and the Authorized Equipment List 2
   - 1.2 Other Classification Terminology 5

2. RADIOLOGICAL CHARACTERISTICS FOR HOMELAND SECURITY 5
   - 2.1 Types of Radiation 5
   - 2.2 Measurement Quantities and Units (dpm, R, rad, rem) 6
   - 2.3 Range of Radiation Levels 8

3. MISSION APPLICATIONS 11
   - 3.1 Interdiction Missions – Detection & Identification 11
   - 3.2 Response Mission – Responder Radiation Safety 12
   - 3.3 Response Mission – Incident Management Duties 15

4. AEL PORTABLE RADIATION DETECTION EQUIPMENT 17
   - 4.1 Personal Dosimeter (07RD-01-DOSP) 18
   - 4.2 Self Reading Dosimeter (07RD-01-DOSS) 19
   - 4.3 Electronic Personal Dosimeter (07RD-01-EPD) 20
   - 4.4 Alarming Personal Radiation Detector (07RD-01-PDGA) 21
   - 4.5 Handheld Survey Meter (07RD-01-HHSM) 23
   - 4.6 Radionuclide Isotope Identifier (07RD-01-RIID) 24
   - 4.7 Other Portable Radiation Instruments (Backpack Systems, SPRDs, Alarming PERDs) 26

5. SUMMARY 29

6. REFERENCES 30

APPENDIX A. DISCUSSION OF RADIOLOGICAL TERMINOLOGY: R, RAD, AND REM A-1
   - A.1 Quantities vs. Units A-1
   - A.2 Exposure (R), air kerma (rad), Absorbed Dose (rad) A-1

A.3 Dose Equivalent (rem), Effective Dose (rem) A-2
A.4 $H_p(10)$ Personal Dose Equivalent (rem) A-3
A.5 International Units: Gray (Gy) and Sievert (Sv) - factor of 100 .... A-4
A.6 References Cited in Appendix A A-4

APPENDIX B. RADIATION INSTRUMENT TECHNOLOGIES B-1

LIST OF TABLES

Table 1-1 Product Category Summary 4
Table 3-1 Reference Values for Emergency Responder Radiation Safety 13
Table 3-2 Examples of Decision Guidelines for Actions to Protect the Public 16
Table 3-3 Summary of Radiological Characteristics and Equipment Capabilities for Interdiction and Response Missions 17
Table 4-1 Summary of Portable Radiological Detection Equipment Features, Applications, and Reference Documents 28

LIST OF FIGURES

Figure ES-1 Homeland Security Missions, Equipment Ranges, and Reference Values vi
Figure 1-1 Examples of Some Commonly Encountered Terminology for Portable Radiological Equipment 1
Figure 1-2 Key Radiological Characteristics for Equipment Selection 2
Figure 2-1 Homeland Security Missions, Equipment Ranges, and Key Reference Values 10
Figure 4-1 Examples of Personal Dosimeters 18
Figure 4-2 Examples of Self Reading Dosimeters 19
Figure 4-3 Example of an Electronic Personal Dosimeter 20
Figure 4-4 Example of an Alarming Personal Radiation Detector 21
Figure 4-5 Examples of Handheld Survey Meters 23
Figure 4-6 Examples of Radionuclide Isotope Identifiers 24
Figure 4-7 Example of a Backpack System 26

EXECUTIVE SUMMARY

In homeland security applications, portable radiological equipment is worn or carried into field operations to detect and measure radiation for interdiction or response missions. Interdiction involves detection and identification of radioactive material to prevent a radiological dispersal device (RDD) or improvised nuclear device (IND) event. In response missions after a release of radioactive material, radiation measurements would be used for responder safety, to inform tactical decisions, and in carrying out various response duties. The many different commercially available instruments are designed for specific tasks and, while some have overlapping capabilities, no single instrument can do everything. This leaves potential users with the difficult task of navigating through varied terminology and numerous types of devices to find the right one for their application. This technical guide is intended to explain fundamental concepts in radiation measurement to aid the user in equipment selection. It does not set or describe U.S. Government policy. This report focuses on portable radiation detectors worn or carried into field operations. It excludes fixed and vehicle-mounted systems, and does not discuss nuclear forensics.

The U.S. Department of Homeland Security (DHS) Authorized Equipment List (AEL) specifies the following categories under Portable Radiation Detectors:

- Personal Dosimeter (07RD-01-DOSP);
- Self Reading Dosimeter (07RD-01-DOSS);
- Electronic Personal Dosimeter (07RD-01-EPD);
- Handheld Survey Meter (07RD-01-HHSM);
- Alarming Personal Radiation Detector (07RD-01-PDGA); and
- Radionuclide Isotope Identifier (07RD-01-RIID).

Some instruments do not directly correspond to an AEL category, such as Radiation Detection Backpacks, Spectroscopic Personal Radiation Detectors (SPRDs), and alarming Personal Emergency Radiation Detectors (PERDs). Others may combine multiple functions that overlap AEL categories, and unclear terminology and ambiguous product names may also make it difficult to determine how to classify equipment.

Distinctions between the different types of equipment are determined by three key radiological characteristics: radiation type, measurement units, and measurement range. These three characteristics define whether a detector is appropriate for any particular task. Radiation type refers to the instrument capability for detecting or measuring gamma, neutron, alpha, or beta radiation. Measurement units in Roentgen (R), rad, rem, or disintegrations per minute (dpm) quantify the amount of radiation present and its effects on different materials. The measurement range describes the instrument capabilities for measurements along nine orders of magnitude from background radiation to lethal levels. Appropriate combinations of these characteristics address the many different possible needs and applications in interdiction and response missions.

Interdiction missions involve the measurement of gamma radiation, where it is necessary to measure the exposure rate at levels near background (approximately 10 μR/h) with a fast response time to detect illicit sources; the photon spectrum may be used to identify the source. Neutron detection is also applicable in specialized interdiction missions. In RDD or IND response missions gamma radiation is of primary interest for responder radiation safety, where the measurement of exposure rate in units of Roentgen per hour (R/h) as well as accumulated dose in rad or rem are applicable to avoiding acute effects and minimizing possible long-term effects. Acute effects can occur at high range (above 100 rad) and can be immediately life threatening, while low levels may

increase the risk of cancer later in life. Neutron measurements are not considered as significant for responder safety because they rarely occur without accompanying gamma radiation and are expected primarily during the initial blast of an IND, becoming a minimal contribution by the time responders would be present. Alpha and beta radiation are not expected to penetrate responder protective gear, but are applicable for contamination measurements (in dpm) for incident management and would be a hazard if ingested or inhaled.

Alarming Personal Radiation Detectors (07RD-01-PDGA) are used for source detection and Radionuclide Isotope Identifiers (07RD-01-RIID) for source identification in interdiction missions. Spectroscopic Personal Radiation Detectors (SPRDs) and Backpack Systems may also be used. These instruments typically do not have the appropriate range or measurement units for responder radiation safety. For radiation safety in response missions, Electronic Personal Dosimeters (07RD-01-EPD) with alarming capabilities are best suited where acute effects are possible. Non-field readable Personal Dosimeters (07RD-01-DOSP) are suitable for lower radiation levels and potential long-term effects. Self Reading Dosimeters (07RD-01-DOSS) can augment measurements in both ranges. The Handheld Survey Meter (07RD-01-HHSM) has applications in both interdiction and response missions, and for responder safety as well as incident management. This report lists applicable SAVER TechNotes, market surveys, and assessment reports, interagency performance standards, and other test reports currently available for these AEL categories.

Figure ES-1 illustrates typical instrument ranges, key reference values, and homeland security missions in the context of the wide range of radiation levels.

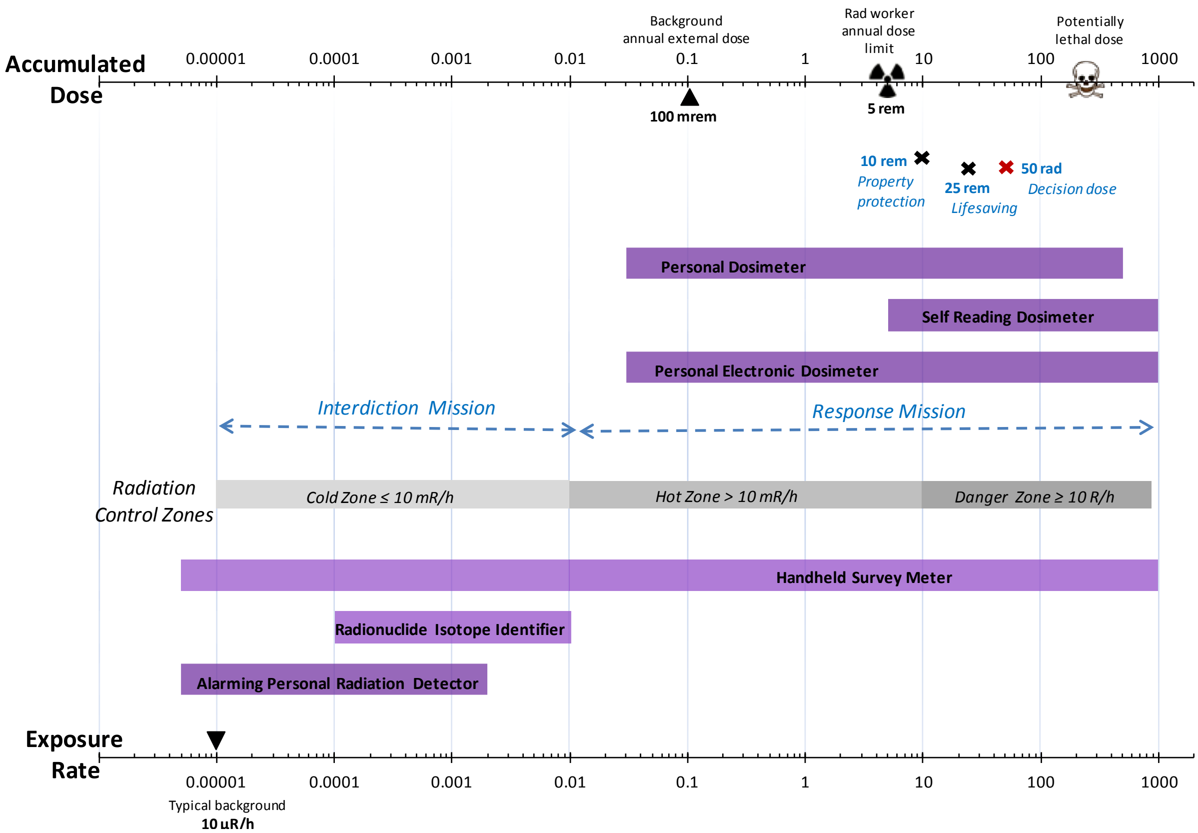


Figure ES-1. Homeland Security Missions, Equipment Ranges, and Reference Values

Each gridline is a factor of 10: the lower x-axis shows exposure rate, the upper x-axis shows accumulated dose. The range of radiation levels applicable in homeland security tasks spans nine orders of magnitude, from natural background (▼) through occupational levels (☢), to potentially lethal doses (☠). Dashed lines show the applicable range of radiation levels encountered in interdiction and response missions. Bars illustrate typical equipment measurement ranges. Responder protective action guidelines (**x**) for tactical decision points are also shown.

1. INTRODUCTION

Ionizing radiation comes from the decay of an unstable element and can transfer energy to the material through which it passes. Although people cannot see, smell, or feel ionizing radiation, it can interact with human tissue and cause immediate or long-term health problems. Radiological instruments are designed to detect and measure radiation for a wide range of applications. Specialized equipment has been developed for many different fields, such as medical diagnostics and treatment, food industries, and nuclear plant operations.

This technical guide is intended to explain fundamental concepts in radiation measurement to aid the user in equipment selection. It does not set or describe U.S. Government policy. This technical guide focuses on homeland security applications involving detection, assessment, personnel safety, and tactical response activities involved after a radiological dispersal device (RDD) or improvised nuclear device (IND) incident. For example, law enforcement may use radiation detectors to search for illicit radioactive material or, in the event of a radiation incident, to determine whether it is safe to enter a contaminated area. Responders may use equipment to monitor their dose in order to take protective actions, and in the course of their response duties to establish appropriate areas for command posts, evacuation paths, decontamination areas, evacuations, and sheltering in place, as well as during subsequent recovery operations. This report focuses on portable radiation detectors worn or carried into field operations. It excludes fixed and vehicle-mounted systems, and does not discuss nuclear forensics.

Hundreds of commercial products with a wide array of capabilities, technologies, and price ranges are marketed to first responder organizations. Understanding the distinctions among the different types of equipment and their uses is the focus of this report. It is not a simple task, as many instruments have overlapping capabilities and terminology is inconsistent. Also, there are several ways to classify radiation instruments. Figure 1-1 illustrates this with examples of commonly used, though in some cases imprecise, terminology.

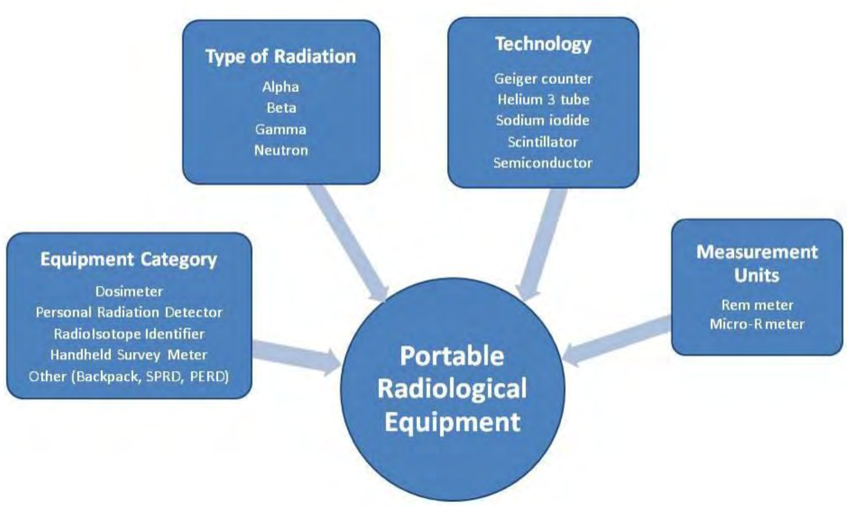


Figure 1-1. Examples of Some Commonly Encountered Terminology for Portable Radiological Equipment

A particular instrument may have multiple features from these groupings; for example, some instruments may measure both gamma and neutron radiation, or contain scintillators and Geiger tubes.

Ultimately, the selection of the appropriate radiation instrument depends on its intended use. In contrast to some of the terminology examples shown in Figure 1-1, there are three key underlying radiological characteristics that can be used to identify which types of portable radiological equipment are needed for different tasks within homeland security interdiction and response missions: radiation type (alpha, beta, gamma, and neutron), measurement units (R/h, rad, rem, dpm), and the measurement range of interest (from a span of nine orders of magnitude) (Figure 1-2).

Figure 1-2. Key Radiological Characteristics for Equipment Selection

In various homeland security scenarios, an emergency responder may encounter varying types of radiation at a range of levels. For example, in assessing contamination after an RDD, a responder would encounter different radiation types and higher levels than in searching for concealed radioactive sources. Commercially available instruments geared toward particular applications use appropriate combinations of the three key radiological characteristics. This technical guide explains how each of the three characteristics applies in response and interdiction missions and the required equipment capabilities.

1.1 Product Category and the Authorized Equipment List

The Authorized Equipment List (AEL), published by the Federal Emergency Management Agency (FEMA) Grant Programs Directorate, U.S. Department of Homeland Security (DHS), lists categories of equipment that are eligible for certain Federal grants. The AEL lists the following categories under Portable Radiation Detectors:

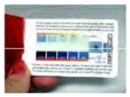
- Personal Dosimeter (07RD-01-DOSP);
- Self Reading Dosimeter (07RD-01-DOSS);
- Electronic Personal Dosimeter (07RD-01-EPD);
- Handheld Survey Meters (07RD-01-HHSM);
- Personal Radiation Detectors (07RD-01-PDGA); and
- Radionuclide Isotope Identifiers (07RD-01-RIID).

Table 1-1 defines each category. Section 4 presents a more in-depth description of the product types along with references to reports, standards, and other resources.

Some commercial products do not correspond directly to an AEL category or may combine multiple functions which overlap categories, such as Spectroscopic Personal Radiation Detectors (SPRDs), Radiation Detection Backpacks, and alarming Personal Emergency Radiation Detectors (PERDs). Unclear terminology and ambiguous product names may also make it difficult to determine how to classify equipment. Also, some technical terms are commonly misused. For example, “detection” and “dosimetry” are often inaccurately interchanged, and the term “exposure” is used in the general sense while it also has a technical definition.

To help resolve these issues, this report explains the three key radiological characteristics that define the equipment capabilities needed for homeland security missions. It discusses the instrument features corresponding to these characteristics which help distinguish between the product categories. It also lists and sorts the SAVER reports, interagency standards, and other test reports applicable to each category.

Table 1-1. Product Category Summary

Sample Photo[1]	Product AEL Number	Description
	**Personal Dosimeter** 07RD-01-DOSP	Low cost, passive (no battery) device worn on the body to measure accumulated dose for personal health applications. These do not provide real time information; they must be read out with special equipment and are widely used in radiation worker safety programs.
 	**Self Reading Dosimeter** 07RD-01-DOSS	Passive (no battery), field-readable device worn on the body to measure accumulated dose for personal radiation safety applications. This category includes carbon fiber pocket ion chambers and self-developing photochemical (radio-chromic) dosimeters (non-alarming PERDs).
	**Electronic Personal Dosimeter** 07RD-01-EPD	Battery powered device worn on the body with a digital readout that provides real-time dose-rate information to the wearer. May have alarm capability.
	**Personal Radiation Detector (PRD)** 07RD-01-PDGA	Pocket-sized, field-readable, alarming, instrument that is worn on the body and used for rapid detection of radioactive materials for detection and interdiction.
	**Handheld Survey Meter (HHSM)** 07RD-01-HHSM	Handheld instruments that measure the activity or the exposure rate from radioactive material. HHSMs are used where radioactivity is suspected to be present in order to locate or to assess the intensity of the radioactivity. They generally measure gamma radiation and some have changeable detector probes. Those with thin detector windows are used to measure alpha or beta contamination and are also referred to as contamination monitors. Some products also measure neutrons.
	**Handheld Radionuclide Isotope Identifier (RIID)** 07RD-01-RIID	Handheld, battery powered instrument used for gamma-ray exposure measurement and to detect and identify radionuclides; some have an indication of neutron radiation. Isotope identification capability aids in discriminating between threats and benign sources of radioactivity. RIIDs may be used for follow-up measurements after a PRD or other alarm.
	**Other Equipment[2]:** **Spectroscopic Personal Radiation Detector (SPRD)** **Radiation Detection Backpack** **Alarming Personal Emergency Radiation Detector (PERD)**	Battery powered instrument that combines the qualities of a PRD with radioisotope identification capability. • Overlaps 07RD-01-PDGA and 07RD-01-RIID. Detection equipment housed in a backpack used for covert searches for gamma- and/or neutron-emitting radioactive materials. These systems may have spectroscopic capability to identify what isotopes are present, which aids in discriminating between threats and benign sources. • Can overlap multiple AEL categories depending on the equipment contained. Battery powered instrument used for exposure control but not for dosimetry of record for radiological emergency operations. • No AEL number at the time of this report.

1 Photographs are provided by NUSTL to show examples of the type of product described. No endorsement of any particular product is implied.
2 Examples of portable radiological equipment not directly corresponding to a single AEL category but for which a performance standard has been published.

1.2 Other Classification Terminology

Aside from product category, other terms are used when describing radiation detectors. For example, a "neutron detector" refers to the type of radiation detected, and any one of the product categories above (Personal Radiation Detector, Handheld Survey Meter, Backpack, etc.) could potentially include neutron detection capability. The choice of what type of radiation to measure depends on the intended use for the instrument. Section 2.1 describes the four types of radiation (alpha, beta, gamma, and neutron) and their relation to different mission needs.

Similarly, terms like a "sodium iodide detector" or a "Geiger counter," refer to the technology used. There are different materials and techniques used to detect and measure the different types of radiation. The choice of technology used in a detector relates to the type of radiation one wants to measure and the application since each technology has trade-offs in price, sensitivity, durability, weight, and other factors. Appendix B contains a brief description of common technologies.

Thus, while there are several ways to sort radiological equipment, Section 2 explains the three key underlying characteristics, type of radiation, measurement units, and measurement range which are linked to homeland security applications in Section 3.

2. RADIOLOGICAL CHARACTERISTICS FOR HOMELAND SECURITY

Three main characteristics distinguish one type of instrument from another: first, what type of radiation is measured; second, in what quantity the measurement is taken; and third, what level of radiation is of interest.

2.1 Types of Radiation

Radiation comes from the random decay of an unstable element as it transforms into something stable. As they decay, some unstable elements may emit particles, which are called alpha, beta, or neutrons, and some may emit photons (electromagnetic energy) in the form of "x-rays" and "gamma rays."[1] The energy of the emitted particles or photons depends on the radioactive source. Alphas, betas, neutrons, and gamma rays have different properties and methods of detection and they factor differently into various homeland security missions.

Alpha particles do not travel very far in air and do not penetrate the outer layer of human skin. Beta radiation can travel tens of feet in the air and are primarily only an external hazard to the skin and eyes. However, they are both an internal health concern if inhaled, ingested, or enter through a wound. None of the instruments covered in this report are designed to measure this "internal dose," but some are used to measure alpha or beta emitting material that becomes

[1]The difference between x-rays and gamma rays is how they are produced: gamma rays result from changes in the nucleus of an atom, while x-rays result from electrons as they make transitions in an atom or decelerate as they pass through matter. Typically x-rays are lower energy than gamma rays, but they can overlap. This distinction between x and gamma rays is not relevant here; therefore, in the remainder of this report, the use of the term "gamma" is used interchangeably with "photon" and meant to apply to all the photons of interest, including both gamma and x-rays.

deposited on surfaces so that it can be controlled in order to avoid inhalation. Since alpha and beta particles would not penetrate the outer package of rugged instrumentation, special thin windows are required to allow them to reach the radiation sensitive element of the instrument. Neutron and photon radiations travel further in air and can penetrate the skin. Because of this, they can be a health risk at a distance from a radioactive source; this is called external radiation. Neutrons are difficult to measure and rarely occur without accompanying gamma radiation. Neutrons are not a measurement priority for radiation safety in IND and RDD response missions: the National Council on Radiation Protection (NCRP), in guidance documents published in 2005 and 2010, notes that a significant neutron dose would be expected only during the initial blast from an IND and would be a minimal contribution by the time responders are present (NCRP-19, 2005; NCRP-165, 2010). However, neutron detection can be very important for radionuclide identification in interdiction missions.

Gamma rays are the most relevant type of radiation for most responders. Their measurement is applicable in both interdiction and response missions, and is especially important for responder radiation safety because, as will be explained in Section 3.2, the NCRP radiation protection guidelines for responders apply to this type of radiation (NCRP-165, 2010). All of the product categories covered in this report include equipment designed to measure gamma rays.

2.2 Measurement Quantities and Units (dpm, R, rad, rem)

Most radiation instruments provide more than a simple indication of whether radiation is present; they relay information about the amount of radiation measured. Radiation is quantified in different ways and different instruments display different units. In general, the units commonly encountered for homeland security missions are the following:

● **Disintegrations per minute (dpm)** are used to measure the **activity**[2] of radioactive source material. The counts indicated over a period of time, such as counts per minute or counts per second (cps), refer to a measurement of events at the detector, often corresponding to the audible clicks heard on some detectors. (The conversion from counts at the detector to disintegrations of the source depends on the sensitivity of the individual detector.) While an object exposed to alpha, beta, or gamma radiation does not itself become inherently radioactive,[3] pieces of the radioactive source material could be spread around. “Contamination” is radioactive material that is deposited in unwanted places. For radioactive material deposited on a surface, contamination is commonly measured in units of disintegrations per minute per square centimeter (dpm/cm^2).

● **Roentgen (R)** measures the effect of photon radiation on air as it breaks the molecules down into positively charged ions and negatively charged electrons. This is the technical meaning of the word exposure. Many radiation detectors measure exposure in R or the rate of exposure as Roentgen per hour (R/h).

● The **“rad”** is the unit used to quantify the energy absorbed by a material, such as air, human tissue, or other substance.

[2] The “Curie” (Ci) is the quantity of a radioactive material having 37,000,000,000 transformations in one second.

[3] In contrast, neutrons *can* induce radioactivity in certain elements; this is called activation. For example, hydrogen and cadmium can absorb neutrons and then emit characteristic gamma radiation. This effect can be exploited in some specialized applications, but is not relevant for most responders.

● The **"rem"** is the unit used to quantify dose equivalent and is used with instruments that are specially calibrated to take into account the biological effects of different types of radiation. These effects can depend on the type of radiation and its energy. (This is used in a technically defined operational radiation safety quantity called "Personal Dose Equivalent" discussed in Appendix A.)

Some instruments use System Internationale (SI) units, particularly, Becquerel (Bq) for activity, Gray (Gy) for absorbed dose, and Sievert (Sv) for dose equivalent. As English units are conventionally used in the United States, they will be used in this report. (See Appendix A for more information about SI units.)

In contrast with units of "dpm" which relate to the radioactive source material itself, the "R," "rad," or "rem" units relate to the effects that the emitted photons or particles have on materials that they come in contact with. Different materials may not absorb the same amount of radiation and, as might be expected, the effects of radiation on a nonliving material such as air are not as complex as its effects on the human body. Biological factors are highly variable; for example, some tissues and organs are more sensitive to radiation than others, and effects vary with age and gender. For the purposes of emergency response, a common approximation is that for gamma radiation an exposure of 1 R produces an absorbed dose of 1 rad, and a dose equivalent of about 1 rem.[4] The mission applications where the distinctions between these units are significant are explained in Sections 3 and 4. Appendix A discusses these distinctions and the technical meanings of R, rad, and rem in more detail.

An instrument can indicate an accumulated radiation measure, or it can show the radiation rate (often exposure per hour [R/h]). Some instruments measure both. The essential distinction is the same as that between a speedometer (rate of travel) and an odometer (distance traveled). This means that a reading in R/h can indicate the amount of radiation one would be exposed to in one hour; an accumulated reading indicates the total amount of radiation received over the period of exposure. The applicability of radiation rate vs. accumulated values is discussed in detail in Sections 3 and 4.

Certain instruments, Radionuclide Isotope Identifiers (RIIDs), display a radiation spectrum, which is a graphical distribution of the number of gamma rays detected over a range of energies. Since most radioisotopes emit gamma rays with characteristic energies, the spectra can be used to identify which isotope is the source of the radiation. Just as visible photons span a spectrum of energies that the human eye perceives as colors, the invisible photons emitted by radioisotopes also span a range of energies, which are quantified in units of electron volts (eV). Instrument specifications for many types of radiological equipment, not just RIIDs, usually list the range of photon energies the instrument can measure and its accuracy over that range. This range may span from about 20 kilo-electron volts (keV) to a few mega-electron volts (MeV). Performance standards specific for each type of instrument specify acceptable accuracy and energy range.

[4] See, for example, homeland security radiation detection standards such as ANSI N42.32, as well as NCRP -19 (p. 17) and ASTM E 2601-8 Standard Practice for Radiological Emergency Response.

2.3 Range of Radiation Levels

For different applications in interdiction and response missions, the radiation levels of interest cover a wide range, spanning nine orders of magnitude (factors of ten) in the units of R, rad, or rem discussed above in Section 2.2.

Radiation can be harmful to health in two distinctly different ways: immediately, or many years after exposure.[5] Immediate effects could occur only if the dose is high enough to cause sufficient biological damage to cells that they die in large numbers. Then, damage to the body's blood, immunological, and gastrointestinal systems could cause life threatening health effects within days. The severity and immediacy of these acute effects increases with greater radiation doses. Response to radiation varies greatly between individuals and the outcome depends on subsequent medical intervention; as a general approximation, acute effects are expected to start to occur at accumulated doses of about 100 rad. The dose that is expected to cause death in 50% of the exposed population[6] ranges from 250 – 500 rad, where 500 applies to cases with more medical care (NCRP-161).

In contrast, at lower levels, radiation may be harmful if it damages but does not destroy the DNA of cells, which could result in an increase in the rate of mutations. In these effects, the probability, rather than the severity, increases with dose, and some organs of the body are more sensitive than others. The primary health concern is that if not repaired, mutations could lead to the development of cancer years later[7].

Because unstable elements occur naturally in the environment, a natural background[8] of radioactivity is always present which therefore defines the lower end of equipment measurement capabilities. To manage this wide range of radiation levels, two prefixes are commonly used to describe very small values:

- **µ -** The Greek symbol "mu" stands for "micro" which is one millionth (1/1,000,000 or 10^{-6}) and is used in measurements of the natural background radiation rate. For example, as a rough rule of thumb, a typical natural background external exposure rate is about 10 µR/h.
- **m -** The lowercase "m" stands for "milli" and means one thousandth (1/1,000 or 10^{-3}). For example, as a rough rule of thumb, the accumulated external exposure in one year from naturally occurring radioactive elements in the earth's surface and from the cosmic ray background is on the order of about 100 mR.

Thus the µR, mR, and R provide convenient 1,000-unit increments for radiation measurements.

---

[5] This discussion does not include prenatal exposures. For an embryo/fetus exposed in the uterus, the risk for death and developmental effects is greater and depends on the gestational stage.

[6] The lethal dose expected to cause death in 50% of the exposed population is known as "LD_{50}." Its definition reflects the variability in human health effects.

[7] Hereditary or genetic effects passed on to the next generation through mutations of egg or sperm cells before conception have not been observed in epidemiological studies of human populations, though they have been observed in studies of fruit flies and mice (NCRP–161).

[8] Natural background radiation varies spatially with the local geography and temporally due to atmospheric effects. The values of 10 µR/h typical exposure rate and 100 mR annual exposure are given as order of magnitude points of reference for measurements responders may encounter. They do not include internal exposures from inhalation of natural radon gas or ingestion of natural radionuclides in found in food and water.

Figure 2-1 illustrates this wide range of radiation levels and summarizes several topics that are covered in this report. It illustrates how responder dose guidelines developed by the NCRP and other key reference values, instrument ranges, and homeland security missions relate to each other over the range of radiation levels.

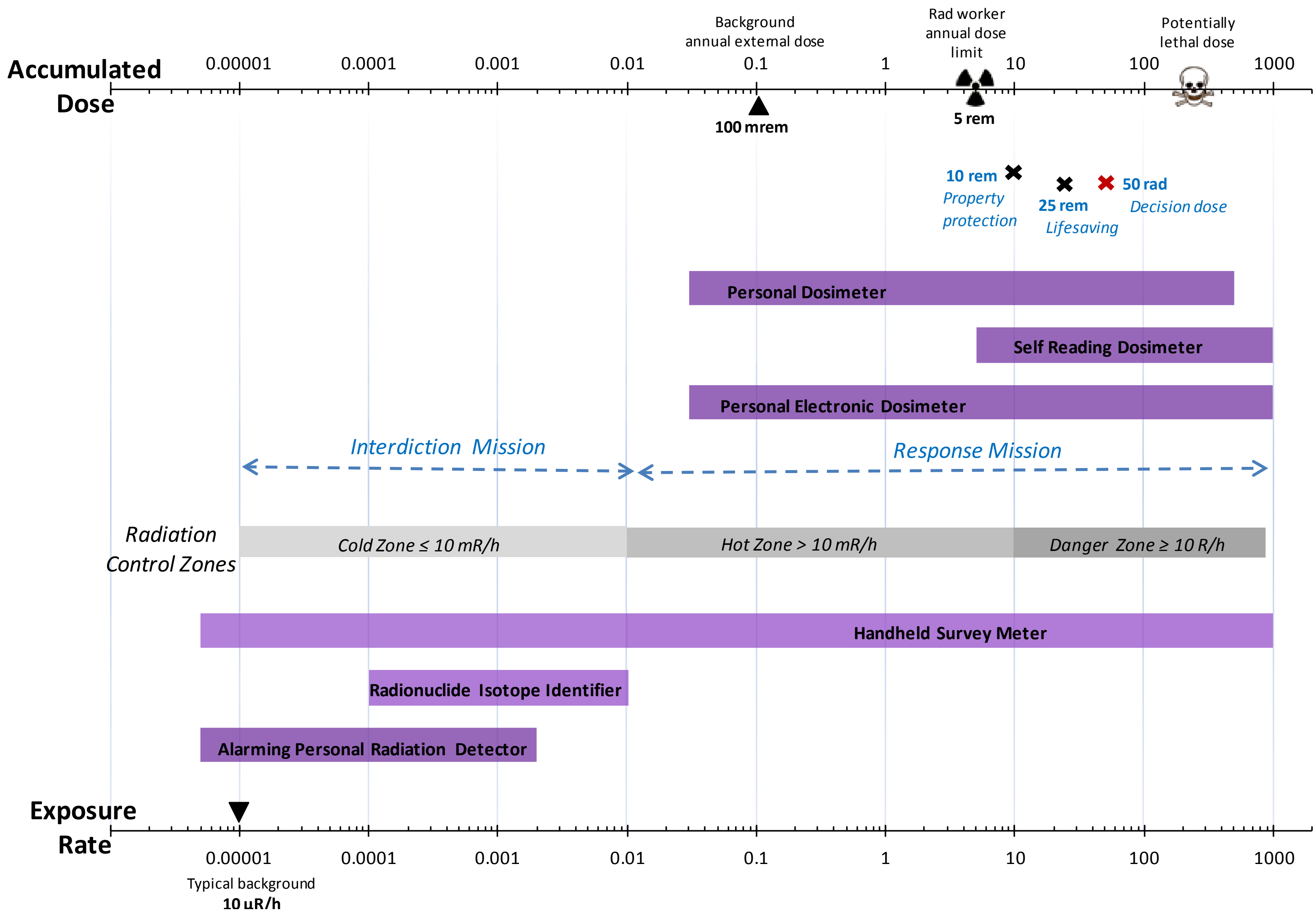


Figure 2-1. Homeland Security Missions, Equipment Ranges, and Key Reference Values

Each gridline is a factor of 10: the lower x-axis shows exposure rate, the upper x-axis shows accumulated dose. The range of radiation levels applicable in homeland security tasks spans nine orders of magnitude, from natural background (▼) through occupational levels ( ), to potentially lethal doses ( ). Acute health effects are expected to occur at an accumulated dose of about 100 rad and greater. Dashed lines show the generally applicable range of radiation levels that may be encountered in interdiction and response missions. Bars illustrate typical measurement ranges for different radiological equipment based on ANSI performance specifications or SAVER market surveys; specific individual product ranges will vary. The range for dosimeters refers to accumulated dose (upper x-axis), and the range for other instruments is in exposure rate (lower x-axis). The protective action guidelines (**x**) for tactical decision points involving property protection (10 rem), and lifesaving (25 rem) activities, and the NCRP 50 rad (**x**) decision dose are explained in section 3.2 and Table 3-1. (See Appendix A for more information about the use of R, rad, and rem.)

3. MISSION APPLICATIONS

Missions involving radiological equipment can be divided into two categories: interdiction and response. In interdiction missions, the goal is to detect illicit radiation sources in order to stop them from being released, which can involve first detection and then identification of the material. Response missions occur after an intentional or accidental release of radioactive material. Within response missions, radiation measurements are needed for several purposes: to inform tactical response decisions, for the safety of individual emergency responders while they are carrying out response duties, and as part of response duties (such as protecting the public).

The following sections explain the radiological characteristics (radiation type, measurement units, and measurement range) applicable to each mission, and the corresponding equipment capabilities. Emphasis is given to the applications for which the equipment is best suited. However, as noted in the *Planning Guidance for Response to a Nuclear Detonation* (Second Edition, June 2010), during a large scale emergency, resources could be overwhelmed and any available radiological equipment may be put to use wherever possible. Therefore, some examples of non-standard potential applications and their limitations are also noted.

3.1 Interdiction Missions – Detection & Identification

The goal in interdiction missions is to intercept the illicit movement of radioactive material. The challenge of this mission is to distinguish threats from common, innocent occurrences of radiation, such as those from naturally occurring materials or medical applications. Typically a phased approach is used, where radioactive material is first detected and then identified.

For interdiction missions, gamma and neutron radiation are of interest. Alpha and beta radiations are not initially relevant because they would be easily shielded and not detectable. The detection of neutrons could be valuable because there are few authorized sources of neutrons, they are more difficult to shield, and their presence could indicate special nuclear material. However, neutrons generated by cosmic rays can be a source for false alarms, especially near large metal structures.

The exposure rate in units of μR/h is often the initial measurement quantity used for detection of elevated gamma radiation. The activity in dpm may be used to locate the source or quantify its magnitude. Once a suspicious radiation source is detected by initial screening, the photon energy spectrum could be used to identify the isotope, thus providing information that can be used to help determine whether the source of radioactivity constitutes a high level threat.

Since illicit sources may be shielded, it is necessary to be able to detect small increases in the background radiation rate, i.e., in the μR/h range. Once a possible source is detected, the equipment should be capable of measuring a higher level so that the user can close in on the source's location. Thus, the interdiction mission typically spans low to medium radiation ranges, from a few μR/h to a few mR/h.

3.1.1 Equipment for Interdiction Missions

Interdiction missions may require several different types of instruments. Initial detection equipment should be sensitive to low exposure rates with a fast response time to indicate radiation that is shielded and fleeting. Alarming Personal Radiation Detectors (PRDs) have these capabilities, are designed to be worn unobtrusively by law enforcement personnel performing other tasks, and alarm discreetly where the radiation rate changes. Some PRDs use special software algorithms to discriminate between innocent alarms due to naturally occurring or medical material (without displaying the spectral lines). To identify the radiation source, a RIID or SPRD could be used. Some RIIDs and PRDs also have neutron indicators which could be important to identify a potential nuclear device. Though more commonly used in response applications, an instrument with a wider sensitivity range such as a Handheld Survey Meter (HHSM) could be used to help determine the source's location and magnitude (some also have neutron indicators). For dedicated search operations during special events or in situations where information suggests a possible threat, Backpack Systems and more sensitive detectors may be used from the outset to both detect and identify radioactive material.

The Personal Dosimeter, Self Reading Dosimeter, and Electronic Personal Dosimeter are not designed for detection and interdiction applications. The Personal Dosimeter does not give real time information, and the Self Reading Dosimeter does not have sensitivity to low levels of radiation, so neither of these is helpful for interdiction missions. The energy compensating material required for the Electronic Personal Dosimeter to have a reading proportional to the human health hazard would typically reduce their sensitivity for detection and interdiction applications. In some situations (e.g., where higher energy photons are involved), some models could potentially be used for screening or as a crude survey meter in non-standard usage. While some electronic dosimeters may include neutron sensitivity, the neutron component of the dose may not be distinguished from the gamma component, so it is not likely to be helpful in identifying a potential nuclear device.

3.2 Response Mission – Responder Radiation Safety

The purpose of radiation protection for emergency responders is to take actions to prevent acute effects and to minimize potential long-term health effects as they go about their duties. The Department of Homeland Security has published planning guidance which includes radiation protection guidelines. The guidelines are not inflexible limits but are predetermined dose values that help responders determine what actions to take under unique emergency situations. The DHS guidance also notes that the principle of ''as low as reasonably achievable'' (ALARA) dose is applicable after an incident.

For non-emergency occupations involving routine work with radiation (such as in medical or nuclear power applications), regulations limit the annual worker dose to 5 rem. This limit would be applicable to responders only for intermediate- and late-phase recovery activities such as cleanup (DHS-Guidance, 2008). This 5 rem limit is not applicable to emergency responders in the extreme situations of early-phase response to radiological or nuclear terror (NCRP-165, 2010). Instead of a dose limit, dose guidelines recommended by national radiation protection experts have been developed to help protect emergency responders as they perform their duties under these extreme emergency conditions. Incident commanders may use these guidelines, or alternative doses established at the local level, to make tactical decisions for sending responders in or pulling them back, depending on the individual emergency situation. Guidance documents also recommend exposure rate levels that can be used to define radiation control zones and appropriate protective actions. Table 3-1 summarizes some of these accumulated dose and exposure rate values for reference; some are also illustrated in Figure 2-1. For comparison, the table includes both United States and international guidance from the International Atomic Energy Agency (IAEA).

Table 3-1. Reference Values for Emergency Responder Radiation Safety[1]

Terminology	Accumulated Dose	Recommended Application or Action	Document
Standard radiation worker annual dose limit	5 rem	Intermediate- & late-phase response	DHS (2008) Federal Register Planning Guidance for Protection and Recovery Following Radiological Dispersion Device (RDD) and Improvised Nuclear Device (IND) Incidents
Protective Action Guideline (PAG)	10 rem	Protect valuable property	
	≥ 25 rem	Lifesaving or protection of large populations	
Decision Dose	50 rad external gamma dose	Decide whether to remove responder or continue mission, based on operational awareness and mission priorities	NCRP No. 165 (2010) Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers
Turn Back Dose Guidance	50 rem	Prevent severe health effects or injuries	IAEA (2006) Manual for First Responders to a Radiological Emergency
	100 rem	Lifesaving actions	
Radiation Control Zones	**Exposure Rate**	**Recommended Application or Action**	**Document**
Cold zone ("outer perimeter")	≤ 10 mR/h	Alarm threshold	NCRP No. 165 (2010) Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers
Hot zone	> 10 mR/h	Restrict actions to time sensitive, mission critical such as lifesaving	
Dangerous-radiation zone[2]	≥ 10 R/h		

1 Local agencies may have alternate guideline values for responder operations.

2 The term "Dangerous Fallout Zone (DFZ)" is used in IND response planning.

For response missions, gamma radiation is of primary interest for measuring the emergency responder dose. Neutrons are not likely to be present (except during the initial blast of a nuclear device before responders are on the scene) and are generally accompanied by gamma radiation; alpha and beta particles would not penetrate responder gear (NCRP-165, 2010). Therefore, the NCRP radiation protection guidelines shown in Table 3-1 refer to the whole body dose from external exposure to photons only. This does not mean that an internal exposure is not a health concern, but reflects that fact that it cannot be measured in the field. Internal dose would have to be measured in a laboratory, by in-vivo scanning for gamma emitters, or bioassay of biological samples for alpha or beta. However, alpha, beta, and gamma surface contamination can be measured to establish radiation control zones and to verify the personal protective equipment (PPE) required. For situations where PPE was breached, high surface contamination on the body could indicate potential internal dose.

Both exposure rate (R/h) and accumulated dose (rad or rem) measurements are used for radiation safety. The exposure rate can be used to determine how long a responder can safely stay in an area and what tasks are appropriate. For example, the International Commission on Radiation Protection (ICRP) guidelines recommend that actions in the dangerous zone (≥10 R/h) should be restricted to time sensitive, mission critical tasks such as lifesaving. The rate can be used to determine stay times and to rotate personnel as needed. Similarly, the cumulative absorbed dose measured in real time can be used to trigger a decision on whether to withdraw a responder to avoid acute radiation effects and minimize long-term health effects.

Most of the guidance documents cited in this report refer to the exposure rate in R/h to define radiation control zones, and use rad or rem for the cumulative absorbed dose to responders. Surface contamination is commonly measured in units of disintegrations per minute per square centimeter (dpm/cm^2).

As noted in Section 2.2, the R, rad, and rem are often used interchangeably. In this application, that holds true primarily for avoiding acute effects. When measuring an individual's accumulated dose for potential long-term health effects, the distinctions can become important. As explained in Appendix A and Section 4.3, a dosimeter that reads the quantity Personal Dose Equivalent $H_p(10)$ is calibrated to account for the differing biological effects of various photon energies for potential long-term health impacts and is applicable for a worker's dosimetry of record.

The accumulated doses relevant to first responder tactical decisions would likely range from about 10 rad to hundreds of rad, where the higher end is applicable to acute effects and the lower end is applicable to potential long-term effects. An accumulated dose of tens of mrem to a few rem would be applicable in non-emergency intermediate- and late-phase response and recovery. Measurements of the exposure rate in lower ranges, such as µR/h, can be useful to verify no significant exposure, either during or after an emergency. At the higher end, the 2010 Planning Guidance for Response to a Nuclear Detonation recommends that "local authorities within a particular response unit (e.g., firehouse) have at least one instrument capable of reading dose rates up to 1,000 R/h…to ensure that they are not entering an area that exceeds 100 R/h."

In general, an instrument's measurement range should bracket the range of interest to extend beyond both the upper and lower levels in order to provide a margin of safety. The specific numerical values required for instrument ranges and for setting equipment alarm thresholds will be defined by the localities' operating procedures and regional response plans.

3.2.1 Equipment for Response Missions – *Responder Radiation Safety*

Several different types of instruments are applicable for emergency responder safety after a radiological incident. To avoid acute effects during early-phase response when the radiation levels are unknown, responders' equipment should be capable of measuring high levels in real time with pre-set alarms. For high radiation areas, the Electronic Personal Dosimeter is most applicable because it is capable of measuring from low to high gamma radiation levels and can indicate both exposure rate and accumulated dose. Alarming Personal Emergency Radiation Detectors cover the high range needed for exposure control in emergency situations (designed to measure exposure rather than personal dose).

Other types of equipment have some of the required capabilities for avoiding acute effects and they could be useful to augment Electronic Personal Dosimeters during response missions. Handheld Survey Meters show real time measurements and may have alarming capabilities; however, most do not cover high radiation range levels nor measure the accumulated dose. Self Reading Dosimeters provide field readable accumulated dose but they lack alarming capability and would have to be checked periodically. The Personal Dosimeter does not display the dose in real time so is not useful for tactical decisions but could be used for later verification of field instrument readings or during intermediate- and late-phase recovery operations. The Personal Dosimeter is most applicable for potential long-term health effects.

The Alarming Personal Radiation Detector and Radionuclide Isotope Identifier are not designed for radiation safety and are not applicable for several reasons. First, they are designed for low radiation levels and could go off scale for radiation levels that are of concern; second, they are not calibrated to account for the different biological effects of various photon energies for long-term health effects; and third, they may not be designed to report accumulated dose. However, isotope identification by RIIDs may be useful for subsequent medical interventions.

In exigent circumstances, instruments designed for low radiation levels could be put to use by combining exposure rate measurements with distance estimates (given that exposure rate varies with the inverse square of the distance).

3.3 Response Mission – Incident Management Duties

After a radiological incident, radiation measurements would be used for responder safety and would also be needed for response duties such as establishing appropriate areas for command posts, evacuation paths, and triage and decontamination areas. Radiological measurements may be used during evacuations and sheltering in place, management of contaminated persons and pre-hospital treatments, and could also be part of investigations.

For incident management purposes, alpha, beta, and gamma radiation measurements could all be applicable to emergency response actions. Alpha and beta contamination are of concern for those not wearing protective equipment.

For public safety, the primary measurement quantities of interest would be exposure rate (R/h) and surface contamination (dpm/cm^2). The choice of response actions such as shelter in place versus evacuation are typically based on the projected cumulative dose derived from the external exposure rate and contamination that could result in internal exposure. However, some emergency plans include the use of dosimeters as area monitors for populations that are difficult to evacuate such as nursing home or hospital patients.

The external gamma exposure rate and the surface contamination would be measured to establish appropriate locations for command posts, evacuation paths, and triage and decontamination areas. As part of medical triage, members of the public may need to be individually scanned for contamination. For example, those with gross external contamination on the upper part of the body would be more likely to have potentially received a significant inhalation dose from a passing plume, while those with contamination mainly on the lower body may have more likely walked through a contamination zone (Musolino, 2006).

While the same broad ranges of medium and high radiation levels (e.g., 10-100 R) used in responder radiation safety are applicable here, the mid-range (about 1-10 R) to low range (μR-mR) would become more relevant as the public is removed from high radiation areas. National guidelines for exposures and surface contamination are given in Table 3-2 for reference to show the range of values that may be encountered.

Table 3-2. Examples of Decision Guidelines for Actions to Protect the Public[1]

Quantity	Value	Recommended Action	Document
Gamma external exposure rate	10 mR/h	Evacuate[2] members of the public from areas with these levels	NCRP Commentary No. 19 (2005) *Key Elements of Preparing Responders for Nuclear and Radiological Terrorism*
Beta & gamma surface contamination	60,000 dpm/cm^2		
Alpha surface contamination	6,000 dpm/cm^2		
Spot contamination on the skin	> 2,200,000 dpm	Priority for decontamination	NCRP Commentary No. 19 (2005)
Beta & gamma skin & clothing surface contamination	>600,000 dpm/cm^2	Decontamination should always be performed	NCRP Report No. 165 (2010) *Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers*
Alpha skin & clothing surface contamination	>60,000 dpm/cm^2		
Contamination level at 10 cm from skin & clothing	0.1 mR/h		
Projected dose in early phase (external & internal dose)	1-5 rem	Sheltering or evacuation[2]	EPA (1992) *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*
Projected dose in intermediate phase (external & internal dose in first year)	≥ 2 rem	Relocation	

1 Not a comprehensive list, these examples are provided as context for radiation levels that could be encountered during a response and do not include region specific plans.

2 Current regional planning based on improved calculations is in progress and emphasizes the importance of sheltering in place in the first hours after an IND.

3.3.1 Equipment for Response Missions – *Incident Management*

The Handheld Survey Meter would be most applicable to the types of measurements described in this section for incident management. In most survey meter models, an internal detector measures the external gamma exposure rate, and additional probes are used for surface contamination. For hazard assessment, in some cases, alpha, beta, and gamma contamination can be distinguished by taking measurements with and without different covers over the probe and looking at the percent reduction in readings.

Some secondary and non-standard instrument uses may be possible as well. Though its primary purpose is for the responders' safety, the exposure rate reading from an Electronic Personal Dosimeter can also be used to guide some initial response actions for external exposure. Radionuclide Isotope Identifiers could be helpful too, since knowledge of the isotope could help in the subsequent treatment of contaminated individuals, but it is not needed to determine the initial emergency response. Alarming Personal Radiation Detectors are not designed for this application but could perhaps be put to some use for verifying low exposure rates such as monitoring at shelters *(*See *Planning Guidance for Response to a Nuclear Detonation, Second Edition, page 62).*

Self Reading Dosimeters and Personal Dosimeters carried by responders are for their own safety. However, if distributed to the public, these devices could potentially help minimize the worried well seeking medical treatment who might otherwise overwhelm hospitals.

Table 3-3 summarizes the key points covered in Sections 3.1, 3.2, and 3.3.

Table 3-3. Summary of Radiological Characteristics and Equipment Capabilities for Interdiction and Response Missions

Mission	Type of Radiation	Measurement Quantity	Level	Relevant Equipment
Interdiction: Detect & Identify	• gamma • neutron	gamma: • exposure rate (R/h) • spectra neutron: • yes/no indicator	Gamma: Low (μR/h – mR/h)	Alarming PRD, SPRD, HHSM, RIID, Radiation Detection Backpack Electronic Personal Dosimeter[2]
Response: Responder Safety	gamma	Exposure rate (R/h) Accumulated dose (rad, rem)	Medium to High (R-100s R)	Electronic Personal Dosimeter Personal Dosimeter Self Reading dosimeter PERD HHSM[1]
Response: Incident Management	• gamma • alpha / beta	Exposure rate (R/h) Contamination (dpm/cm^2)	Low to High (μR/h – 100s R/h)	HHSM RIID[1]

1 Secondary use
2 Non-standard, potential use

4. AEL PORTABLE RADIATION DETECTION EQUIPMENT

This section is organized into subsections corresponding to AEL equipment categories to explain in more detail the capabilities and applications for each of the portable radiological equipment types discussed above. The type of radiation, measurement quantity, and range of radiation levels, along with the technologies used and the significant distinctions with other types of equipment are discussed. Where applicable, technical terminology and words in common usage are clarified, and some performance requirements from national standards are summarized.

As noted in Section 3, emphasis is given to the applications that the equipment is best suited for, but during a large scale emergency where resources are overwhelmed it may be necessary to use any available radiological equipment wherever possible. Therefore, some examples of non-standard potential applications and their limitations are also noted here for completeness.

Finally, each subsection lists other resources available for more information on that equipment type, including SAVER documents, national performance standards published by the Institute of Electrical and Electronics Engineers (IEEE) and the American National Standards Institute (ANSI), other reports, and national testing or accreditation programs. For many of these instrument types, the SAVER program has completed TechNotes, Market Surveys, and Assessments to provide information for procurement decisions, and several national standards are applicable to specify performance criteria. Additional standards and SAVER documents on these topics are in progress. The SAVER documents are available on the SAVER website, which can be found at www.dhs.gov/science-and-technology/SAVER.

At the end of this section, the key information is tabulated for each AEL category in Table 4-1 on page 28.

4.1 Personal Dosimeter (07RD-01-DOSP)

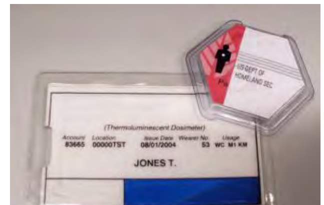


Figure 4-1. Examples of Personal Dosimeters
Photo provided by NUSTL

Personal Dosimeters measure gamma radiation and some are also sensitive to beta and/or neutrons. They usually measure the accumulated dose in rem; additional equipment is required to read out or display the measurement results. Their sensitivity spans the low to high ranges from a few mrem to hundreds of rad[9]. Personal Dosimeters are typically based on one of the following technologies: thermoluminescent dosimetry (TLD), optically stimulated luminescence (OSL), or direct ion storage (DIS).

Personal Dosimeters may be used for response mission applications that do not require real time measurements or alarming functions. They are usually passive (requiring no batteries or power) and inexpensive devices and require no training or attention to use. Generally, personal dosimeters are widely used for routine occupational exposure for dosimetry of record, where they have proven accurate and reliable.

For responders, Personal Dosimeters could be applicable for later verification of real time measurements made during early-phase response. Since they are inexpensive and more rugged than electronic devices, they could provide back-up dosimetry in case of instrument failure or other unforeseen events. Personal Dosimeters are also applicable for intermediate- and late-phase response and recovery operations where the radiation levels are known. Measurements with Personal Dosimeters are suitable for monitoring individual exposure for permanent records[10] of the total dose after the incident.

Alternate terminology: radiation badges; personnel dosimeters; personal "dosemeters" (British)

SAVER Reports:

TechNote – *Dosimeters for Response & Recovery (July 2008)*

Market Survey Report – *Radiation Dosimeters for Response & Recovery (January 2010)*

Standards:

ANSI N13.11 – Personnel Dosimetry Performance - Criteria for Testing (2009)
This standard describes test conditions and performance criteria for proficiency testing of personnel dosimetry systems used for routine occupational dosimetry monitoring.

Testing Program:

National Voluntary Laboratory Accreditation Program (NVLAP)
NVLAP is a proficiency program that tests dosimetry providers to the performance specifications of ANSI N13.11. Accreditation is available to any service laboratory that processes personnel dosimeters used to monitor individual occupational exposure to ionizing radiation. Some organizations such as the Nuclear Regulatory Commission (NRC) require

---

[9] As explained in Appendix A, "rem" is the applicable unit for personal dosimeters at lower levels, while by convention the "rad" is used for high doses where acute effects can occur.

[10] DHS Guidance in Federal Register, Department of Homeland Security, Vol. 73, No. 149 August 1, 2008, p. 45039

NVLAP accredited dosimetry programs for radiation workers at NRC licensed facilities. NVLAP is administered by the National Institute of Standards and Technology (NIST). A list of accredited providers, their dosimeters, and categories accredited are found at the NIST website http://ts.nist.gov/Standards/scopes/dosim.htm.

4.2 Self Reading Dosimeter (07RD-01-DOSS)

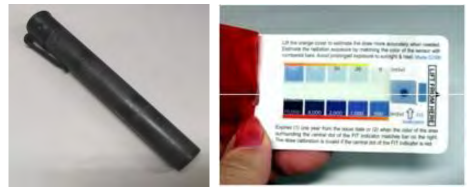


Figure 4-2. Examples of Self Reading Dosimeters

Photo provided by NUSTL

Self Reading Dosimeters measure gamma radiation. Most measure the accumulated dose in rad: results are viewed on an analog or digital scale or are interpreted visually (e.g., with a color matching scale) by the wearer. They require minimal training for use. Sensitivity varies between products but typically spans the medium to high range. Most Self Reading Dosimeters are passive and are based on either electret or radio-chromic technologies; others use silicon semiconductors. Self Reading Dosimeters generally do not have the precision or accuracy of Personal Dosimeters. They are not covered by the NVLAP accreditation program (Section 4.1) and are not used for dosimetry of record. But Self Reading Dosimeters are useful for response mission applications that require field readability but do not require alarming functions. Because passive self-reading devices can potentially be stockpiled for large-scale distribution where field readability is required, they offer lower cost preparedness equipment to augment Electronic Personal Dosimeters.

Alternate terminology: SRD; pencil dosimeter; optical dosimeter, pocket ion chamber; carbon fiber detectors; color-changing dosimeter, radio-chromic dosimeter, self-developing photochemical detector; non-alarming personal emergency radiation detector (PERD).

SAVER Reports:

TechNote – *Dosimeters for Response & Recovery (July 2008)*

Market Survey Report – *Radiation Dosimeters for Response & Recovery (January 2010)*

Standards:

ANSI N322 – Inspection, Construction, and Performance Requirements for Direct Reading Electrostatic/Electroscope Type Dosimeters (1997)

This standard describes the requirements and procedures for testing the physical and dosimetric properties of pocket ion chambers. It includes tests for mechanical integrity, environmental conditions, and radiological response.

ANSI N42.49B – Performance Criteria for Non-alarming Personal Emergency Radiation Detectors (PERDs) for Exposure Control (in progress)

This standard will cover non-alarming devices used for exposure control but not for dosimetry of record, specifically self-developing film and carbon fiber chambers.

Other Reports:

Self-Indicating Instant Radiation Alert Dosimeter (SIRAD) Test Results (U.S. Department of Homeland Security, Science and Technology Directorate, CounterMeasures Test Beds) DHS/S&T/SED/CMTB-2007-003 *(February 2007)*
http://www.tswg.gov/subgroups/cbrnc/detection/products.html

4.3 Electronic Personal Dosimeter (07RD-01-EPD)

Figure 4-3. Example of an Electronic Personal Dosimeter
Photo provided by NUSTL

Electronic Personal Dosimeters measure gamma radiation and some are also sensitive to neutrons. They typically measure the dose rate in rem/h and accumulated dose in rem, with results shown on a digital display. Their sensitivity generally spans the low to high ranges from a few mrem to hundreds of rad. Electronic Personal Dosimeters are typically based on one of the following technologies: Geiger-Mueller (GM) tube, ionization chamber, or silicon semiconductor.

Electronic Personal Dosimeters are used for emergency responder radiation safety applications where dangerous dose levels could be encountered and therefore real time measurements and alarming functions are required. It is this ability to alarm at high levels that distinguishes Electronic Personal Dosimeters from other dosimeters: they are significantly more expensive than passive Personal Dosimeters and passive Self Reading Dosimeters. For responders, they are applicable when working in the hot zone and dangerous zone (see Table 3-1). They require training for their use and for the actions to take in response to an alarm.

Electronic Personal Dosimeters are often confused with equipment under the Alarming Personal Radiation Detector category (07RD-01-PDGA) discussed in the next section. Part of the confusion is due to the use of the word "personal" in both titles. This is unfortunate because, with Alarming Personal Radiation Detectors, the word "personal" simply refers to the fact that it is designed to be worn unobtrusively by a person. With the Electronic Personal Dosimeters the word "personal" also has more significance: it means that this instrument is designed to provide a measure of an individual's accumulated dose. This is where the technical distinction between "detector" and "dosimeter" becomes significant. Electronic Personal Dosimeters are specially calibrated and designed to give a response that is proportional to the potential long-term health hazards of radiation. A dosimeter usually requires energy compensation, which is material added to moderate the effects of various photon energies on the radiation sensitive components inside, in particular shielding some low energy photons so as not to overestimate the dose. Thus, an Electronic Personal Dosimeter will not have the same sensitivity to low energy photons as an Alarming Personal Radiation Detector.

While these distinctions are relatively subtle, the most important distinction between the two equipment categories is the range of radiation levels they respond to. Alarming Personal Radiation Detectors are set to alarm in the low radiation range, for example, at perhaps three times the radiation background exposure rate. This level of exposure is not significant for health effects, so the Electronic Personal Dosimeter would not alarm there. Instead, the Electronic Personal Dosimeter would typically be set to alarm at a level 1,000 times higher.

With some commercial products, it can be difficult to categorize the device as a detector or a dosimeter, especially where R, rad, and rem are used interchangeably,[11] and for products that span low to high radiation levels. As in the AEL, the words detector and dosimeter are sometimes interchanged in common usage. Regardless of the product name, the key for responders is to choose equipment that brackets applicable radiation levels.

---

[11] One indicator of a dosimeter applicable for long-term health effects is the term "$H_p(10)$" in product specifications. As explained in Appendix A, $H_p(10)$ is the international standard operational radiation protection quantity.

Alternate terminology: EPD

SAVER Reports:

TechNote – *Dosimeters for Response & Recovery (July 2008)*

Market Survey Report – *Radiation Dosimeters for Response & Recovery (January 2010)*

Focus Group Report – *Electronic Personal Dosimeters (April 2010)*

Assessment Report – *Electronic Personal Dosimeters (October 2010)*

Standards:

ANSI N13.11 – Personnel Dosimetry Performance – Criteria for Testing (2009)
This standard describes test conditions and performance criteria for proficiency testing of personnel dosimetry systems used for routine occupational dosimetry monitoring.

ANSI N42.20 – Performance Criteria for Active Personnel Radiation Monitors (2003)
This standard applies to active electronic devices worn on the trunk of the body to measure personal dose equivalent or dose equivalent rate. It does not cover proficiency testing.

ANSI N42.49A – Performance Criteria for Alarming Electronic Personal Emergency Radiation Detectors (PERDs) for Exposure Control (2011)
This standard covers alarming devices for exposure control but not for dosimetry of record for homeland security and other radiological emergency operations.

Testing Program:

National Voluntary Laboratory Accreditation Program
This proficiency program tests dosimetry providers to the performance specifications of ANSI N13.11. Accreditation is available to any organization that processes personnel dosimeters used to monitor individual occupational exposure to ionizing radiation. NVLAP is administered by NIST. Some electronic dosimeter users have been NVLAP accredited.

4.4 Alarming Personal Radiation Detector (07RD-01-PDGA)

Alarming Personal Radiation Detectors measure gamma radiation and some are sensitive to neutrons as well. They typically measure the exposure rate in μR/h or mR/h with a digital display. Their sensitivity spans the low to medium ranges. Alarming Personal Radiation Detectors are typically based on one of the following technologies: GM, cesium iodide, or sodium iodide. Those that measure neutrons may also use helium-3 or lithium iodide. They require some training for use and for the procedures in response to an alarm.

Figure 4-4. Example of an Alarming Personal Radiation Detector
Photo provided by NUSTL

Alarming Personal Radiation Detectors used for interdiction mission applications are worn during daily operations and alarm on elevated radiation levels. This application requires a small-sized instrument with a fast response time and sensitivity to low exposure rates. ANSI/IEEE Standard N42.32 requires that alarming Personal Radiation Detectors be capable of measuring the exposure rate in the range from 5 μR/h to 2 mR/h or greater with a response time of less than or equal to 2 seconds, and weigh less than 0.9 pounds. To minimize risk in high radiation areas, N42.32 requires an over-range indicator.

To optimize sensitivity, Alarming Personal Radiation Detectors generally do not have the energy compensation required to measure the radiation dose in rem. This distinction and the difference in range of response compared with the Electronic Personal Dosimeter (07RD-01-EPD) are discussed in Section 4.3.

Some commercially available products are described as being a combination survey meter and alarming personal radiation detector. But generally speaking, an Alarming Personal Radiation Detector is usually different from the Handheld Survey Meter in three ways: it is smaller and lighter, it is sensitive to lower exposure rate levels, and it has as faster response time.

Alternate terminology: PRD; (formerly "pager"[12])

SAVER Reports:

TechNotes – *Radiation Pagers (April 2006)*

Assessment Report – *Radiation Pagers and Survey Meters (November 2006)*

Standards:

ANSI/IEEE N42.32 – American National Standard Performance Criteria for Alarming Personal Radiation Detectors for Homeland Security (2006)

This standard describes performance criteria and test methods for self-reading, alarming, pocket-sized radiation detectors that are worn on the body and used to rapidly detect the presence of ionizing radiation for the purpose of detection and interdiction.

Other Reports:

DNDO State and Local Summary Report: Personal Radiation Detectors Test Campaign (November 2007)

Provides unbiased evaluation information on PRD models and their potential application in operationally relevant environments.

Results of Test and Evaluation of Commercially Available Personal Alarming Radiation Detectors and Pagers for the Department of Homeland Security (May 2005); Results of T&E of Commercial Personal Alarming Radiation Detectors and Pagers for DHS - Round 2 (June 2006)

These NIST reports detail the tests of commercially available PRDs against ANSI/IEEE standard N42.32-2003. They also include the technical specifications given by the manufacturers and short descriptions of the instruments.

Testing Program:

Graduated Rad/Nuc Detector Evaluation and Reporting (GRaDER) Program

This program will evaluate commercial off-the-shelf Alarming Personal Radiation Detectors against standard ANSI/ IEEE N42.32 (2006).
http://www.dhs.gov/files/programs/gc_1218637329931.shtm

[12] Formerly used in the general sense, the term "pager" is the trademarked name of a commercial product.

4.5 Handheld Survey Meter (07RD-01-HHSM)

Handheld Survey Meters can measure alphas, betas, gammas, and in some cases neutrons, through the use of various probes. They measure the activity in dpm and some may also report the exposure rate in R/h. Their sensitivity typically covers the low range (μR - mR/h), while some products extend into the medium range (R/h) and a few into the high range (100s of R/h). ANSI/IEEE Standard N42.33 addresses the photon exposure rate measurement capabilities of survey meters and requires that they are capable of measuring the range from 5μR/h to10 mR/h or more, with a response time of 5 seconds or less and weight of 6.6 pounds or less. Survey meters are generally larger and heavier than Alarming Personal Radiation Detectors, have a higher upper range, and slower response time.

Figure 4-5. Examples of Handheld Survey Meters
Photo provided by NUSTL

Handheld Survey Meters are typically based on GM tubes or ionization chambers. They are used for both response and interdiction mission applications to determine the nature and extent of contamination. In response missions, they can be used to indicate the presence of radiation for hazard assessment, delineate radiation protection zones, scan people for contamination, and give an indication of potential for internal exposure. In measuring contamination, survey meters are useful to detect contamination that subsequently could be taken into the body by inhalation, ingestion, or absorption into wounds. In some applications, alpha, beta, and gamma radiation can be discriminated with different probes in combination with and without end caps, and swipes can be counted to show if contamination is removable. Significant training is required to use survey meters in these applications.

Alternate terminology: Handheld Radiation Survey Meter (HHRSM); count rate instrument; Geiger counter

SAVER Reports:

TechNotes – *Radiation Detectors - Radiation Survey Meters (April 2006)*

Neutron Detection Instruments (April 2009)

Market Survey Report – *Handheld Radiation Survey Meters (June 2010)*

Focus Group Report – *Handheld Radiation Survey Meters (September 2010)*

Assessment Reports – *Radiation Pagers and Survey Meters (November 2006)*

Handheld Radiation Survey Meters (January 2012)

Standards:

ANSI/IEEE N42.33-2006 – American National Standard for Portable Radiation Detection Instrumentation for Homeland Security
N42.33 covers the use of survey meters for detection and interdiction applications.

ANSI N42.17A – American National Standard Performance Specifications for Health Physics Instrumentation – Portable Instrumentation for Use in Normal Environmental Conditions (1994)

This standard establishes testing methods and minimum performance criteria for health physics instrumentation for use in ionizing radiation fields.

ANSI N42.17C – American National Standard for Performance Specifications for Health Physics Instrumentation – Portable Instrumentation for Use in Extreme Environmental Conditions (1989; Reaffirmed 2001)

This standard is a companion to N42.17A but covers testing methods and performance criteria under various extreme environmental conditions.

Other Reports:

Radiation Detection – Radiation Survey Meters (COTS) Test & Evaluation Results (June 2007); Results of Test and Evaluation of Commercially Available Survey Meters for the Department of Homeland Security (May, 2005)

These NIST reports provide test results for commercially available radiation survey meters based on ANSI N42.33, as well as the technical specifications given by the manufacturers, and short descriptions of the instruments.

Testing Programs:

Graduated Rad/Nuc Detector Evaluation and Reporting (GRaDER) Program

This program will evaluate commercial off-the-shelf (COTS) survey meters against standard ANSI/ IEEE N42.33-2006.
http://www.dhs.gov/files/programs/gc_1218637329931.shtm

4.6 Radionuclide Isotope Identifier (07RD-01-RIID)

Figure 4-6. Examples of Radionuclide Isotope Identifiers
Photo provided by NUSTL

RIIDs detect photons and can distinguish between different photon energies. RIIDs count the number of photons at each energy and display the counts versus energy in a photon energy spectrum to reveal characteristic peaks. RIIDs are used in the low radiation range, where the sensitivity and resolution (how well peaks can be separated) are the key features. RIIDs are primarily used in interdiction missions to identify the source of elevated radiation and help differentiate innocent alarms from real threats. Some products include neutron detectors that can be important in this application. Some RIIDs also have the ability to save and send spectra to reachback facilities for further analysis. RIIDs also have applicability during the response mission, but care must be taken to avoid medium and high radiation areas that can overload these instruments. During the response mission, isotope identification can assist with the medical treatment of contaminated people and protective measures for responders, and can also be used for evidence investigation and forensics. Specialized training is required to use RIIDs for these applications, and follow-up analysis may be necessary.

RIIDs are based on scintillators (sodium iodide, lanthanum bromide, or semiconductor detectors such as high-purity germanium or cadmium zinc telluride). Some products may combine a GM tube or ionization chamber to measure the exposure rate as well.

Alternate Terminology: Spectroscopic detector, Radioisotope identifier

SAVER Reports:

TechNote – *Radioisotope Identification Devices (October 2009)*

Neutron Detection Instruments (April 2009)

Market Survey Report – *Radiation Isotope Identifier Devices (RIIDs) (January 2007)*

Focus Group Report – *Radioisotope Identifiers (June 2008)*

Assessment Report – *Radioisotope Identifiers (June 2008)*

Standards:

ANSI/IEEE N42.34 – American National Standard Performance Criteria for Hand-Held Instruments for the Detection and Identification of Radionuclides (2006)
This standard specifies general requirements and test procedures, radiation response requirements, and electrical, mechanical, and environmental requirements for instruments that can be used for homeland security applications to detect and identify radionuclides. It includes tests for gamma-ray exposure rate measurement and indication of neutron radiation.

Other Reports:

Results of Test and Evaluation of Commercially Available Radionuclide Identifiers for DHS (May 2005); Results of the Test and Evaluation of Commercially Available Radionuclide Identifiers for the Department of Homeland Security: Round 2 Testing (June 2006)
These NIST reports provide test results for commercially available radionuclide identifiers based on ANSI N42.34. They also include the technical specifications given by the manufacturers and a short description of the instrument.

Testing Programs:

Graduated Rad/Nuc Detector Evaluation and Reporting (GRaDER) Program
This program will evaluate commercial off-the-shelf handheld instruments for the detection and identification of radionuclides against standard ANSI/ IEEE N42.34-2006.
http://www.dhs.gov/files/programs/gc_1218637329931.shtm

Illicit Trafficking Radiological Assessment Program +10 (ITRAP+10)
This program was initiated by the European Union to evaluate and compare the performance of commercially available European manufactured radiation detection equipment against standards. The European Commission Joint Research Center invited the U.S. government and the International Atomic Energy Agency to participate in expanding this testing to other globally available systems. The U.S. and its European partners will have access to nearly 100 devices across nine different categories of detection equipment.
http://www.dhs.gov/files/programs/dndo-itrap.shtm

4.7 Other Portable Radiation Instruments (e.g., Backpack Systems, SPRDs, Alarming PERDs)

Figure 4-7. Example of a Backpack System
Photo provided by NUSTL

Although not specifically called out in the AEL, other portable radiation instruments are relevant to interdiction and response mission applications. Some examples include Backpack Systems, Spectroscopic Personal Radiation Detectors, Portable Neutron Panel Detectors, and Alarming Personal Emergency Radiation Detectors (PERDs).

Backpack Systems are of particular interest in interdiction applications. They measure gamma and neutron radiation, and some have spectral capability. Backpack Systems provide information on count rates, exposure rates, and nuclide identification. Their sensitivity depends on the type and quantity of material used but, in general, their larger detector size makes them more sensitive to radiation sources than other interdiction equipment, such as Alarming Personal Radiation Detectors. Backpack Systems are typically based on scintillation materials such as sodium iodide, cesium iodide, and polyvinyl toluene (PVT) for detecting and identifying gamma-emitting radionuclides. Helium-3 tubes and lithium-6 fibers are used to determine neutron count rates. Backpack Systems are typically used in special purpose search missions for interdiction, but could also be used to survey large areas in response missions.

Spectroscopic Personal Radiation Detectors may be used in interdiction missions to rapidly detect and identify radioactive materials. Like Alarming Personal Radiation Detectors, they are typically pocket-sized, worn during daily operations, and alarm for elevated radiation levels. They contain detectors to discriminate among isotopes but are not meant to provide identification to the same level as RIIDs. They primarily measure gamma radiation, and some may have neutron detection capability.

Alarming Personal Emergency Radiation Detectors may be used in response missions to provide users with an indication of when a radiation exposure or exposure rate is unsafe. Like Electronic Personal Dosimeters and Self Reading Dosimeters, PERDs are designed for the personal radiation safety of the wearer. However, they measure exposure rather than personal dose equivalent, and are not used for dosimetry of record. They may be pocket sized or in form factors such as a wristwatch.

SAVER Reports:

Market Survey Report – *Radiation Detection Backpacks (March 2011)*

Focus Group Report – *Radiation Detection Backpacks (January 2011)*

Assessment Report – *Radiation Detection Backpacks (in progress)*

Assessment Report – *Radioisotope Identifiers (June 2008)*

Market Survey Report – *Radiation Isotope Identifier Devices (RIIDs) (January 2007)*

Standards:

ANSI/IEEE N42.48 – American National Standard Performance Requirements for Spectroscopic Personal Radiation Detectors (SPRDs) for Homeland Security (2008)

This standard describes design and performance requirements along with testing methods for evaluating radiation detection instruments that are pocket-sized and worn on the body for the purpose of rapid detection and identification of radioactive materials.

ANSI N42.49A – Performance Criteria for Alarming Electronic Personal Emergency Radiation Detectors (PERDs) for Exposure Control (2011)

N42.49A covers alarming devices for exposure control but not for dosimetry of record for homeland security and other radiological emergency operations. It is applicable to devices that measure exposure in R rather than personal dose equivalent. (A companion standard, ANSI N42.49B, in progress, will cover non-alarming PERDs.)

ANSI/IEEE N42.43 – American National Standard Performance Criteria for Mobile and Transportable Radiation Monitors Used for Homeland Security (2006)

This standard specifies the operational and performance requirements for transportable and/or mobile radiation monitors used in homeland security applications. This includes radiation monitors that are used while being carried by a person, such as a backpack. (It also covers equipment beyond the scope of this technical guide, such as those mounted on vehicles.)

Other Reports:

Radiation Isotope Identification Device (RIIDs) Field Test and Evaluation Campaign DOE/NV/25946-234

This document describes the DHS Domestic Nuclear Detection Office Anole campaign in early 2006 that tested commercially available handheld, backpack, and mobile radiation detection systems.
http://www.osti.gov/bridge/servlets/purl/924123-JcRtCA/924123.pdf

Table 4-1. Summary of Portable Radiological Detection Equipment Features, Applications, and Reference Documents

	Personal Dosimeter 07RD-01-DOSP	Self Reading Dosimeter 07RD-01-DOSS	Electronic Personal Dosimeter 07RD-01-EPD	Alarming Personal Radiation Detector 07RD-01-PDGA	Survey Meter 07RD-01-HHSM	Radionuclide Isotope Identifier 07RD-01-RIID
Radiological Characteristics: ▪ **Type** ▪ **Quantity** ▪ **Range**	▪ Gamma (some beta, some neutron) ▪ Personal dose equivalent ▪ Low – high levels (mrem – 100s of rad)[1]	▪ Gamma ▪ Absorbed dose ▪ Medium-high levels (rad-100s rad)	▪ Gamma (some neutron) ▪ Personal dose equivalent ▪ Low – high rad levels (mR – 100s of R)	▪ Gamma (some neutron) ▪ Exposure rate ▪ Low levels (μR /h – mR /h)	▪ Gamma, beta, alpha (some neutron) ▪ Count rate (some exposure rate) ▪ Low (μR /h – mR /h) Some medium (R) Some high (100s of R)	▪ Gamma (some neutron) ▪ Photon energy spectrum ▪ Low levels (μR/h)
Applications: Primary	Response: worker safety – long-term health	Response: Worker safety – long-term health	Response: Worker safety - acute	Interdiction: Detect elevated radiation	Response: Incident management Worker safety	Interdiction: Identify source
Secondary (nonstandard)[2]	(Public; area monitoring)	Response: Worker safety - acute (Response: Incident management)	Response: Worker safety – long-term health	(Response: Incident management)	Interdiction: Characterize source	Response: Incident management Worker safety
Distinctive Features	▪ Worn on body (weighs a few ounces) ▪ Not user readable ▪ No training	▪ Worn on body (~oz.) ▪ Visual reading, no alarms ▪ Little training	▪ Worn on body ▪ Visual reading ▪ Alarming ▪ Some training	▪ Worn on body while performing other tasks (< 1 lb) ▪ Fast response in field (≤ 2s) ▪ Some training	▪ NOT worn, carried (< 7 lb) ▪ Higher rad levels than Personal Radiation Detectors ▪ Field readable but not as fast as alarming PRD (≤ 5s) ▪ Training required	▪ NOT worn, carried ▪ Field readable but may require additional analysis ▪ Requires specialized training
Application Considerations	Not used for tactical decisions. Can be used for dose of record.	Some tactical application, but not where alarming function is required. Not used for dose of record.	Useful where high radiation levels could be encountered.	Not for radiation safety since: - alarms at levels below concern; - off scale for high levels; - no energy compensation for personal dose equivalent; - does not measure accumulated dose	Survey meters are slower than alarming personal detectors but can read hotter sources & measure alpha & beta	Not good in medium & high radiation levels, but some RIIDs also show exposure rate
Technology	Thermoluminescent Dosimeter (TLD), Optically Stimulated Luminescence (OSL), direct ion storage	Electrets, radio-chromic, silicon diode	Geiger-Mueller (GM), ionization chamber, silicon diode	Geiger-Mueller (GM), ionization chamber, cesium iodide (CsI), sodium iodide (NaI), helium-3 (^{3}He) [+ lithium iodide (LiI) for neutrons]	Geiger-Mueller (GM), ionization chamber	Sodium iodide (NaI), lanthanum bromide (LaBr), High-purity Germanium (HPGe), Cadmium Zinc Telluride (CZT)
Also known as	Radiation badge; Personnel dosimeter; Personal dosemeter *(British)*	SRD; pencil / optical dosimeter, pocket ion chamber; carbon fiber detectors; color-changing / radio-chromic / self-developing photochemical detector; non-alarming electronic dosimeter.	EPD	Radiation pager[3]	Handheld Radiation Survey Meter (HHRSM); count rate meter, Geiger counter	Spectroscopic detector
SAVER Reports	▪ TechNote ▪ Market Survey	▪ TechNote ▪ Market Survey	▪ TechNote ▪ Market Survey	▪ TechNote ▪ Market Survey ▪ Assessment	▪ TechNote ▪ Market Survey ▪ Assessment	▪ TechNote ▪ Market Survey
Standards / *Other reports*	**ANSI N13.11– 2009**	**ANSI NN322–1997; 2003** **ANSI/IEEE N42.49B** (in progress) *Self-Indicating Instant Radiation Alert Dosimeter (SIRAD) Test Results Final Report (2007)*	**ANSI N42.20– 2003**	**ANSI/IEEE N42.32– 2006** *N42.32 Test Results(2007)*	**ANSI N42.33 – 2006** *N42.33 Test Results(2007)*	**ANSI N42.34– 2006** *N42.34 test Results(2007)*

1 As explained in Appendix A, the unit of "rem" is the applicable unit for Personal Dosimeters at lower levels, while by convention the "rad" is used for high doses where acute effects can occur.
2 Non-standard potential applications are shown in parenthesis; these are beyond the instrument's designed use but could be applied where resources are overwhelmed. See Sections 3 & 4.
3 Formerly used to refer to equipment of this type in the general sense, "radiation pager" has been trademarked.

5. SUMMARY

The various types of commercially available portable radiological detection equipment have different measurement capabilities which must be matched appropriately to the required application. Three key radiological characteristics: radiation type (alpha, beta, gamma, and neutron), measurement units (R/h, rad, rem, dpm), and measurement range of interest (from about 10 μR/h to hundreds of R/h or hundreds of accumulated rad), are used to identify which types of portable radiological equipment are needed for different tasks within homeland security interdiction and response missions.

Interdiction missions require the measurement of gammas at low exposure rates, in the range of μR/h - mR/h, with a fast response time, in order to detect radioactive material. Alarming Personal Radiation Detectors (07RD-01-PDGA), SPRDs, and Backpack Systems are applicable here. For follow up measurements in the interdiction mission, photon energy spectra are used to identify the material and help rule out innocent occurrences of radiation. The AEL category Radionuclide Isotope Identifier (07RD-01-RIID) is applicable for the photon energy spectrum measurement. Neutron detectors also help in interdiction, and may be included with RIIDs, Alarming Personal Radiation Detectors, and Backpack Systems.

In response missions, responder radiation safety requires equipment that can measure gamma radiation. For measurements to avoid acute effects, instruments must have capabilities at the high end of the radiation range, to hundreds of R/h (or hundreds of accumulated rad) with field readable indications. Equipment in the AEL category Electronic Personal Dosimeter (07RD-01-EPD) have the appropriate measurement range and alarming capabilities that are critical for establishing radiation control zones. Equipment in the AEL category Self Reading Dosimeter (07RD-01-DOSS) can measure gamma radiation in the medium to high levels of a few rad to hundreds of rad with field readability and may augment situations where the alarming capability is not required. For measurements pertaining to potential long-term health effects in response and recovery missions, instruments will measure in the medium radiation ranges (about 1- 10 rem) and in some cases down to tens of mrem. This is covered by equipment in the AEL category Personal Dosimeter (07RD-01-DOSP). For incident management during response missions, alpha and beta contamination measurements in dpm are applicable in addition to gamma radiation. Equipment in the AEL Survey Meter category (07RD-01-HHSM) is used for many response mission tasks.

As instrument technologies continue to evolve, commercially available equipment may not fit neatly into the AEL categories. The features identified here show what characteristics to look for regardless of the product name or how it may be categorized.

6. REFERENCES

ASTM E2601-8 (2008). *Standard Practice for Radiological Emergency Response,* American Society for Testing and Materials International.

DHS Federal Register, Department of Homeland Security, Vol. 73, No. 149, August 1, 2008.

EPA (1992). *Manual of Protective Action Guidelines and Protective Actions for Nuclear Incidents.*

IAEA (2007). *Combating Illicit Trafficking in Nuclear and Other Radioactive Material*, International Atomic Energy Agency; Technical Guidance Reference Manual.

International Atomic Energy Agency. *Manual for First Responders to a Radiological Emergency*, IAEA, October 2006.
http://www-pub.iaea.org/MTCD/publications/PubDetails.asp?pubId=7606

Musolino, S. V. (2006). Emergency Response Guidance for the First 48 hours After the Outdoor Detonation of an Explosive Radiolgical Dispersal Device. *Health Physics, 90* (4), 377-385.

NCRP-165 (2010). *NCRP Report No. 165 Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers.* Bethesda, MD: National Council on Radiation Protection and Measurements.

NCRP-161 (2008). *NCRP Report 161 Management of Persons Contaminated with Radionuclides (I&II).* Bethesda: National Council on Radiation Protection and Measurements.

NCRP-19 (2005). *Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism; NCRP Commentary No. 19.* Bethesda, MD: National Council on Radiation Protection and Measurements.

NCRP-138 (2001). *Management of a Terrorist Event Involving Radiological Material*; Bethesda, MD: National Council on Radiation Protection and Measurements.

Planning Guidance for Response to a Nuclear Detonation, Second Edition. National Security Staff Interagency Policy Coordination Subcommittee for Preparadness & Response to Radiological and Nuclear Threats. (June 2010).

APPENDIX A. DISCUSSION OF RADIOLOGICAL TERMINOLOGY: R, RAD, AND REM

This appendix is provided for completeness for those interested in the concepts behind terminology found in equipment specifications and various guidance documents. However, it is not necessary for emergency responders to understand these subtleties of radiation protection concepts in order to use the radiological equipment covered in the main body of this report.

The concepts mainly relate to potential long-term health effects that are most relevant to occupations that involve routine, low to medium level exposures over many years. In contrast, for homeland security applications, emergency responders would primarily be concerned about avoiding acute effects under unique emergency conditions where high radiation areas could be encountered. Minimizing long-term health effects is also important, but most emergency responders would not expect to be routinely occupationally exposed. An exception would be Hazardous Material (HAZMAT) personnel, who may work with radioactive materials more frequently, or those that may be involved in recovery operations.

For most homeland security applications, the basic approximation that ***1 R ≈ 1 rad ≈ 1 rem*** is sufficient. This appendix gives an overview of the concepts underlying this approximation and explains the conditions where the difference between units of R, rad, and rem can be more significant.

A.1 Quantities vs. Units

One underlying concept that often gets muddled in radiological measurements is the distinction between *quantities* and *units*. A quantity is expressed as a numerical value multiplied by a unit. A familiar example is the quantity of length in the units of inches: this is an example where the unit is specific to a single quantity. Confusion sometimes arises with radiological measurements because some units can apply to more than one quantity.

As noted in Section 2.2, one way to measure radiation is to look at the effects that the emitted energy or particles have on materials that they come in contact with. One such effect is "ionization." There are several different quantities and units that can measure this effect.

A.2 Exposure (R), air kerma (rad), Absorbed Dose (rad)

The physical effects of radiation on air, for example, are straightforward to understand and to measure: radiation can knock out some electrons from the atoms in air, leaving them with a positive charge ("ions") so that a measurable electric current flows if a voltage is applied across the air (this is how gas-filled radiation detectors work). The amount of electrical charge created for a given mass of air is the technical meaning[13] of the quantity "**exposure**" and it is measured in units called **Roentgen,** which is abbreviated as a capital "**R**." The ionization effect could also be quantified by measuring the *energy released* in the air – this is called the "**air kerma**" and is measured in units called "**rad**." Or, the ionization effect could also be quantified by measuring

[13] The precise technical definition of **exposure** is only for photons ≤ 3 MeV (where all the charged particles are completely stopped in the volume of air). Thus, the unit R is not applicable for photons of higher energy or for other types of radiation such as neutrons.

the energy that was *absorbed* by the air: that is the quantity "**absorbed dose,**" which is also measured in units of "**rad**."

While "exposure" and "air kerma" are specifically defined for air, "absorbed dose" could also be measured for materials other than air. For example, it could be air, some other gas or, most commonly, it is a "tissue-equivalent" material that has properties similar to parts of the human body. Note that unlike the inch, the "rad" is an example of a unit that is applicable to more than one quantity, as it is used for both air kerma and absorbed dose in tissue. The "R," on the other hand, is used only with exposure.

Exposure is a quantity that can be directly measured and has been commonly used in laboratory settings along with the quantity air kerma (rad). The factor to convert from exposure (R) to air kerma (rad) is 0.876 [International Commission on Radiation Units and Measurements (ICRU) Report 17].

A.3 Dose Equivalent (rem), Effective Dose (rem)

Biological effects of radiation are more complicated than those in air or those in a tissue equivalent material. For example, neutrons can be more damaging to cellular DNA than photons because they may transfer all their energy in the short distance of a DNA strand. Also, some organs of the body are more sensitive to radiation, and the biological effects also tend to vary with age and gender.

The quantity "**Dose Equivalent**" was defined to take into account the more damaging effects of different energies of neutrons compared to those for photons. This involved multiplying the tissue absorbed dose in rad by a radiation "quality factor" to determine the Dose Equivalent in **"rem."** These quality factors apply to potential long-term health effects, not the acute effects seen at high radiation levels[14]. The quality factor for neutrons of certain energies is 10; for photons it is equal to 1. That is why some literature states simply that 1 rad = 1 rem for x-rays and gamma rays. However, as noted above, the units of "rad" or "rem" are used for more than one radiological quantity. The statement 1 rad = 1 rem is true for the conversion of absorbed dose in tissue (rad) to Dose Equivalent (rem), but it is not the case for the conversion of air kerma (rad) to another quantity called Personal Dose Equivalent (rem), as explained in section A.4. In this latter case, the variations in biological effects for photons of different energies result in conversion factors that vary with photon energy.

With increasing knowledge of long-term biological effects, international radiation protection organizations developed more precisely defined quantities. For example, the "**Effective Dose**," (rem) is a weighted sum of the absorbed dose to individual organs[15] of the body, using population averages to approximate the effects to different organs. It is applicable to potential long-term health effects, not short-term acute effects. This radiation protection quantity is used to estimate health risks and specify dose recommendations, but it cannot be directly measured because it is a calculation for a hypothetical person. Therefore, another category of "**operational quantities**"

---

[14] Therefore, to be rigorous, at high levels (such as 50-100 rad or more) units of "rad" are used instead of units of "rem" for protection guidelines. (This was noted in section 4.1 footnotes.)

[15] The quantity "**Equivalent Dose**" (rem) is the absorbed dose to each individual organ in the sum.(Additional details are available in International Commission on Radiological Protection Publication 60 (ICRP-60).

are used to give conservative approximations of the protection quantities. The operational quantities are those used for monitoring workers, and they have precise definitions.

A.4 $H_p(10)$ Personal Dose Equivalent (rem)

The international standard operational quantity for assessing and controlling radiation is called the "**Personal Dose Equivalent**." It also uses units of "**rem**."[16] It is defined as the dose at a certain depth in the body. To approximate the human body in the laboratory, a "phantom" is used, consisting of a standardized block of Lucite (or Lucite filled with water). The abbreviation for Personal Dose Equivalent[17] is "**$H_p(10)$**." Instruments measuring personal dose equivalent are specially calibrated and "energy compensated" to take into account variations in the dosimetric effects of different photon energies. Testing of different instruments irradiated with and without a phantom showed variations from 20% -35% (Pibida, 2010).

The factor to convert from exposure (R) to air kerma (rad) is close to one, it is 0.876. The factor to convert from air kerma (rad) to $H_p(10)$ Personal Dose Equivalent (rem) depends on the photon energy. It is close to 1 for photons greater than 500 keV, but for lower energy photons it fluctuates from less than one to greater than one.[18] That is why it was noted above that the statement "1 rad = 1 rem" for gamma and x-rays is somewhat misleading, because it does not specify the quantity being considered.

It is appropriate for responders to use the approximation 1 R ≈ 1 rad ≈ 1 rem for avoiding acute effects and for comparing the response range of radiological equipment. This is because the relevant response ranges span several factors of ten, while the differences between R, rad, and rem are on the order of about 20% for many photon energies. Also, at higher radiation levels corresponding to acute effects, the rad is often used by convention instead of the rem, since the quality factors and radiation weighting factors used in radiation protection calculations apply to potential long-term health effects only. Thus for avoiding acute effects, devices reading in R, rad, or rem can all be useful.

The distinction between R, rad, and rem becomes important in the measurement of the accumulated dose to an individual at doses in the low and medium range for the purpose of minimizing long-term health effects. Even here, responder applications do not require knowledge of details about the different biological effects. The key point is to realize that radiation dosimeters measuring the accumulated dose to an individual report in units of rem. Products that specifically measure Personal Dose Equivalent $H_p(10)$ are calibrated to take into account the effects of different photon energies. Such products will provide a more accurate measure of an individual's dose for radiation safety for minimizing long-term health effects. However, they may not be as sensitive at low energies and therefore less applicable for detection in interdiction missions.

---

[16] International Standard replaces the "rem" with the "Sievert" (abbreviated "Sv") and considers the "rem" obsolete.

[17] The Personal Dose Equivalent $H_p(10)$ is known as the *deep dose* and refers to a depth of 10 mm in the body. The *shallow* Personal Dose Equivalent, written "$H_p(0.07)$," is used for the skin dose. The shallow dose is not relevant for the responder applications in this report.

[18] For example, the conversion factor from air kerma (rad) to $H_p(10)$ (rem) is 0.613 for 20 keV photons and is 1.890 for 60 keV photons.

A.5 International Units: Gray (Gy) and Sievert (Sv) - factor of 100

Some product literature may specify the radiation range using International Standard (known as "SI") units. Just as the United States is moving to metric units for length and volume, international units would replace the rem and the rad. There is no SI unit that would directly replace the "R". (Instead, "air kerma" in "Gy" is used in place of "exposure.")

The international unit to replace the "rem" is the "Sievert," abbreviated "Sv," and the international unit to replace the "rad" is the "Gray," abbreviated "Gy." To convert from rad to Gy or from rem to Sv it is necessary to multiply by 100.

Many regulations and guidance documents in the United States still use the R, rad, and rem, although in other countries, the SI units are widely and exclusively used and the R, rad, and rem are considered obsolete.

A.6 References Cited in Appendix A

ICRU-47 (1992). *ICRP Report No. 47 Measurements of Dose Equivalents from External Photon and Electron Radiations*. Bethesda, MD: International Commission on Radiation Units and Measurements.

Pibidia, L. M. (2010). Validation Testing of ANSI/IEEE 42.29 Standard Requirement for Personal Emergency Radiation Detectors. *Health Physics, 98* (4), 597-602.

APPENDIX B. RADIATION INSTRUMENT TECHNOLOGIES

Why isn't there one instrument that does everything?

The science of radiation measurements involves trade-offs. Different materials and techniques are used to detect gamma, alpha, beta, and neutron radiation, and they also vary with the range of levels to be measured. In some cases, adding shielding impairs the measurement (e.g., alpha detector) and in others, helps (e.g., moderators for slowing down neutrons). Some technologies may be too fragile or impractical for field use, but perfectly suited to an indoor, fixed system. Generally, an instrument would be more sensitive, i.e., capture more events, if it were bigger or made of more sensitive materials; however, this may make it difficult to carry or too expensive for widespread use. Sometimes more sensitivity is not necessary and would only lead to false alarms. Many different techniques have been tested and are in use in specialized applications. Commercially available instruments are geared toward particular applications and measure appropriate combinations of the three key radiological characteristics.

The most common technologies used for portable radiation instruments for homeland security applications are gas-filled detectors, scintillation detectors, and semiconductor detectors. An overview of these technologies is provided here. However, the overall performance of any radiation detector not only depends on the detector technology, but the associated electronics, software, features, and packaging. For many of the instrument types discussed in this report, the SAVER program has completed TechNotes, Market Surveys, and Assessments that detail instrument capabilities, features, cost, and performance information. The SAVER documents are available on the SAVER library which can be found at www.dhs.gov/science-and-technology/SAVER.

Gas-filled detectors

Radiation passing through air or a gas ionizes it, that is, breaks the molecules down into positively charged ions and negatively charged electrons. In a gas-filled detector, a voltage is applied across a chamber to create a positive and negative side, attracting the electrons and ions respectively. The ion-electron flow produces a measurable electrical current that is related to the intensity of the radiation. Three classes of detectors use ionization reactions to measure radiation:

- GM detectors;
- Proportional counters; and
- Ionization (Ion) chambers.

Of these three, GM detectors are the most sensitive to low radiation levels, followed by proportional counters, and then ionization chambers. Ionization chambers are generally more suited to high radiation areas because GM detectors require resolving time to clear a cascade effect of ion pairs. Ionization chambers are more often used in the nuclear industry than in handheld equipment applicable to homeland security missions.

GM detectors are filled with inert gases such as helium, neon, or argon, and only provide information on the presence and intensity of radiation; not energy or wavelength. They are used with HHSMs as a relatively inexpensive and robust contamination meter. Energy compensated GM tubes are also used for measuring exposure.

Proportional counters operate at lower voltages than GM detectors and often contain a quench gas in addition to the inert gas in order to prevent multiplication of ion pairs (P-10, comprised of 90% argon and 10% methane, is a widely used quench gas). They are commonly used for quantifying alpha and beta activity in thin window instruments, or neutron detection in sealed counters[19]. Proportional counters are designed to provide information about the energy of the incident radiation.

Scintillation detectors

Scintillation detectors use a material that glows or scintillates when radiation interacts with it. Scintillation materials are commonly solid crystals and are more sensitive to lower activity levels of radiation than a similar size gas-filled detector. The amount of light produced by the scintillating material is proportional to the amount of radiation. Sodium iodide (NaI) detectors are scintillation detectors commonly used for gamma measurements. These instruments provide spectral information on gamma energies and can help identify the type of radioactive material. Other crystal materials and special plastics with scintillating properties (e.g., lithium iodide (LiI), cesium iodide (CsI), and lanthanum bromide ($LaBr_3$)) can also be used instead of sodium iodide. Scintillating materials, such as zinc sulfide (ZnS), which is sensitive only to alpha radiation, can also be used as a probe of a Handheld Survey Meter. Certain other scintillating materials are sensitive to neutron radiation.

Semiconductor Detectors

Semiconductor instruments detect electron-hole pairs created in semiconductor materials by ionizing radiation. The number of electron-hole pairs is proportional to the radiation energy. Semiconductor materials include silicon, high-purity germanium (HPGe), lithium drifted germanium (GeLi), and cadmium telluride (CdTe). Compared with a gas-filled detector, the sensitivity per similar sized detector is higher, and the energy resolution is higher, which aides in isotope identification. Some semiconductor systems need cooling in order to operate properly.

Additional information about radiation detector technology can be found from various sources, including:

G.F. Knoll, *Radiation Detection and Measurement*, 3rd ed., New York, Wiley, 2000.

NUREG-1575, Supp. 1 “Appendix D: Instrumentation and Measurement Techniques,” in *Multi-Agency Radiation Survey and Assessment of Materials and Equipment (MARSAME),* January 2009. http://www.epa.gov/radiation/marssim/docs/marsame/appendixD.pdf

Health Physics Society, *How Can You Detect Radiation?* August, 2011. http://hps.org/publicinformation/ate/faqs/radiationdetection.html

[19] In general, neutron detectors are designed with materials (i.e., moderators) that slow neutrons down to thermal energies or are designed to convert the neutrons into charged particles, and then coupled with a conventional radiation detector (e.g., gas-filled counter).