



System Assessment and Validation for Emergency Responders (SAVER)

Neutron-Detecting Personal Radiation Detectors (PRDs) and Spectroscopic PRDs Market Survey Report

February 2015



**Homeland
Security**

Science and Technology

U.S. Department of Homeland Security



System Assessment and Validation for Emergency Responders

Prepared by the National Urban Security Technology Laboratory

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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 of DHS, the SAVER Program conducts assessments and validations on commercially available equipment and systems, and develops knowledge products that provide relevant equipment information to the emergency responder community. The SAVER Program mission includes:

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

SAVER Program knowledge products provide information on equipment that falls under the categories listed in the DHS Authorized Equipment List (AEL), focusing primarily on two main questions for the responder community: “What equipment is available?” and “How does it perform?” These knowledge products are 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. As a SAVER Program Technical Agent, the National Urban Security Technology Laboratory (NUSTL) has been tasked to provide expertise for chemical, biological, radiological, nuclear, and explosive weapons detection; emergency response and recovery; and related equipment, instrumentation, and technologies. In support of this tasking, NUSTL conducted a market survey of commercially available personal radiation detectors and spectroscopic personal radiation detectors that incorporate neutron detection. These fall under AEL reference number 07RD-01-PDGA titled Detector, Radiation, Alarming, Personal (Gamma and Neutron), though some spectroscopic personal radiation detectors could also fall under AEL 07RD-01-RIID titled Identifier, Isotope, Radionuclide.

Visit the SAVER website on First Responder.gov (www.firstresponder.gov/SAVER) for more information on the SAVER Program or to view additional reports on personal radiation detectors or other technologies. SAVER limited-distribution documents are available at the First Responder Communities of Practice. Please request an account at <https://communities.firstresponder.gov>.

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1. INTRODUCTION

Personal radiation detectors (PRDs) are small electronic devices used to detect the presence of illicit radioactive materials that emit gamma rays and in some cases neutrons. Some PRDs, known as spectroscopic personal radiation detectors (SPRDs), can measure the energy spectrum of gamma rays to identify the specific material emitting the gamma radiation. Neutrons can indicate the presence of a nuclear explosive device or special nuclear materials, such as plutonium, which could be used to make one. To provide emergency responder organizations with information on PRDs and SPRDs that can detect neutrons, the System Assessment and Validation for Emergency Responders (SAVER) Program, conducted a market survey on commercially available PRDs and SPRDs with neutron detection capability.

This market survey report is based on information gathered between January 2013 and September 2014 from Internet searches, product literature obtained from manufacturer/vendor websites, responses to a government-issued Request for Information posted on the Federal Business Opportunities website (<https://www.fbo.gov>), manufacturer/vendor responses to a neutron detector product questionnaire, and answers to direct telephone and e-mail queries of manufacturers and vendors.

For inclusion in this report, instruments had to be PRDs or SPRDs that meet the following criteria:

- Able to detect neutrons
- Commercially available
- Suitable for use by emergency responders.

Due diligence was performed to develop a report that is representative of products in the marketplace. Additional PRD and SPRD products may be available that are not included in this market survey report.

2. OVERVIEW OF NEUTRON-DETECTING PRDs AND SPRDs

2.1 PRDs and SPRDs

PRDs are pocket-sized alarming instruments with user-readable displays that are worn on the body and used to detect radioactive materials for interdiction and prevention purposes and to indicate the gamma radiation exposure rate and neutron count rate. These devices are also known as radiation pagers because of their small size. Although they are less sensitive than larger instruments, PRDs can detect and alarm when radiation increases to just a few times higher than background. They are much more sensitive than electronic personal dosimeters, which are designed to measure the dose to workers occupationally exposed to radiation. PRDs are the smallest, least expensive, and most commonly deployed instruments used to detect radioactive materials for homeland security related applications.

SPRDs are PRDs that record the gamma-ray energy spectrum and can identify the element and isotope (nuclide) emitting the radiation, doing so either within the SPRD or by communication with a separate portable computational device. SPRDs share many of the capabilities of handheld radionuclide identification devices (RIDs), and SPRDs can be considered as small

wearable RIDs. Both are alarming instruments used to detect and identify radionuclides, to measure and display gamma-ray exposure rate, and (optionally) to indicate neutron radiation. They typically acquire the gamma-ray spectrum and identify radionuclides through comparison with an internal “library” of radionuclide gamma-ray spectra. (RIDs are also known by several other names, including radionuclide identifiers, radioactive isotope identification devices (RIIDs), radioisotope identification devices, radioisotope identifiers, radiation isotope identifiers, handheld radiation identifiers, and spectrometers.)

Neutron detection is a secondary or optional feature of PRDs and SPRDs, and many models are available that detect or measure gamma radiation and not neutrons. Only instruments that include neutron detection capability are included in this market survey report.

2.2 Applications

Portable electronic instruments that detect ionizing radiation are available in a wide range of sizes, capabilities, and prices. The usefulness of a class of instruments for a given purpose should be evaluated before selecting a specific instrument within that category for purchase. What sets PRDs and SPRDs apart from other radiation detection devices is that they are small and designed to be worn, usually on a belt, so they can be used to continually and automatically detect radioactive materials while personnel perform their normal activities. They can also be used for specific detection missions.

Because PRDs are small, lightweight, inexpensive, and simple to use, they have become the most commonly deployed instrument used to detect and interdict the illicit movement of radioactive material. They are worn by thousands of responders performing their normal duties to conduct continual incidental searches for radiological threats. SPRDs provide additional capabilities, but can be used in similar ways for initial detection.

PRDs and SPRDs are used by police and fire departments, hazardous materials teams, customs inspectors, border patrol agents, and the U.S. Coast Guard, and for personnel and site security in critical infrastructures. Operational scenarios where PRDs and SPRDs can be used include: passive surveying while wearing an instrument during normal foot patrols or inside a vehicle during routine road patrols, actively surveying an event site, localizing radioactive sources in cargo, monitoring people passing through a pedestrian chokepoint such as an airport or stadium entrance, and measuring exposure rate to set a safety exclusion area around a radioactive source. For some of these uses, for example surveying during road patrols, larger devices designed for the specific use would have a longer detection range and be more effective, but PRDs already being worn by responders can provide some radiation detection capability in many situations when other resources are not available.

PRDs can detect the presence of radioactive materials, but are very limited in their ability to tell the operator the nature of the material that has been discovered. Most of the PRDs now sold do not have neutron detection capability. The primary purpose of neutron detection for homeland security is to help identify nuclear threats and distinguish them from other radioactive materials such as industrial, medical, and natural gamma-ray sources or even terrorist radiological dispersal devices. PRDs with neutron detection allow responders who find radiation above background level to tell if the radioactive material emits neutrons, narrowing the possible nature of the source of the radiation to industrial neutron sources or the nuclear threat material, plutonium.

Spectroscopic PRDs allow responders wearing them not only to detect radioactive materials, but also to potentially resolve radiation alarms themselves by identifying the radionuclide emitting the radiation. If the radionuclide can be identified, it can be classified as naturally occurring, medical, industrial, or nuclear, and its threat level assessed. In many cases, this may avoid having to call in backup teams with larger RIDs and associated delays in the activity being monitored while waiting for backup to arrive. Neutron detection is an important capability for a device which might be used to determine if a discovered radioactive source contains plutonium.

The DHS Domestic Nuclear Detection Office (DNDO) has instituted the Human-Portable Tripwire (HPT) Commercial Off-the-Shelf program to identify and develop more capable SPRDs and put them into the hands of more Federal, state, and local law enforcement officials by integrating them into standard equipment. Beginning with instruments for DHS components, including U.S. Customs and Border Protection, U.S. Coast Guard, and the Transportation Security Administration, HPT systems are being evaluated for passive monitoring operations (not deliberate screening) intended to increase the opportunity and likelihood of detecting illicit radioactive and nuclear material. HPT systems may not all include neutron detection, but those for the U.S. Coast Guard may, since on-the-spot capabilities are particularly important in their operations.

It is important for organizations considering purchase and deployment of neutron-detecting PRDs and SPRDs to understand the limitations of neutron detection using these devices. As discussed in Section 2.3.2, neutron detection is useful to detect plutonium, but not highly enriched uranium (HEU), because HEU emits very few neutrons. The neutron detectors in PRDs and SPRDs are necessarily small and therefore not highly sensitive. An operator wearing a typical neutron detecting PRD while performing normal duties such as a foot patrol might not discover nearby plutonium using neutron detection alone. If hidden plutonium is not surrounded by shielding that absorbs gamma rays, the gamma alarm of a detector will generally be triggered at a larger distance than the neutron alarm. While neutron detection capability in PRDs and SPRDs can aid in detecting plutonium, its more important use may be to confirm that a radioactive source that has been found is emitting neutrons and might be a nuclear threat.

2.3 Radiation and its Detection and Measurement

In order to compare the features and capabilities of the radiation detection instruments in this market survey report, it will be useful to review the basic concepts of radiation and its detection and measurement.

The radiation emitted by radioactive materials is *ionizing* radiation. When ionizing radiation passes through matter, it knocks electrons out of atoms and leaves loose electrons and electrically charged atoms (ions) in its path. When people are exposed to radiation, the ionization can damage cells in the human body and increase the risk of eventually getting cancer. The electrically charged ions and electrons released by ionization can also be used to detect and measure radiation.

2.3.1 Gamma-Ray Detection and Measurement

X rays and gamma rays are one kind of ionizing radiation. They are the same kind of radiation, but if the radiation is emitted by the electrons of an atom it is called an x ray, and if it is emitted by the nucleus of an atom it is called a gamma ray. In this market survey report, the terms

gamma ray and gamma radiation are often used to refer to both gamma rays and x rays emitted by radioactive materials.

The amount of gamma radiation as measured by the amount of electric charge it releases in air is called *exposure*, and the ionization charge released per unit time is the exposure rate. This is a special use of the word “exposure.” The U.S. unit of exposure rate is roentgens per hour (R/h). Another way to measure the amount of radiation is the amount of energy the radiation deposits per unit mass in matter, particularly in the tissues of the human body. This is called *absorbed dose*. The U.S. unit of radiation absorbed dose is the rad. Muscle tissue exposed to medium-energy gamma radiation producing an exposure of 1 R will receive an absorbed dose close to 1 rad, so for practical purposes 1 R = 1 rad, even though roentgens and rads are units of different quantities.

Different kinds of radiation, such as alpha particles and neutrons, can cause more biological damage than gamma rays for the same absorbed dose, so the amount of radiation in terms of the harm it can cause to people is often measured using an adjusted quantity called *dose equivalent*. Dose equivalent combines the amount of radiation absorbed and the medical effects of that type of radiation. The conventional U.S. unit of dose equivalent is the roentgen equivalent man (rem). The international unit of dose equivalent is the sievert (Sv), and 1 Sv = 100 rem. For alpha-particle and neutron radiation, dose equivalent can be as much as 20 times the absorbed dose. For gamma radiation, the dose equivalent is the same as the absorbed dose, so numerically 1 rem = 1 rad = 1 R.

All of the SPRDs and most of the PRDs in this report can display a dose-equivalent rate or exposure rate, which they derive from the gamma-ray count rate they measure. The product literature and specifications for many of the instruments make no distinction between dose-equivalent rate, absorbed-dose rate, and exposure rate and often simply use the term “dose rate,” using $1 \text{ R/h} = 1 \text{ rad/h} = 1 \text{ rem/h} = 0.01 \text{ Sv/h}$. The dose rate measured by these instruments is only the dose rate from the gamma radiation. It does not include the dose-equivalent rate from neutrons that may be present.

A specific type of radioactive material is often referred to as a radioisotope, but this usage is incorrect. The correct term is *radionuclide*. A nuclide is a “type of atom”: a collection of all atoms that have the same number of protons and neutrons in their nuclei. A radionuclide is a nuclide that emits radiation. Two nuclides are isotopes only if they have the same number of protons, but a different number of neutrons, which is equivalent to stating that they belong to the same chemical element. For example, uranium-238 (^{238}U) and plutonium-240 (^{240}Pu) are two radionuclides, while ^{240}Pu and ^{239}Pu are (radio)isotopes of plutonium. The number associated with the name or symbol of a nuclide is the total number of protons and neutrons.

Though they are called rays, gamma rays are detected as individual particles, each with its own energy. The energy of a gamma ray is measured in thousands of electron volts (kilo electron volts, keV) or millions of electron volts (MeV). Gamma rays are emitted with specific energies that are characteristic of the radionuclide emitting them. The energy of each gamma ray can be measured, and the number of gamma rays with each energy—the gamma ray spectrum—can be used to identify the nuclide that emitted the radiation. Identifying the nuclide can be very useful in determining whether a radioactive material is a nuclear threat, an industrial radiation source, a medical radionuclide, or a naturally occurring radioactive material (NORM).

Cesium-137 (^{137}Cs) and cobalt-60 (^{60}Co) are two radionuclides that are commonly used for both medical and industrial applications and frequently used in tests and specifications of radiation detectors because they emit gamma rays with just one or two easily recognizable energies.

Small concentrations of naturally occurring radionuclides are present in almost everything, including rock, soil, concrete, food, and the human body. The radiation from NORM forms an ever-present background level of radiation that varies from place to place. Radiation detection devices such as PRDs and SPRDs need to detect possibly threatening radioactive materials in the presence of the natural background radiation without alarming just from changes in the background level.

Because of background radiation and the random times that individual gamma rays hit the detector and get counted, radiation detectors cannot just alarm whenever they detect a gamma ray. To reliably detect radiation sources above background levels without producing false alarms, instruments must measure the detection count rate averaged over a length of time, called the *integration time* or count time. Together with the sensitivity of the radiation sensor in an instrument, the integration time is an important parameter influencing how quickly and reliably an instrument alarms in response to a radiation source. A longer integration time in the range from 2 to 20 seconds is suitable for incidental searches to discover radioactive materials with a low false alarm rate, while a shorter integration time of less than 2 seconds is better for finding the exact location of a radioactive source once it has been discovered. The integration time of most PRDs and SPRDs is set by the manufacturer, though some devices allow this parameter to be adjusted by a supervisor or advanced user. Some instruments have different modes with different integration times for different applications. Integration time is at least as important for neutron detection as it is for gamma-ray detection.

2.3.2 Neutrons and Neutron Sources

Neutrons are subatomic particles with no electric charge and approximately the same mass as a proton. (A proton is the nucleus of the simplest atom, ordinary hydrogen.) Neutrons are found bound with protons in the nucleus of atoms heavier than hydrogen. Free neutrons are one kind of ionizing radiation.

There are several ways that free neutrons can be produced. The most familiar mechanism is nuclear fission, in which the nucleus of an atom splits apart and in the process emits several neutrons and gamma and x rays. Fission can be induced when a neutron strikes the nucleus of an atom of special nuclear material (SNM), which can produce a fission chain reaction in reactors and nuclear explosions. Some unstable nuclides can also fission spontaneously. Plutonium-240 has a significant rate of decay by spontaneous fission, and it is always present along with the plutonium-239 that is used for nuclear weapons. This is the main reason that neutron detection is useful for detecting plutonium. Uranium-238 also has a small rate of spontaneous fission and emits neutrons, but uranium, including the HEU used for weapons, has a much lower rate of neutron emission than plutonium. Consequently, neutron detection is generally not useful to detect hidden HEU.

Industrial neutron sources are used in the petroleum industry for well logging, in construction and agriculture for moisture gauges, and for industrial process controls. One type uses the radionuclide californium-252 (^{252}Cf), which has a high rate of spontaneous fission. Another type, commonly encountered in moisture gauges, generates neutrons by bombarding beryllium

with alpha particles emitted by a radionuclide such as americium-241. Industrial neutron sources are shielded to reduce neutron and gamma-ray emissions when not in use and during shipment. Nevertheless, they are frequently detected during efforts to screen vehicles and cargo for SNM.

Another source of neutrons is the impact of high-energy cosmic rays on atoms high in the atmosphere. Cosmic rays are actually energetic atomic nuclei which continually bombard the Earth from space. When they collide with the nuclei of atoms in the atmosphere, they break up the nuclei and eject some of the bound neutrons. These free neutrons are a part of natural background radiation. The neutron background count rate is much lower than the gamma background count rate, but effective neutron detection systems still need ways to avoid alarming just from random background counts and changes in the neutron background rate.

As mentioned above in Section 2.3.1, gamma rays are emitted with specific energies that are characteristic of the radionuclide emitting them, and the energies of gamma rays can be measured to identify the nuclide that emitted them. This is not so for neutrons. Neutrons emitted from an atomic nucleus by fission or alpha particle bombardment have a broad distribution of energies, anywhere from about 0.01 MeV to 15 MeV, though most have energies between 0.5 and 5 MeV. In addition, it is much more difficult to measure the energy of neutrons than it is to measure the energy of gamma rays, especially with a small instrument. It is not possible to measure the energy distribution of neutrons with a device as small as a PRD well enough to tell the nature of the source emitting the neutrons.

When neutrons are emitted from a nucleus, they typically have energies of a few MeV and a speed that is several percent of the speed of light. These are called *fast neutrons*. Fast neutrons tend to go through most materials without being absorbed, but they do bounce off the nuclei of the atoms in materials, losing some of their energy and speed at each collision. The process of neutrons slowing down in multiple collisions is called *moderation*. Neutrons lose the most energy when they collide with light nuclei, and the lightest is the nucleus of hydrogen. Water and most plastics contain a lot of hydrogen, and these materials are good neutron moderators. After a few tens of collisions with the hydrogen in a moderator, neutrons get slowed down to speeds similar to the speed of atoms vibrating from thermal motion. Such slow neutrons are called *thermal neutrons*. Thermal neutrons are much easier to detect than fast neutrons.

2.3.3 Neutron Detection

One important reason to detect neutrons is that the gamma rays from SNM can be shielded. The gamma rays from plutonium are mostly low-energy and can be absorbed by less than an inch of lead or other heavy metals, shielding the SNM from gamma-ray detection. Neutrons are not absorbed by those materials, so plutonium shielded with lead can still be detected by its neutron emission. Neutrons can be shielded by neutron-moderating materials such as plastic and water, but it takes thick layers of these low-density materials to produce effective neutron shielding.

Detecting neutrons is more complicated than detecting gamma rays. This is mostly because neutrons do not interact with the cloud of electrons in the atoms of detector materials, only with the much smaller atomic nuclei. Even so, it is not all that difficult to detect some neutrons. What is hard is to detect neutrons and know that the particles that are detected really are neutrons and not gamma rays. That is the main reason special techniques are used for neutron detection.

The primary purpose of neutron detection for homeland security is to help identify nuclear threats and distinguish them from other radioactive materials such as industrial, medical, and natural gamma-ray sources, or even terrorist radiological dispersal devices (dirty bombs). The threat of mass destruction from a nuclear device is much greater than from merely radioactive materials, and the response correspondingly much more urgent, so false neutron detection alarms are more serious than false gamma detection alarms. It is particularly important that a neutron detector not alarm from a moderately high gamma-ray dose rate when no neutrons are present. The (false) neutron count rate reading when the instrument is exposed to only gamma radiation of a given intensity is called the *gamma-rejection* of the instrument, and it is an important specification for neutron detectors. At the same time, it is also important that the instrument be able to detect real neutrons in the presence of gamma rays.

The method of neutron detection used in PRDs and SPRDs is to capture thermal neutrons using one of three unusual materials. There are a few isotopes of elements that absorb thermal neutrons about 1,000 times more than most materials do. These nuclides include helium-3 (^3He), lithium-6 (^6Li), and boron-10 (^{10}B). When the nucleus of an atom of one of these three nuclides captures a neutron, the result is a pair of energetic heavy charged particles. In a suitably designed detector, the ionization caused by these charged particles can make a signal that is distinctly larger than the signal from electrons produced by gamma rays. If a large signal is detected, it is counted as a neutron; if the signal is small, it is either ignored or counted separately as a gamma ray.

The purpose of neutron-detecting PRDs and SPRDs is to detect fast neutrons from SNM, but these instruments can detect only thermal neutrons, so there has to be a significant amount of moderating material near the instrument for it to do its job. PRDs and SPRDs are much too small to contain the needed moderator, but the human body contains a lot of water, so the body is an effective moderator. A PRD or SPRD can only detect neutrons from bare SNM efficiently if the instrument is worn on, or held close to, the body of the operator. This fact needs to be emphasized in operator training.

It is possible to detect fast neutrons by detecting the recoiling ion when a neutron hits the nucleus of an atom in a detector, especially hydrogen in organic liquid scintillators, but this method is generally not as efficient as capturing thermal neutrons and is more useful in large detectors.

PRDs and SPRDs don't display the neutron dose-equivalent rate, just the neutron count rate. They cannot measure the dose equivalent from neutrons because neutron dose equivalent depends on the energy of the neutrons, and these instruments cannot measure the neutron energy.

2.4 Current Technologies

A radiation detection instrument such as a PRD or SPRD consists of one or more radiation sensors; a power source (batteries); electronics to process, count, measure, store, and communicate signals from the sensor(s); software/firmware; alarms and displays to alert and inform the user; and a case. All of these components are important for the usefulness of the instrument. Most responders are familiar with rapidly developing digital electronics and software, and these aspects of PRDs and SPRDs are generally proprietary, so the discussion of technologies in this market survey report concentrates on the various radiation sensors and their advantages and disadvantages. Nevertheless, the reader should be aware that the capabilities or weaknesses of the electronics and software of an instrument can compensate for some of the

effects of having a better or worse sensor and can be decisive in determining the effectiveness of an instrument for a particular application.

The technology of radiation detection sensors, particularly for neutron detection, is evolving as this report is being written, but most PRDs and SPRDs that are commercially available now still use radiation sensor technologies that have been in use for many years.

2.4.1 Current Gamma-Ray Detection Technologies

Most PRDs and SPRDs use a scintillator to detect and measure gamma radiation. A scintillator is a material that emits light when it absorbs radiation. The pulse of scintillation light can be detected and converted into an electronic signal in a device such as a photomultiplier tube or a photodiode. In a suitable scintillator, the amount of light emitted when a gamma ray is absorbed is proportional to the energy of the gamma ray. In SPRDs and RIDs, the size of the light pulses is measured to determine the energies of the gamma rays hitting the detector.

There are many kinds of scintillators, including organic and inorganic crystals, plastics, organic liquids, and glasses. The scintillator used in most PRDs and SPRDs is the inorganic crystal cesium iodide, activated (doped) with a small amount of thallium (CsI(Tl) or just CsI). CsI(Tl) is one of the brightest scintillators, the color of the light it emits works well with photodiodes, and the relatively high atomic number of the cesium helps it absorb gamma rays efficiently. One SPRD in this market survey report uses cesium iodide doped with sodium (CsI(Na)). CsI(Na) is less bright but works better with photomultiplier tubes. One PRD uses bismuth germanate, also called bismuth germanium oxide (BGO). BGO is significantly less bright than CsI, but it has a very high density and atomic number, so it is very efficient at absorbing gamma rays. Another PRD uses a glass scintillator material that contains the neutron-absorbing isotope lithium-6, so the same scintillator can be used for detecting both gamma rays and neutrons (see Section 2.4.2).

A new type of scintillator called CLYC and the semiconductor detector material cadmium zinc telluride are emerging technologies discussed in Section 2.5.

The Geiger-Mueller (GM) tube is one of the oldest radiation detection technologies still in use. A GM tube is a sealed tube of gas with a thin wire in it that is kept at a high voltage relative to the walls of the tube. When charged particles produced by gamma rays or other radiation ionize the gas, the ionization electrons accelerate toward the wire, ionize more gas, and cause a large electrical signal on the wire. A small GM tube can operate at higher gamma-ray dose rates than scintillation detectors. Some PRDs and SPRDs have an optional version that includes a GM tube to measure the gamma-ray dose rate when the dose rate is too high for the scintillator to function properly.

2.4.2 Current Neutron Detection Technologies

About half of the PRDs and SPRDs in this report detect neutrons using a lithium iodide scintillator (LiI) with the lithium enriched in ^6Li . The heavy charged particles released when the ^6Li absorbs a thermal neutron produce a large signal in the scintillating crystal that can be distinguished from smaller signals produced by electrons from gamma-ray interactions. Lithium iodide is a compact and efficient thermal-neutron sensor, but it has a weakness. If the gamma-ray exposure rate is high, several gamma-ray pulses can occur at nearly the same time, pile on top of one another, and cause a signal large enough to be counted as a neutron. This happens

even though LiI is not very efficient at absorbing and detecting gamma rays. The problem gets worse if the crystal of ^6LiI is large or if the gamma ray energy is high (for example, ^{60}Co gamma rays). For ^6LiI to work well, the pulse-size threshold separating neutron pulses from gamma-ray pulses must be carefully adjusted to avoid false neutron alarms from gamma rays.

Scintillators made of glass that contains ^6Li have been used for many years in large neutron detectors. One PRD in this report uses a single piece of this ^6Li -glass scintillator to detect both neutrons and gamma rays. To avoid false neutron alarms from gamma-ray pulse pile-up, the pulse-size threshold for neutron detection had to be set high enough to somewhat decrease the efficiency for detecting high-energy gamma rays from ^{60}Co . Since the instrument has one radiation sensor instead of two, the scintillator could be relatively large, compensating for its lower gamma-detection efficiency per unit volume compared to CsI and resulting in a sensor with good gamma-ray sensitivity and high neutron sensitivity.

For a wide range of radiation detection systems, the most important neutron detection sensor has been the proportional counter filled with ^3He gas. Six of the instruments in this report, including most of those with the highest neutron sensitivities, use ^3He proportional counters as the neutron sensor. A gas proportional counter is similar to a GM tube but operated at a somewhat lower voltage. Instead of always producing a big electric pulse when a charged particle enters it, a proportional counter produces a pulse with a size that is proportional to the energy deposited by the charged particle in the gas filling the counter. Electrons produced by gamma rays deposit only a small amount of energy in the gas and create small pulses. When ^3He absorbs a thermal neutron, two short-range charged particles are produced that deposit all or most of their energy in the gas and produce a large pulse. Helium-3 proportional counters have an excellent ability to distinguish neutrons from gamma rays even when the gamma-ray exposure rate is high because the difference in the size of the pulses produced by neutrons and gamma rays is large and because gamma rays don't interact much in the low-density helium gas.

Helium-3 proportional counters do have some drawbacks. For high neutron sensitivity, the counter either has to be big or the gas pressure has to be high. If the gas pressure is high, instruments used to be subject to U.S. Department of Transportation (DOT) safety regulations restricting the shipping of compressed gasses to cargo-only aircraft. In 2009, DOT issued a ruling, 49 CFR 173.307, that manufactured articles and apparatuses containing not more than 100 mg of inert gasses are exempt from the shipping regulations. This exemption covers all the instruments in this report. When proportional counters are struck or vibrated, they can produce electronic pulses that might be counted as though they were pulses from radiation detection. To avoid false alarms in rough use, the electronic logic of the instrument needs to be able to distinguish the two kinds of pulses and reject the pulses from mechanical shocks. The main disadvantage of ^3He proportional counters is availability. Helium-3 is very rare in nature. It is only available commercially from the radioactive decay of tritium (hydrogen-3) that was produced to make thermonuclear weapons. A significant fraction of the available supply of ^3He was used up when a lot of large ^3He proportional counters were manufactured for use in radiation detection portal monitors at ports, airports, and border crossings. The price of ^3He rose dramatically, and the U.S. Department of Energy started to ration ^3He . To help alleviate the shortage, DNDI supported development of alternative neutron detection technologies. The small amount of ^3He used in PRDs and SPRDs is relatively insignificant, and manufacturers of these instruments have been able to get the ^3He they need, but some of the recently developed

alternative neutron detection technologies are starting to be used in some new models, as discussed in the second half of the next section.

2.5 Emerging Technologies

Scintillators and gas-filled detectors are not the only kinds of radiation detectors. Detectors made from a semiconducting crystal mounted between conducting electrodes at high voltage can directly detect the ionization charge that radiation deposits in the crystal. Such solid-state detectors can measure the energy of gamma rays more precisely than scintillators can, so they are particularly useful in RIDs and SPRDs. The semiconductor with the best energy resolution is germanium, but germanium must be cooled to near the temperature of liquid nitrogen in order to work, so instruments using it are big and complex. Cadmium zinc telluride (CZT) is a semiconductor that works at room temperature and can be used to make small gamma-ray sensors with medium energy resolution—not as good as germanium, but better than any scintillator. CZT solid-state detectors have been under development since the 1970s, but have not been practical for most potential applications because it has not been possible to produce crystals of the material larger than a few tenths of an inch across that have good energy resolution. CZT sensors with sufficient resolution for an SPRD are now available in sizes over 0.5 inch on a side and 0.2 inch thick, and their small sensitivity is increased by combining several of them. One of the SPRDs in this report uses three CZT crystals as its gamma-ray sensor. Because each CZT sensor is small, it cannot absorb all the energy of high-energy gamma rays, so the resolution is only good for lower-energy gamma rays, which happens to be where it is most needed to identify nuclear threat materials.

Most emerging neutron detection technologies were developed to replace ^3He counters in large radiation detectors, but several of the new sensor technologies are applicable to small instruments including PRDs and SPRDs. One such technology is the recently developed scintillator called CLYC, consisting of the elements cesium, lithium, yttrium, and chlorine, doped with cerium and with the lithium enriched in ^6Li . Its chemical formula is $\text{Cs}_2\text{LiYCl}_6\text{:Ce}$. The material is good for detecting gamma rays, and it has an especially useful property for detecting neutrons as well. In this material, when the ^6Li absorbs a thermal neutron and emits two heavy charged particles, not only is the resulting light pulse brighter than the pulse from gamma-ray detection, the neutron-detection pulse is longer, too—more spread out in time. Signal-processing electronics are used to analyze the pulse shape as well as size so that neutrons can be detected and counted with less contamination from gamma rays. This allows a single relatively large scintillator to be used for both radiations instead of two separate smaller ones, resulting in a detector with good gamma-ray sensitivity, high neutron sensitivity, and good gamma-rejection. CLYC is used in a neutron detecting PRD that came out in 2013 and in an SPRD expected to be available in the first half of 2015.

Another technology developed to replace ^3He counters is zinc sulfide (ZnS) scintillator activated with a small amount of silver and mixed with ^{10}B or ^6Li to absorb thermal neutrons. Zinc sulfide is a bright scintillator, but the polycrystalline material is not very transparent, so it can only be used in thin layers. A PRD that became available in 2014 uses ZnS mixed with ^{10}B in multiple narrow grooves cut into a plastic light guide to create a large area neutron sensor in a small volume. Some of the light emitted by the ZnS is ultraviolet, so the plastic also has a wavelength-shifting material in it that converts the ultraviolet into visible light the photomultiplier tube can detect efficiently.

A new type of solid-state thermal-neutron detector has recently been developed that is especially promising for use in small instruments. A thin silicon particle detector is etched over its surface with myriad microscopic grooves, and the grooves are filled with ^{10}B or ^6Li . Efficient neutron detectors of this kind with areas up to 4 cm^2 have been fabricated on a limited scale. It seems likely that such detectors will soon be produced on a commercial scale and find application in PRDs, SPRDs, and other devices that detect and measure neutrons.

An SPRD with a CsI scintillator that went on sale in 2014 has been demonstrated to be able to detect neutrons with very good gamma rejection (see Section 3.2.8). Details about how this device detects neutrons are currently proprietary information and were not provided by the manufacturer. It is possible that this device detects neutrons using a sensor or method that has not been used before in an SPRD and is not described above.

2.6 Standards and Testing Programs

Several standards documents have been developed for portable radiation detectors for use in homeland security applications. Many of these are published by the American National Standards Institute (ANSI) (www.ansi.org), the Institute of Electrical and Electronic Engineers (IEEE) Standards Association (<http://standards.ieee.org/about/get/>), and the International Electrotechnical Commission (IEC) (www.iec.ch/), and some by the International Organization for Standardization (ISO) (www.iso.org) and ASTM International (www.astm.org).

The U.S. and international performance standards relevant for PRDs and SPRDs are:

- ANSI/IEEE N42.32-2006, American National Standard Performance Criteria for Alarming Personal Radiation Detectors for Homeland Security
- ANSI/IEEE N42.42-2012, American National Standard Data Format Standard for Radiation Detectors Used for Homeland Security
- ANSI/IEEE N42.48-2008, American National Standard Performance Requirements for Spectroscopic Personal Radiation Detectors (SPRDs) for Homeland Security
- IEC 62401:2007, Radiation protection instrumentation – Alarming personal radiation devices (PRD) for detection of illicit trafficking of radioactive material (similar to ANSI/IEEE N42.32)
- IEC 62618:2013, Radiation protection instrumentation – Spectroscopy-based alarming Personal Radiation Detectors (SPRD) for the detection of illicit trafficking of radioactive material (similar to ANSI/IEEE N42.48)
- IEC 62755:2012, Radiation protection instrumentation – Data format for radiation instruments used in the detection of illicit trafficking of radioactive materials (similar to ANSI/IEEE N42.42)
- ISO 22 188:2004, Monitoring for Inadvertent Movement and Illicit Trafficking of Radioactive Material.

These standards specify required documentation and general, radiological, environmental, electromagnetic, and mechanical performance requirements and methods to test instruments for meeting the requirements. The general requirements cover things that affect usability, such as size, weight, controls, displays, user interface, alarms, batteries, battery lifetime, and data format.

The radiological requirements cover how well the instruments detect radiation, including the time to alarm for gamma rays and neutrons, rate of false alarms, accuracy of gamma-ray dose-rate readings, over-range indication, and neutron indication in the presence of gamma rays. For SPRDs, the radiological requirements also include ability to identify 18 specified single radionuclides, a pair of radionuclides, and threat radionuclides (HEU and Pu) masked by other radionuclides. The environmental, electromagnetic, and mechanical requirements cover the conditions under which the instrument must operate and its ruggedness and durability, including resistance to temperature extremes, humidity, moisture, dust, electrostatic discharge, radiofrequency and magnetic fields, vibration, and impact. There are over 40 different requirements for the PRDs, and many more for the SPRDs. Many of the capabilities and features covered in the standards are discussed in the product information in Section 3 below.

Tests of early models of PRDs against criteria in the initial 2003 version of the N42.32 standard were conducted in 2004-2005 by the National Institute of Science and Technology (NIST) in collaboration with four National Laboratories. The 2005 NIST document “Results of Test and Evaluation of Commercially Available Personal Alarming Radiation Detectors and Pagers for the Department of Homeland Security” is available to responders who register for an account at <https://communities.firstresponder.gov>. While many of the tested devices have since been improved or discontinued and much of the test information is out of date, this document is still useful to show how PRDs are tested and compared.

DNDO has supported several more recent programs to test how well commercially available radiation detectors in each instrument category, including PRDs and SPRDs, meet the standards for their category. The two major testing programs are the Graduated Rad/Nuc Detector Evaluation and Reporting (GRaDER[®]) Program (www.dhs.gov/guidance-grader-program) and the Illicit Trafficking Radiological Assessment Program + 10 (ITRAP+10) (www.dhs.gov/illicit-trafficking-radiological-assessment-program-10-itrap10). Testing of SPRDs and a few PRDs for comparison is being done for the HPT program (see www.dhs.gov/blog/2011/11/02/dndo-hosts-industry-day-“commercial-first”-initiative). The overall aim is to improve radiation detection capabilities. In these programs, detection systems are generally offered for testing by their manufacturers, and detailed test reports on each system are provided to that system’s manufacturer. None of these reports are currently available to the public, but accredited responder organizations may soon be able to access some of them through DNDO.

As this SAVER market survey report is being written, ANSI/IEEE N42.32 and N42.48, the U.S. standards for PRDs and SPRDs, and IEC 62401, the international standard for PRDs, are all in the process of being revised. Some of the test methods and performance criteria will be changed significantly in the revised standards.

3. PRODUCT DATA

Ten commercially available PRDs and ten SPRDs with neutron detection capability were identified for this market survey. This count includes different models from the same manufacturer that differ only slightly. A PRD-like instrument that detects only neutrons and an SPRD that is about to become available are also described. Descriptions of PRDs and SPRDs are given in Section 3.1 and Section 3.2, respectively. Tables 3-1 and 3-2 summarize product data for each category, and a short description of each instrument in the category follows the

table. The manufacturer's suggested retail price for the PRDs ranges from just under \$3,000 to \$5,500. The SPRDs range in price from just under \$4,000 to just under \$10,000.

For convenience, most quantitative information about the products is given in conventional U.S. units—dimensions are in inches, weight in pounds, temperature in degrees Fahrenheit (°F), and radiation exposure rate in roentgens per hour (R/h). Specifications in metric units are available from the manufacturers. Metric units are used in the specification of neutron sensitivity.

The product data presented here are based on information gathered between January 2013 and September 2014 from Internet searches, product literature obtained from manufacturer/vendor websites, responses to a government issued Request for Information posted on the Federal Business Opportunities ("FedBizOpps") website (<https://www.fbo.gov>), manufacturer/vendor responses to a neutron detector product questionnaire, and answers to direct telephone and e-mail queries of manufacturers and vendors. The information has not been confirmed by the SAVER Program.

Emergency responder agencies that may be considering purchasing neutron detecting PRDs or SPRDs should carefully consider the overall capabilities and limitations of each instrument category and each product in relation to their agency's operational needs. Different applications will have different requirements for radionuclide identification, gamma and neutron detection sensitivity, size and weight, ruggedness, battery life, display readability, alarm types, and other specifications and features.

3.1 PRDs with Neutron Detection

As briefly defined in Section 2.1, PRDs (AEL 07RD-01-PDGA) are small, self-reading, alarming instruments that are worn on the body and used for rapid detection of radioactive materials. Although less sensitive than larger instruments, PRDs can detect increases in the level of radiation to just a few times higher than background and are much more sensitive than electronic personal dosimeters, which are designed to measure the dose to workers occupationally exposed to radiation. PRDs are becoming widely used to detect and interdict the illicit movement of radioactive material because they are small, lightweight, and relatively inexpensive, so PRDs can be worn by large numbers of responders performing their normal duties to conduct continual incidental searches for radiological threats. Most of the PRDs now sold do not have neutron detection. Only PRDs that include neutron detection capability are included in this market survey report.

Since a PRD is too small to include an internal neutron moderator, the instrument alone can detect only thermal neutrons. The manufacturers of most of the PRDs in this report have provided the thermal neutron sensitivity of the neutron detectors in their devices, allowing comparison of the relative neutron sensitivity of the different instruments. The manufacturers of some of the PRDs provided the sensitivity to fission neutrons from ^{252}Cf . To detect fission neutrons, a PRD must be worn on the body of the operator so the body can act as a moderator. Since that is not practical during testing, tests of the fast-neutron detection sensitivity of PRDs are done with the device mounted on a plastic block, called a *phantom*, which provides neutron moderation simulating that of a human body.

A product comparison matrix for PRDs with neutron detection is given in Table 3-1. Information listed in the table, and in the instrument descriptions following the table, was

provided by manufacturers and has not been independently verified by the SAVER Program. Product characteristics in the product comparison matrix are defined as follows, listed in column order:

Manufacturer/Vendor: products are listed in alphabetical order by manufacturer or primary vendor. Some of the products may be available from multiple vendors.

Product Name/Model: as designated by the manufacturer/vendor.

Price: approximate manufacturer suggested retail price (MSRP) for one unit, in U.S. dollars; quantity discounts are available.

Weight: in pounds, rounded to the nearest 0.01 pound, including batteries.

Dimensions: length \times width \times thickness, in inches, rounded to the nearest 0.1 inch, not including clip or holster.

Battery Type, Life (h): number, size (AA, AAA, 9-volt, or lithium 123A), and run-time life in hours. One model uses a lithium battery, all of the others can use alkaline or rechargeable nickel metal hydride (NiMH) batteries, and the run time is given for alkaline.

IP Rating: ingress protection rating code, a two-digit code for protection against (1) solid objects (dust) and (2) liquids; higher numbers are better. First digit: 5 = function not affected by dust; 6 = dustproof. Second digit: 4 = device not harmed by splash water from any direction; 5 = not harmed by low pressure water jets; 6 = not harmed by strong water jets; 7 = not damaged by temporary immersion up to 1 meter.

Neutron Detector Type: ^6LiI , ^6Li glass, or $\text{Cs}_2^6\text{LiYCl}_6\text{:Ce}$ (CLYC) scintillator, zinc sulfide scintillator with boron (ZnS+B), or ^3He proportional counter.

Neutron Sensitivity: for thermal-energy neutrons unless otherwise specified; units are counts per (neutron/ cm^2) = counts cm^2 /neutron. If specified for ^{252}Cf , the sensitivity is for ^{252}Cf fission neutrons with the PRD mounted on a plastic phantom and located 25 cm (9.84 inches) from a source with specified neutron emission rate or producing a specified neutron dose equivalent rate at the detector.

Gamma Rejection: the neutron count rate reading when the instrument is exposed to only gamma radiation (from ^{60}Co unless otherwise specified) of a given intensity. Usually specified as no neutron alarm or the maximum neutron count rate in counts per second (cps) for a given gamma-ray exposure rate in mR/h or R/h. A lower neutron count rate in a higher gamma dose rate is better.

Gamma Detector Type: BGO, CLYC, thallium-doped CsI, or glass scintillator; Geiger-Mueller tube (GM).

Gamma Sensitivity: in counts per second per microrentgen per hour (cps/($\mu\text{R/h}$)) for ^{137}Cs 662 keV gamma rays.

Table 3-1. Product Comparison Matrix for PRDs with Neutron Detection

Manufacturer/ Vendor*	Product Name/ Model	Price [†] (\$)	Weight (lbs)	Dimensions (inches)	Battery Type, Life (h)	IP Rating [‡]	Neutron Detector Type	Neutron Sensitivity (cnts cm ² /n) [§]	Gamma Rejection	Gamma Detector Type	Gamma Sensitivity (cps/μR/h)
Mirion Technologies	PDS-100GN	3,000	0.66	4.8 × 2.9 × 1.7	2 AA, 100	IP54	⁶ LiI	²⁵² Cf: 3 cps/ 28,000 n/s	No n alarm at 9 mR/h	CsI	4
PoliMaster	PM1401 GNA	3,667	0.88	7.2 × 2.2 × 1.3	1 AA, 800	IP65	³ He	7.0	No n alarm at 10 mR/h	CsI	1
PoliMaster	PM1703GN	2,933	0.43	3.4 × 2.8 × 1.3	1 AA, 1,000	IP65	⁶ LiI	1.2	No n alarm at 10 mR/h	CsI	0.85
PoliMaster	PM1703 GNA	3,389	0.47	3.4 × 2.8 × 1.3	1 AA, 1,000	IP65	⁶ LiI	1.5	No n alarm at 10 mR/h	CsI	1
PoliMaster	PM1703 GNM	3,200	0.51	3.9 × 3.0 × 1.4	1 AA, 1,000	IP65	⁶ LiI	1.2	No n alarm at 10 mR/h	CsI + GM	0.85
RAE Systems	NeutronRAE II	2,995	0.69	4.9 × 2.7 × 1.4	2 AA, 500	IP67	⁶ LiI	0.6	0 cps at 10 mR/h	CsI	0.3
Sensor Technology Engineering	HRM	5,500	0.81	8.3 × 2.0 × 1.2	1 Li 123A, 720	IP65	³ He	10.5	No n alarm at 4 R/h	CsI	2.2
Technical Associates	DSI-2GN	3,950	0.75	6.5 × 2.7 × 1.3	1 9-volt, 200	Not provided	ZnS+B	0.25	<0.05 cps at 20 mR/h	BGO	1
Thermo Scientific	RadEye GN	3,250	0.35/ 0.41 [#]	4.0 × 2.6 × 1.5 [#]	2 AAA, 400	IP65	⁶ Li glass	7.8; ²⁵² Cf: 4.3cps/ 20,000 n/s	<0.2 cps at 1 R/h	glass	1.2
Thermo Scientific	RadEye GN+	3,950	0.35/ 0.41 [#]	4.0 × 2.6 × 1.5 [#]	2 AAA, 400	IP65	CLYC	5.3; ²⁵² Cf: 2.9cps/ 20,000 n/s	No n alarm at 10 mR/h	CLYC	1.1
Thermo Scientific	RadEye NL	2,420	0.35/ 0.41 [#]	3.8 × 2.4 × 1.2	2 AAA, 500	IP65	³ He	²⁵² Cf: 0.15 cps/ mrem/h	<0.2 cps at 1 R/h	none	Not applicable

Notes:

* Some of these products may be available from multiple vendors.

† MSRP for one unit; quantity discounts are available.

‡ Ingress protection (IP) rating: two-digit code for protection against (1) dust and (2) liquids; higher numbers are better.

§ For thermal neutrons unless otherwise specified; units are counts cm²/neutron. If specified for ²⁵²Cf, the sensitivity is for ²⁵²Cf fission neutrons with the PRD mounted on a plastic phantom and located 25 cm (9.84 inches) from a source with specified neutron emission rate or producing a specified neutron dose equivalent rate at the detector.

|| For ¹³⁷Cs 662 keV gamma rays.

Including supplied shock-absorbing sheath

Descriptions of each of the PRD instruments are given below. Unless otherwise stated in their individual descriptions, each instrument has:

- A scintillator for gamma-ray detection
- Separate neutron detector
- Ability to disable the audible and/or visual alarms for stealth operation
- Vibratory alarm
- High-dose-rate warning/danger alarm
- Over-range indication
- Low-battery indication
- Numeric display of gamma-ray exposure rate in $\mu\text{R}/\text{h}$, dose rate in $\mu\text{Sv}/\text{h}$, or count rate in counts per second (cps)
- Separate display of neutron count rate
- Back-lit or illuminated numeric display
- Programmable or adjustable settings including adjustable alarm thresholds for gamma-ray dose/exposure rate and neutron count rate
- Removable batteries
- Markings indicating the locations of the gamma-ray and neutron sensors
- Operating temperature range covering at least -4°F to 122°F
- Clip or holster to allow the PRD to be worn on a belt.

All of the PRDs described below come with a warranty covering at least 1 year. Those that take AA or AAA batteries can use alkaline or rechargeable nickel metal hydride batteries. Volume-purchase discount pricing is available for all of these PRDs.

3.1.1 Mirion Technologies PDS-100GN

The PDS-100GN is designed to detect, locate, and quantify radioactive and nuclear materials and to respond to incidents involving radiological dispersal devices. The gamma-ray sensor of this PRD is a CsI scintillator with a relatively large volume of 9 cm^3 . The device has an organic light-emitting diode (OLED) alpha-numeric display on the front and is operated using two push buttons on the front. Alarm lights for gamma and neutron detection are visible from the top and front. The battery compartment cover on the back is removed using a screwdriver. The PDS-100GN has been available since about 2006.

The PDS-100GN has two main operating modes: “Detection” and “Search,” each with its own specific response time and display configurations. In Detection mode, the display’s neutron count rate integration time is 10 seconds, and the display can show gamma count rate in cps, dose rate in $\mu\text{Sv}/\text{h}$, or exposure rate in $\mu\text{R}/\text{h}$ with an integration time of 5 seconds. In Search mode, the neutron and gamma-ray integration times are both 1 second for fast response to variations in the radiation field. The gamma-ray exposure rate indication range is $0\text{ }\mu\text{R}/\text{h}$ to $10\text{ mR}/\text{h}$. The instrument can store measurement data for up to 1,000 events and up to 50 spectra (1,024 channels). Instrument set-up and retrieval of stored data is performed via an Infrared Data Association (IrDA) infrared port, Bluetooth[®], or optional tri-band Global System



PDS-100GN
*Photo courtesy of
Mirion Technologies*

for Mobile communications (GSM) connection. Available accessories include an external power supply/battery charger, earphone, silicone protective cover, software for remote display of gamma-ray energy spectra, recorded readings, and parameter settings, and software for remote gamma-ray spectrum analysis and radionuclide identification.

A spectroscopic version of this PRD with embedded radionuclide identification is also available; see 3.2.2 below.

3.1.2 Polimaster PM1401GNA

The PM1401GNA is designed to detect gamma and neutron radiation emitting materials. The instrument is equipped with a CsI scintillator for detection of gamma radiation and a ^3He proportional counter for detection of neutron radiation and will alert the user if radiation levels exceed the preset threshold values. When the instrument is turned on by pressing the Mode button, it performs a self-test, measures the background of gamma and neutron radiation, calculates the corresponding alarm thresholds, and goes into search mode with no further user actions.



PM1401GNA
Photo courtesy of Polimaster

The Polimaster PM1401GNA has better neutron sensitivity than most of the other PRDs listed in this report, but it is longer and heavier than the others. When worn using the supplied belt clip, the long dimension is vertical with the front panel facing away from the body. The instrument is operated with two buttons on the front panel, which is also where the liquid crystal display (LCD) and markings for the centers of the gamma-ray and neutron sensors are located. The LCD is read with the long dimension of the instrument horizontal. The single alarm-indication light emitting diode (LED) is located on the top end of the unit. There is no difference in the alarm indication between gamma ray and neutron detection, but there is a separate numerical display for the intensity of each kind of radiation. The battery compartment cover, which is on the top end, is removed using a coin or screwdriver. Vibration alarm is by means of a small separate device supplied with the PRD and connected with a cable. The vibration device may be put in a pocket or worn on a wrist strap. The gamma-ray exposure rate indication range is 0 to 9,999 $\mu\text{R/h}$, with $\pm 30\%$ accuracy from 10 to 7,000 $\mu\text{R/h}$ for ^{137}Cs gamma radiation. The neutron count rate indication range is 0 to 999 cps. The instrument can record and store data for up to 1,000 events in its nonvolatile memory and transmit the recorded data to a personal computer (PC) via IrDA infrared channel. PC software is supplied for setup, data processing, and analysis. The PM1401GNA has been available since 2004. Supplied accessories include the vibration alarm device, an infrared communications adapter, and software. Available optional accessories include a carrying case, telescopic extension tube, and external neutron moderator.

A spectroscopic version of this PRD is also available; see 3.2.3 below.

3.1.3 PoliMaster PM1703GN, PM1703GNA, and PM1703GNM

The PM1703GN, PM1703GNA, and PM1703GNM are personal radiation detectors designed to detect materials that emit gamma rays or neutrons. The instruments are equipped with a CsI scintillator for gamma detection and a $^6\text{LiI(Eu)}$ scintillator for neutron detection. When any of these instruments is turned on by pressing the Mode button, it performs a self-test, measures the

background of gamma and neutron radiation, calculates the corresponding alarm thresholds, and goes into search mode with no further user actions. The GNA model has larger gamma and neutron sensors than the GN, with correspondingly higher detection sensitivity (see Table 3.1). The GNM model has a Geiger-Mueller tube as an additional gamma-ray sensor to give dose-rate readings when the dose rate is too high for the CsI sensor. The GN and GNA models were first available in 2002; the GNM in 2012.

These PM1703 models have data storage for up to 1,000 events in the instruments' nonvolatile memory and can transmit the stored information to a PC via an IrDA infrared channel using supplied software. They come with a detachable belt clip, and when worn on a belt, the two operating buttons, small but bright LED alarm light, and 0.9-inch by 0.5-inch LCD display are on the top. There is no difference in the alarm indication between gamma ray and neutron detection, but there is a separate numerical display for the intensity of each kind of radiation. The gamma-ray exposure rate indication range is 0 to 9,999 $\mu\text{R/h}$, with $\pm 30\%$ accuracy from 10 to 7,000 $\mu\text{R/h}$ for ^{137}Cs gamma radiation. The neutron count rate indication range is 0 to 999 cps. The battery compartment is opened using a coin to remove the cover. Available optional accessories include an IrDA to serial port adapter (GN, GNA), holster, and carrying case.



PM1703GN

Photo courtesy of Polimaster

The PM1703GNM has the features of the PM1703GNA plus an extended dose-rate range, higher accuracy, and PC communication via a universal serial bus (USB) interface.

3.1.4 RAE Systems NeutronRAE II

The NeutronRAE II is a PRD that provides rapid detection of both gamma and neutron radiation sources using a single instrument even in potentially flammable environments. It is certified intrinsically safe and waterproof for chemical decontamination purposes. Its immersible design makes for reliable operation in wet environments and easy decontamination. The 1 cm^3 CsI and ^6LiI scintillators of the NeutronRAE II provide a 2-second gamma alarm response and 5-second neutron alarm response to radiological threats. The NeutronRAE II accumulates approximate gamma dosage. Stored dosage data can be accumulated or cleared and reset for each use period. The NeutronRAE II logs 30,000 data points, including time and date, dose rate, and total dose. Data log download to a PC is via built-in Bluetooth radio using supplied software. The NeutronRAE II has been available since 2006.



NeutronRAE II

*Photo courtesy of
RAE Systems*

The device is operated using two buttons on the front. The battery compartment cover on the side of the unit is opened using a coin or screwdriver. The graphic numeric display on the top has a 1.2-inch by 0.75-inch viewable area and can be inverted for viewing by the user when worn. Large flashing alarm lights for radiation detection are visible from the top and front. There is no difference in the alarm indication between gamma ray and neutron detection, but there is a separate numerical display for the intensity of each kind of radiation. The radiation intensity is displayed in cps (gamma, neutron) or as exposure rate in

$\mu\text{R/h}$ (gamma only). The gamma exposure rate range is 1 to 4,000 $\mu\text{R/h}$. No information on optional accessories was provided.

3.1.5 Sensor Technology Engineering Handheld Radiation Monitor (HRM)

The HRM is a small, self-contained gamma ray and thermal-neutron radiation detector for use in interdicting and locating nuclear materials. It was specifically designed to be easily used by trained security forces and emergency responders. The high sensitivity of the instrument is made possible by the use of a miniature photomultiplier tube and large CsI scintillator combined with a high-pressure ^3He -filled proportional counter. The HRM is the size of a flashlight and is intended to be handheld or worn on the operator's belt in the nylon holster provided. When gamma rays or neutrons are detected at levels significantly above the natural background, the unit alerts the operator by either sounding an audible alarm or vibrating, and lighting the single-digit LED displays. The operator can locate the radiation source using the single-digit LED displays and audible alarm or vibration, which increase in frequency with increasing radiation level. The HRM is designed for operators who need to quickly and discreetly detect and locate a radiation threat in an unpredictable radiation background.



HRM

Photo courtesy of Sensor Technology Engineering

At 0.81 pound, the HRM is heavier than most of the other PRDs, and at 8.3 inches long, it is noticeably longer than other PRDs. Its length allows it to have a relatively large ^3He tube, which gives it the highest detection sensitivity for thermal neutrons of the PRDs in this report. It also has a higher sensitivity for gamma-ray detection than all but one of the other PRDs. Unlike the other instruments, the HRM does not display the gamma-ray exposure, dose, or count rate or the neutron count rate, but instead has gamma and neutron detection indicators that display a unit-less LED numeric value between one and nine. The HRM is designed to be a search instrument, not a personal dose-rate meter. Because the controls and information displayed by the instrument are relatively simple, the training required to use the HRM can be relatively simple. Though intended to be hand-held for gamma-ray searches, for neutron detection it should be worn on, or held close to, the body of the operator, which acts as a moderator and allows detection of fission neutrons. The HRM should be worn at least 6 inches away from radios and cell phones to avoid false alarms from radio interference.

3.1.6 Technical Associates DSI-2GN

The DSI-2GN precision radiation proximity analyzer uses gamma-ray and neutron sensors that are unusual in a PRD. The gamma radiation sensor is a 1-inch diameter 0.4-inch thick BGO scintillator with sensitivity equivalent to a 1-inch by 1-inch sodium iodide scintillator. The neutron sensor is a composite scintillator consisting of zinc sulfide mixed with boron applied to a plastic wavelength-shifting light guide. Both sensor elements are coupled to a single high-gain photomultiplier tube. The DSI-2GN became available in 2014.



DSI-2GN

Photo courtesy of Technical Associates

The gamma-ray exposure rate measured by the DSI-2GN is displayed in $\mu\text{R/h}$ on the digital LCD display located on the top of the instrument as worn on the body. An on-off switch, LED alarm light, reset and battery-test button, and battery OK light are also on the top panel. The exposure rate range is 1 to 2,000 $\mu\text{R/h}$, so there is no high-dose-rate danger alarm. The gamma alarm level can be set between 10 and 100 $\mu\text{R/h}$. There is a separate LED indicator for neutron alarms, and the user presses a button on the side of the case to toggle the display between gamma-ray exposure rate and neutron count rate. The display is not backlit, and there is no vibrating alarm. The operating temperature range was not provided. Available optional accessories include telescoping wands and a shock absorbing carrying case.

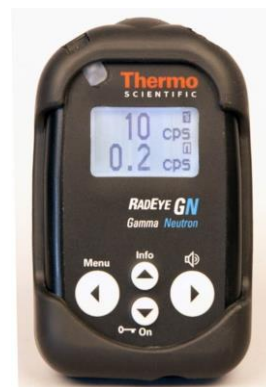
3.1.7 Thermo Scientific RadEye™ GN and GN+

The RadEye GN Gamma Neutron Pager has the second highest neutron sensitivity of the instruments in this report, and the manufacturer claims that this PRD exceeds the neutron time-to-alarm requirements of ANSI 42.32-2006 and IEC 62401. Both RadEye GN and RadEye GN+ pagers incorporate a single scintillation detector equipped with a miniature photo-multiplier to detect both gamma and neutron radiation. The RadEye GN pager uses a conventional glass scintillator material containing ^6Li , and the RadEye GN+ pager contains a Ce-doped $\text{Cs}_2^6\text{LiYCl}_6$ (CLYC) crystal. CLYC provides superior gamma-neutron separation, making the RadEye GN+ an effective tool even in neutron fields combined with high-energy gamma radiation.

While the GN version is slightly more sensitive to neutrons and to ^{137}Cs medium-energy gamma rays, the GN+ version is twice as sensitive to the low-energy gamma rays from SNM and is also more sensitive than the GN to high-energy gamma rays such as those from ^{60}Co . The RadEye GN became available in 2012; the GN+ became available in 2013.

The RadEye GN and GN+ are operated using four buttons on the front and one alarm-acknowledgement button on top. The 1.25-inch by 0.77-inch LCD display on the front has 0.3-inch high numerals and large, clear radiation units. The display includes a quick-view bar graph of current count-rate or exposure/dose-rate and alarm points. The alarm lights are visible from the top and front. The battery compartment cover is on the back and can be removed without tools. A mark indicating the center of the radiation sensor is on the back. There is an earphone jack on the bottom. A rubber shock absorbing sleeve is supplied with the instruments, and all controls and displays are accessible/visible with the sleeve in place. Even with the rubber sleeve, both instruments weigh less than the other PRDs in this report.

The RadEye GN and GN+ indicate whether alarms are due to gamma rays or neutrons by different-colored alarm LEDs, different tones, and flashing the count rate/dose rate display readings with an inverted display background of the alarming channel or both channels as appropriate. A bright orange LED lights for gamma alarms, and a bright blue LED light for



RadEye GN

Photo courtesy of Thermo Scientific



RadEye GN+

Photo courtesy of Thermo Scientific

neutron alarms. These PRDs employ a proprietary method, called NBR for natural background rejection, to determine the approximate energy distribution of gamma radiation and distinguish detection of NORM from artificial radioactive materials. The instruments have different audible alarm sounds to discriminate between elevated background/NORM and any artificial isotope alarm.

The instruments calculate and display energy-compensated gamma-ray dose/exposure rate. The gamma-ray exposure rate indication range is 1 μ R/h to 25 mR/h. The neutron count rate range is 0.1 to 1,000 cps. The latest 1,600 dose-rate values are stored in data memory. The RadEye GN and GN+ communicate via an IR interface with a PC to change settings or download data from stored measurements. They can also be fitted with a Bluetooth back that can be set to talk to a PC or to other devices for networking.

Available optional accessories include: a holster, desktop holder for PC communications, USB connection cable, serial adapter cable, Bluetooth battery cover, PC software, external neutron moderator, lutetium and thoriated tungsten gamma source test adapters, extension poles, earphone, docking station/car adapter, and external power supplies/battery chargers.

3.1.8 Thermo Scientific RadEye NL

The RadEye NL personal neutron meter is light and small, looks and handles like a PRD, and detects neutrons, but it does not detect gamma rays. The neutron detector RadEye NL can be used to detect and localize neutron radiation. The RadEye NL uses low-power electronic components and performs microprocessor-based, fully automatic self-checks. No maintenance is required. The RadEye NL incorporates a 2.5-atmosphere ^3He detector allowing for the detection of low neutron-radiation levels in conjunction with rejection of gamma radiation. The low 2.5-atmosphere pressure was designed to allow the instrument to be shipped with no DOT restrictions. (Since 2009, this pressure limit is no longer required—see Section 2.4.2.) The last 1,600 mean and maximum values of the count rates are recorded internally and can be read via serial interface. Alarms, errors, and configuration changes can also be read via a serial interface. A real-time clock is provided so that all buffer data can be time stamped.



RadEye NL

Photo courtesy of Thermo Scientific

Note: An alternate model, the RadEye N, which had a 10 atmosphere ^3He tube, has been discontinued.

3.2 SPRDs with Neutron Detection

As defined in Section 2.1, SPRDs are PRDs that record the gamma-ray energy spectrum and provide radionuclide identification, either within the PRD or by communication with a separate portable computational device. SPRDs are a cross between PRDs and RIDs, providing most of the radionuclide identification capabilities of full-size RIDs in an instrument small enough to be worn on a belt. Because their radiation sensors are smaller than those in full-size RIDs, SPRDs are less sensitive than RIDs, so they must be closer to a radiation source to detect or analyze it and/or take longer than RIDs to collect enough gamma counts in a spectrum to perform a good

identification. SPRDs have very roughly one tenth the gamma-ray sensitivity, one-tenth the weight, and cost one-third as much as full-size RIDs.

Identification of the radionuclide(s) producing the gamma-ray spectrum measured by an SPRD or RID is sometimes difficult, and the automatic identification provided by these instruments can sometimes be wrong or fail to give an answer. If a nuclear threat is suspected, the presence or absence of neutrons can be an important clue. SPRDs (or the associated external computational device) record the gamma-ray spectrum together with related information and provide a means to send the recorded data to others who are not at the incident site. This capability allows the data to be analyzed by distant gamma-ray spectroscopy experts and is invaluable for situations when the radionuclide identification provided by the device is uncertain. The process of getting rapid expert help for radionuclide identification is called *reachback*. Some responder organizations maintain their own reachback capability. The DNDO Joint Analysis Center makes expert reachback services readily available to state and local entities by connecting them to scientists at national laboratories. Reachback is greatly facilitated if the data recorded in a device is stored and transmitted in a standard format. This format is specified in ANSI/IEEE N42.42-2012. All but two of the SPRDs in this report comply with this data format standard.

Like PRDs, SPRDs are too small to include an internal neutron moderator, so the instrument alone can detect only thermal neutrons. The manufacturers of most of the SPRDs in this report have provided the thermal neutron sensitivity of their devices, allowing comparison of the relative neutron sensitivity of the different instruments. To detect fission neutrons, an SPRD must be worn on or held close to the body of the operator so the body can act as a moderator. This conflicts with the usual method of operating an SPRD for radionuclide identification—held in an outstretched hand while watching the display. As is done for PRDs, tests of the fast-neutron detection sensitivity of SPRDs are done with the device mounted on a plastic phantom that provides neutron moderation simulating that of a human body. The manufacturers of some of the SPRDs in this report supplied neutron sensitivity information for ^{252}Cf fission neutrons with the PRD mounted on a phantom. Like PRDs, neutron-capable SPRDs may not be able to detect a nuclear threat by its neutron emission alone, and their neutron detection capability is best used to confirm the presence of neutrons after a radioactive threat has been located and can be approached closely. Neutron detection is an important capability for a device which might be used to determine if a discovered radioactive source contains plutonium.

A product comparison matrix for SPRDs with neutron detection is given in Table 3-2. Information listed in the table and in the instrument descriptions following the table was provided by manufacturers and has not been independently verified by the SAVER Program. Since the decision to purchase a particular model of SPRD will be driven primarily by its usefulness for detecting and identifying sources of gamma rays rather than neutrons, specifications and features relating to gamma detection and measurement are included in the table and in the product descriptions that follow it. Product characteristics in the product comparison matrix are defined as follows, listed in column order:

Manufacturer/Vendor: products are listed in alphabetical order by manufacturer or vendor.

Some of the products may be available from multiple vendors.

Product Name/Model: as designated by the manufacturer/vendor.

Price: approximate manufacturer suggested retail price (MSRP) for one unit, in U.S. dollars; quantity discounts are available.

Weight: in pounds, rounded to the nearest 0.01 pound, including batteries.

Dimensions: length \times width \times depth, in inches, rounded to nearest 0.1 inch, not including clip or holster.

Battery Type, Life (h): number, size, type, and run-time life in hours. For AA and AAA size batteries, alkaline or rechargeable nickel metal hydride (NiMH) batteries may be used, and the run time is given for alkaline. Battery life is usually given for dose rate or search mode with limited alarm-on time, back light off or dimmed, and Global Positioning System (GPS), Bluetooth, or other communication off.

IP Rating: ingress protection rating code, a two-digit code for protection against (1) solid objects (dust) and (2) liquids; higher numbers are better. First digit: 5 = function not affected by dust; 6 = dustproof. Second digit: 3 = device not harmed by water sprayed at any angle up to 60 degrees from the vertical; 4 = not harmed by splash water from any direction; 5 = not harmed by low pressure water jets; 6 = not harmed by strong water jets.

Neutron Detector Type: ^6LiI , ^6Li glass, or $\text{Cs}_2\text{LiYCl}_6\text{:Ce}$ (CLYC) scintillator or ^3He proportional counter.

Neutron Sensitivity: for thermal-energy neutrons unless otherwise specified; units are counts per (neutron/ cm^2) = counts cm^2 /neutron. If specified for ^{252}Cf , the sensitivity is for ^{252}Cf fission neutrons with the SPRD mounted on a plastic phantom and located 25 cm (9.84 inches) from a source with specified neutron emission rate.

Embedded Radionuclide Identification: radionuclide identification available on the display of the instrument without communication to an external computational device—yes or no.

Gamma Detector Type: cadmium zinc telluride (CZT) solid-state detector; thallium-doped cesium iodide (CsI), sodium-doped cesium iodide (CsI(Na)), or CLYC scintillator; Geiger-Mueller (GM) tube.

Gamma Sensitivity: in counts per second per microrentgen per hour (cps/($\mu\text{R/h}$)) for ^{137}Cs 662 keV gamma rays.

Table 3-2. Product Comparison Matrix for SPRDs with Neutron Detection

Manufacturer/ Vendor*	Product Name/Model	Price [†] (\$)	Weight (lbs)	Dimensions (inches)	Battery Type, Life (h) [‡]	IP Rating [§]	Neutron Detector Type	Neutron Sensitivity (cnts cm ² /n)	Embedded Radionuclide Identification [#]	Gamma Detector Type	Gamma Sensitivity** (cps/μR/h)
FLIR	identiFINDER R300 nano- Raider ZH, ZH r	9,950	0.82, 0.80	4.9 × 2.8 × 1.3 ^{††}	1 Li-ion, 24	IP63	³ He	2.6	Yes	CZT	0.81/0.47 ^{††}
Mirion Technologies	PDS-100GN/ID	4,950	0.66	4.8 × 2.9 × 1.7	2 AA, 100	IP54	⁶ LiI	²⁵² Cf: 3 cps/ 28,000 n/s	Yes	CsI	4
PoliMaster	PM1401GNB	4,800	0.93	7.6 × 2.2 × 1.3	1 AA, 800	IP65	³ He	7.0	No	CsI	1.0
PoliMaster	PM1703GNB	4,312	0.51	3.9 × 3.0 × 1.3	1 AA, 1,000	IP65	⁶ LiI	1.5	No	CsI	1
PoliMaster	PM1704A-GN /-GNM	3,987/ 4,187	0.55 ^{††} / 0.59 ^{††}	4.0/4.6 × 3.4 × 1.5 ^{††}	1 AA, 250	IP65	⁶ LiI	1.5	Yes	CsI / CsI+GM	1
PoliMaster	PM1704GN	3,987	0.79	5.1 × 2.4 × 1.8	1 AA, 300	IP65	⁶ LiI	1.5	Yes	CsI	1
RadComm	MSpec neutron	6,000	0.55 ^{††}	4.9 × 2.7 × 1.2 ^{††}	Li-ion, 12	IP65	³ He	1.8	Yes	CsI(Na)	1.3
Thermo Scientific	RadEye SPRD	3,950	0.36/ 0.42 ^{††}	4.1 × 2.6 × 1.6 ^{††}	2 AAA, 170	IP65	Scintillator ^{§§}	Not provided	Yes	CsI	1.7
Thermo Scientific	RadEye SPRD-GN	~5,000	0.35/ 0.41 ^{††}	4.1 × 2.6 × 1.6 ^{††}	2 AAA, 170	IP65	CLYC	5.3; ²⁵² Cf: 2.9cps/ 20,000 n/s	Yes	CLYC	1.1

Notes:

* Some of these products may be available from multiple vendors.

† MSRP for one unit; quantity discounts are available.

‡ In dose rate or search mode with limited alarm-on time, back light off or dimmed, and GPS, Bluetooth, or other communication off.

§ Ingress protection (IP) rating: two-digit code for protection against (1) dust and (2) liquids; higher numbers are better.

|| For thermal neutrons unless otherwise specified; units are counts cm²/neutron. If specified for ²⁵²Cf, the sensitivity is for ²⁵²Cf fission neutrons with the SPRD mounted on a plastic phantom and located 25 cm (9.84 inches) from a source with specified neutron emission rate.

Radionuclide identification available on the display of the instrument without communication to an external computational device.

** For ^{137}Cs 662 keV gamma rays.

†† Including supplied shock-absorbing sheath.

‡‡ In search mode/in identification mode.

§§ Type of scintillator not provided.

Descriptions of each of the SPRD instruments are given below. Information in these descriptions was provided by manufacturers and has not been independently verified by the SAVER Program. Unless otherwise stated in their individual descriptions, each instrument has:

- A scintillator for gamma-ray detection
- Separate neutron detector
- Operating modes for general radiation monitoring, source localization, and radionuclide identification
- Ability to store and communicate alarm-event and gamma-spectrum data in ANSI/IEEE N42.42 compliant format
- Ability to disable the audible and/or visual alarms for stealth operation
- Vibratory alarm
- High dose rate warning/danger alarm
- Over-range indication
- Low-battery indication
- Numeric display of gamma-ray dose/exposure rate or alternately count rate
- Separate display of neutron count rate
- Back-lit or illuminated display
- Programmable or adjustable settings including adjustable alarm thresholds for gamma-ray dose/exposure rate and neutron count rate
- Markings indicating the locations of the gamma-ray and neutron sensors
- Operating temperature range covering at least -4°F to 122°F
- Clip or holster to allow the SPRD to be worn on a belt.

Unless otherwise stated in their individual descriptions, the gamma-ray rejection in the neutron detection channel of each instrument is sufficient to meet the IEC 62618:2013 criterion of no neutron alarm when exposed to ^{60}Co gamma rays at 10 mR/h for 1 minute and the similar criterion of ANSI/IEEE N42.48-2008 using ^{137}Cs gamma rays. All of the SPRDs described below come with a warranty covering at least 1 year. Those that take AA or AAA batteries can use alkaline or rechargeable nickel metal hydride batteries. Volume-purchase discount pricing is available for all of these SPRDs.

3.2.1 FLIR identiFINDER™ R300 nanoRaider™ ZH and ZH r

IdentiFINDER R300 is the new name for the FLIR nanoRaider SPRD, and the manufacturer currently uses both names to refer to this instrument. It has the same display interface as the FLIR RIDs. The gamma sensor of the identiFINDER R300 consists of three high-resolution semiconductor CZT detectors instead of the scintillators used in other SPRDs. Two of the CZT crystals are used in the dose-rate channel and one is used in the identification channel. The ZH model incorporates a ^3He proportional counter to detect neutrons. The ZH r model has neutron detection but no Bluetooth communication.

For general radiation monitoring, the identiFINDER R300 is carried in a holster attached to the operator's belt with the gamma sensors down and the on/off button and neutron and gamma alarm LEDs upward so the LEDs are visible to the operator. For gamma-ray source localization and radionuclide identification the instrument is optimized for single-handed operation, held with the gamma sensors outward, the color LCD display upward, the gamma (red) and neutron (blue)

alarm LEDs toward the operator, and the two operating buttons on the sides under the thumb and index finger. To survey for neutrons, the instrument is held close to the body. The beep and vibration alarm rates increase with increasing radiation level. The lithium-ion rechargeable battery is not removable. The nanoRaider ZH has been available since 2011.



IdentifINDER R300
(nanoRaider ZH)
Photo courtesy of FLIR

In Dose Rate Mode, the identiFINDER R300 displays the gamma-ray exposure/dose rate with an analog bar and digitally in the range from less than 1 $\mu\text{rem/h}$ to 1 rem/h. Other modes include Finder Mode and Identification Mode. Response times and many other settings can be configured using the operating buttons or a web-browser interface when the instrument is connected to a computer via USB cable or Bluetooth. The identiFINDER R300 has a GPS receiver to log incident locations, and data storage for up to 600,000 identifications and spectra and over 1 million alarms. Through Bluetooth connection to a mobile phone, the One Touch Reachback™ feature allows the user to provide full spectroscopic data as well as detailed device information, time, and GPS location to others with the push of a button. Supplied accessories include holster, wrist strap, wall and car power adapters/chargers, mini USB-B connection cable, and carrying case.

3.2.2 Mirion Technologies PDS-100GN/ID

The PDS-100GN/ID is the spectroscopic version of Mirion Technologies PDS-100GN PRD. The PDS-100GN/ID is designed to detect, locate, quantify, and identify radioactive sources and to discriminate, on the spot, NORM and medical isotopes from industrial sources or SNM. The gamma-ray sensor is a relatively large 9 cm³ CsI(Te) scintillator. The PDS-100GN/ID does not produce a false neutron alarm when exposed to 9 mrem/h of ⁶⁰Co gamma rays for 100 seconds. The device has an OLED alpha-numeric display on the front and is operated using two push buttons on the front. Alarm lights for gamma and neutron detection are visible from the top and front. The battery compartment cover on the back is removed using a screwdriver. The PDS-100GN/ID has been available since 2008.



PDS-100GN/ID
*Photo courtesy of
Mirion Technologies*

The PDS-100GN/ID has two main continual operating modes: “Detection” and “Search,” each with its own specific response time and display configurations. In Detection mode, the display’s neutron count rate integration time is 10 seconds, and the display can show either gamma count rate in cps or dose rate in $\mu\text{rem/h}$ (displayed as $\mu\text{R/h}$) with an integration time of 5 seconds. In Search mode, the neutron and gamma-ray integration times are 1 second or less for fast response to variations in the radiation field. The gamma-ray dose rate indication range is 0 $\mu\text{R/h}$ to 10 mR/h, and the neutron count rate range is 0 to 999 cps. In either mode, acquisition of the gamma-ray spectrum is triggered automatically as soon as an alarm occurs, and the identified radionuclides are displayed as soon as possible without any user action. Radionuclide identification can also be initiated manually. The instrument can store measurement data for up to 1,000 events and up to 50 spectra (1,024 channels). Instrument set-up and retrieval of stored data is performed via IrDA, Bluetooth, or

optional GSM connection. In addition to the GSM option, available accessories include an earphone; belt clip; external power supply/battery charger; car cradle/charger; silicone protective cover; carrying case; software for remote display of gamma-ray energy spectra, recorded readings, and parameter settings; and software for remote gamma-ray spectrum analysis and radionuclide identification.

3.2.3 Polimaster PM1401GNB

The PM1401GNB SPRD is the spectrometric version of the Polimaster PM1401GNA PRD. The GNB can transfer gamma spectra and other information to a PC, Pocket PC personal digital assistant (PDA), or smartphone through Bluetooth connectivity as well as IrDA infrared, allowing identification of radionuclides using supplied software installed on the PC. The instrument is equipped with a CsI scintillation detector for detection of gamma radiation and a ^3He detector for detection of neutron radiation and will alert the user if radiation levels exceed preset threshold values. When the instrument is turned on by pressing the Mode button, it performs a self-test, measures the background of gamma and neutron radiation, calculates the corresponding alarm thresholds, and goes into search mode with no further user actions.



PM1401GNB

Photo courtesy of Polimaster

The PM1401GNB has better neutron sensitivity than most of the other SPRDs listed in this report, but it is longer and heavier than the others. When worn using the supplied belt clip, the long dimension is vertical with the front panel facing away from the body. The instrument is operated with two buttons on the front panel, which is also where the LCD display and markings for the centers of the gamma-ray and neutron sensors are located. The LCD is read with the long dimension of the instrument horizontal. The single alarm-indication LED is located on the top end of the unit. There is no difference in the alarm indication between gamma ray and neutron detection, but there is a separate numerical display for the intensity of each kind of radiation. The battery compartment is opened using a coin or screwdriver to remove the cover, which is on the top end. Vibration alarm is by means of a small separate device supplied with the SPRD and connected with a cable. The vibration device may be put in a pocket or worn on a wrist strap. The gamma-ray exposure rate indication range is 0 to 9,999 $\mu\text{R}/\text{h}$, with $\pm 30\%$ accuracy from 10 to 7,000 $\mu\text{R}/\text{h}$ for ^{137}Cs gamma radiation. The neutron count rate indication range is 0 to 999 cps. The instrument can record and store data for up to 1,000 events in its nonvolatile memory for later transmission to a PC. The data format is not compliant with the ANSI N42.42 data format standard. The PM1401GNB has been available since 2006. Supplied accessories include the vibration alarm device, an infrared communication adapter, software, and a Secure Digital (SD) memory card with the radionuclide identification software. Available optional accessories include a Pocket PC, carrying case, telescopic extension tube, and external neutron moderator.

3.2.4 Polimaster PM1703GNB

The PM1703GNB SPRD is the spectrometric version of the Polimaster PM1703GNA PRD. The GNB can transfer gamma spectra and other information to a PC, Pocket PC PDA, or smartphone through Bluetooth connectivity as well as IrDA infrared, allowing identification of radionuclides using optional software installed on the PC or smartphone. The instrument is equipped with a

CsI scintillation detector for detection of gamma radiation and a ^6LiI scintillator for detection of neutron radiation and will alert the user if radiation levels exceed preset threshold values. When the instrument is turned on by pressing the Mode button, it performs a self-test, measures the background of gamma and neutron radiation, calculates the corresponding alarm thresholds, and goes into search mode with no further user actions.



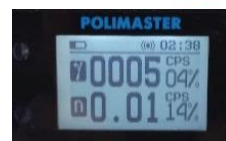
PM1703GNB

Photo courtesy of Polimaster

The PM1703GNB comes with a detachable belt clip, and when worn on a belt, the two operating buttons, small but bright LED alarm light, and 0.9-inch by 0.5-inch LCD display are on the top. There is no difference in the alarm indication between gamma ray and neutron detection, but there is a separate numerical display for the intensity of each kind of radiation. The gamma-ray dose rate indication range is 0 to 9,999 $\mu\text{rem/h}$ (displayed as $\mu\text{R/h}$), with $\pm 30\%$ accuracy from 10 to 7,000 $\mu\text{rem/h}$ for ^{137}Cs gamma radiation. The neutron count rate indication range is 0 to 999 cps. The instrument can record and store data for up to 1,000 alarm events in its nonvolatile memory for later transmission to a PC using supplied communication software. The data format is not compliant with the ANSI N42.42 data format standard. The battery compartment is opened using a coin to remove the cover. The PM1703GNB has been available since 2006. Available optional accessories include proprietary radionuclide identification software, infrared communication adapter, Pocket PC, holster, and carrying case.

3.2.5 Polimaster PM1704A-GN and PM1704A-GNM

The PM1704A-GN and -GNM gamma-neutron SPRDs are new (2014) instruments that combine the functionality of a radiation detector and gamma dosimeter. They can be used to detect and localize radiation sources, record gamma-ray spectra, identify radionuclides, and measure gamma-ray dose rate and gamma and neutron count rate. In identification mode they can distinguish among NORM, medical isotopes, industrial sources, and SNM. The instruments are equipped with a CsI scintillation detector for detection of gamma radiation and a ^6LiI scintillator for detection of neutron radiation. The -GNM model has a Geiger-Mueller tube as an additional gamma-ray sensor to give dose-rate readings when the dose rate is too high for the CsI sensor.



PM1704A-GNM

Photos courtesy of Polimaster

When worn using the supplied belt clip, all displays and controls are on the top edge, accessible to the user, including the LCD display, two operating buttons, alarm LED, and power-on LED. The battery compartment cover can be removed without tools. The frequency of the alarm signal increases with the intensity of the detected radiation. There is no difference in the alarm indication between gamma ray and neutron detection, but the alarm LED is adjacent to the LCD with a separate numerical display for the intensity of each kind of radiation. The gamma-ray dose rate is displayed with an analog bar and digitally. For the -GN model, the gamma-ray dose-rate display range is less than 1 $\mu\text{rem/h}$ to 13.0 mrem/h (displayed as $\mu\text{R/h}$, mR/h), with $\pm 30\%$ accuracy from 10 $\mu\text{rem/h}$ to 10 mrem/h for ^{137}Cs gamma radiation. For the -GNM model, the gamma-ray dose-rate display range is less than 1 $\mu\text{rem/h}$ to 1,000 rem/h (displayed as $\mu\text{R/h}$, mR/h, R/h, kR/h). The neutron count rate indication range is 0.00 to 999

cps. In identification mode, the instruments measure, record, and analyze gamma-ray spectra, identify and categorize radionuclides, and display the results, but the spectrum is not displayed on the LCD. The instrument can record and store data for up to 1,000 gamma-ray spectra in its nonvolatile memory for later transmission to a PC via a USB connection or Bluetooth 4.0 using built-in communication and radionuclide identification software that does not need to be installed on the computer. The PM1704A series became available in 2014. No information on optional accessories was provided.

3.2.6 Polimaster PM1704GN

The PM1704GN gamma-neutron SPRD combines the functionality of a radiation detector and gamma dosimeter. It can be used to detect and localize radiations sources, record gamma-ray spectra, identify radionuclides, and measure gamma-ray dose rate and gamma and neutron count rate. In identification mode it can distinguish among NORM, medical isotopes, industrial sources, and SNM. The instrument is equipped with a CsI scintillation detector for detection of gamma radiation and a ^6LiI scintillator for detection of neutron radiation. It also has a built-in voice recorder to record comments associated with measured gamma-ray spectra.

When worn using the supplied belt clip, the front of the PM1704GN, with the large full-color LCD display and four operating buttons, is away from the body, and the end with the alarm LED, microphone, buzzer, USB connector, and battery compartment cover is upward so the LED is visible to the operator. The battery compartment is opened using a coin to remove the cover. For gamma-ray source localization and radionuclide identification, the instrument is generally hand-held with the back toward the radioactive source and the front toward the operator. To survey for neutrons, the instrument is held close to the body. The frequency of the alarm signal increases with the intensity of the detected radiation. There is no difference in the alarm indication between gamma ray and neutron detection, but there is a separate numerical display for the intensity of each kind of radiation, and the color of each display changes to red when the alarm threshold for that radiation is exceeded. The gamma-ray dose rate is displayed with an analog bar and digitally in the range less than 1 $\mu\text{rem/h}$ to 13.0 mrem/h (displayed as $\mu\text{R/h}$, mR/h), with $\pm 30\%$ accuracy from 10 $\mu\text{rem/h}$ to 10 mrem/h for ^{137}Cs gamma radiation. The neutron count rate indication range is 0.00 to 999 cps. The instrument can be set to acquire the gamma-ray spectrum and perform radionuclide identification with a manual button press or automatically as soon as an alarm occurs. In identification mode, the gamma-ray spectrum and related information can be displayed on the LCD. The instrument can record and store data for up to 100 gamma-ray spectra in its nonvolatile memory for later transmission to a PC via USB connection using built-in communication and radionuclide identification software that does not need to be installed on the computer. The PM1704GN has been available since 2002, and a fourth-generation version was released in 2014. Available optional accessories include a holster.



PM1704GN

*Photo courtesy of
Polimaster*

3.2.7 RadComm MSpec™ neutron

The MSpec neutron is a palm-sized gamma-ray spectrometer and dose-rate meter that utilizes a 0.5-inch by 1.5-inch sodium-doped cesium iodide scintillator for gamma-ray measurement and a ^3He proportional counter for neutron detection. The MSpec can be used to scan suspect material, measure and analyze the gamma-ray spectrum, identify what radionuclides are present, and categorize them as medical, industrial, NORM, or SNM. A user may choose from two modes: Automatic or Manual. Set in Automatic, the MSpec can be used to search for and detect radioactive material. Once in range, the instrument will automatically begin radionuclide identification and display the results. Manual mode gives the user greater control, including the ability for longer scan times, which increases the accuracy of results.



MSpec

Photo courtesy of RadComm

The MSpec neutron's 1.5-inch by 1.75-inch LCD and five operating buttons are on the front face of the instrument. The two alarm lights, red for gamma rays and blue for neutrons, are visible from the top and front. The audible alarm pitch increases with the intensity of the detected gamma radiation. The gamma-ray exposure rate indication range is less than 1 $\mu\text{R/h}$ to 1 R/h, and the neutron count rate range is less than 0.01 to 999 counts per minute. The MSpec stores all results in a record which can be downloaded via USB into a PC running supplied software for archiving of information, and the data be accessed for further analysis or e-mailing of reports. Up to 10,000 count-rate samples and 300 gamma-ray spectra can be stored in the instrument's memory. Gain stabilization for gamma-ray spectrum measurement is automatic, with no internal or external check source required, but it can also be done manually using a supplied check source if desired. Dose rate calibration, servicing diagnostics, and software updates can be done remotely. The operating temperature range is 14°F to 113°F. The lithium-ion rechargeable battery is not removable. The MSpec neutron became available in 2012. Supplied accessories include software, charger, protective sheath, and carrying case. Available optional accessories include a holster with belt clip.

3.2.8 Thermo Scientific RadEye SPRD-GN and SPRD

The RadEye SPRD-GN is the spectroscopic version of the RadEye GN+ PRD. It is not yet available for sale as this market survey report is being written, but is expected to be available in 2015 by the time this report is published. The SPRD-GN is included in this report because it is the first SPRD to utilize a CLYC scintillator and because, along with the RadEye SPRD, it is the smallest and lightest SPRD with embedded radionuclide identification. The use of a single CLYC scintillator as both the gamma-ray and neutron sensor enables the instrument to have high sensitivity to both radiations in a small instrument. It has the same size CLYC scintillator as the RadEye GN+ PRD and the same high neutron sensitivity and good gamma rejection, even for high-energy gamma radiation.



RadEye SPRD (The SPRD-GN is similar in appearance.)

Photo courtesy of Thermo Scientific

The RadEye SPRD went on sale in 2014 as a purely gamma-detecting SPRD with a CsI scintillator. The manufacturer has since demonstrated that the device has neutron detection capability and its neutron detection has very good gamma rejection, though details about how it detects neutrons are still proprietary information and were not provided. The RadEye SPRD is currently supplied with the neutron detection feature off by default and neutron detection is turned on using a software setting. The RadEye SPRD has the second highest gamma sensitivity and the lowest list price of the SPRDs in this report.

The RadEye SPRD and SPRD-GN are both operated using four raised buttons on the front and one alarm-acknowledgement button on top. The 1.25-inch by 0.77-inch LCD display on the front can display information similar to the RadEye GN and GN+ PRDs or a graph of the gamma spectrum or radionuclide identification information. The alarm lights are visible from the top and front. The battery compartment cover is on the back and can be removed without tools. A mark indicating the center of the radiation sensor is on the back. There is an earphone jack on the bottom. A rubber shock absorbing sleeve is supplied with the instruments, and all controls and displays are accessible/visible with the sleeve in place.

In common with the RadEye GN and GN+ PRDs, the SPRD and SPRD-GN indicate whether alarms are due to gamma rays or neutrons by different colored alarm LEDs, different tones, and flashing the count-rate/dose-rate display readings with an inverted display background of the alarming channel or both channels as appropriate. The instruments have different audible alarm sounds to discriminate between elevated background/NORM and any artificial isotope alarm. Once an alarm indicates the presence of significant radiation, the SPRD instruments can be rapidly switched into radionuclide identification mode. The gamma-ray spectrum is recorded in 1,024 channels. Up to 1,600 events, 250 alarms, and 200 spectra can be stored in memory.

The instruments calculate and display energy-compensated gamma-ray dose/exposure rate. The gamma-ray exposure rate indication range is 1 μ R/h to 25 mR/h. The neutron count rate range is 0.1 to 1,000 cps. The SPRD instruments communicate via IR interface with a PC to change settings or download data from stored measurements. They can also be fitted with a Bluetooth back that can be set to talk to a PC or to other devices for networking.

Optional accessories include: a holster, desktop holder for PC communications, USB connection cable, serial adapter cable, Bluetooth battery cover, PC software, lutetium gamma source test adapter, extension poles, earphone, docking station/car adapter, and external power supplies/battery chargers.

4. VENDOR CONTACT INFORMATION

Additional information on the portable radiation detectors with neutron detection included in this market survey report can be obtained from the manufacturers listed in Table 4-1. A distributor of PRDs and SPRDs from several manufacturers is also included, designated by an asterisk (*).

Table 4-1. Vendor Contact Information

Manufacturer/ Vendor	City, State/Country Website	Products	Contact Information
FLIR Systems, Inc.	Oak Ridge, TN www.flir.com	identiFINDER R300 (nanoRaider) ZH, ZH r	radiation.support@flir.com 865-220-8700 jeffrey.perkins@flir.com 865-253-3969
Laurus Systems, Inc.*	Ellicott City, MD www.LaurusSystems.com	Distributor of radiation detectors from many manufacturers	sales@laurussystems.com 410-465-5558
Mirion Technologies, Inc.	Smyrna, GA www.mirion-hp.com	PDS-100GN, PDS-100GN-ID	Info@mirion.com kspero@mirion.com 770-432-2744
Polimaster, Inc.	Arlington, VA www.polimaster.us	PM1401GNA, PM1401GNB, PM1703GN/GNA/GNM, PM1703GNB, PM1704A-GN/GNM, PM1704GN	info@polimaster.us kanevsky@polimaster.us 866-560-7654, 703-525-5075
Radcomm Systems	Oakville, ON, Canada www.radcommsystems.com	MSpec neutron	saikin@radcommsystems.com 416-473-8055
RAE Systems, Inc.	San Jose, CA www.raesystems.com	NeutronRAE II	jkane@raesystems.com 877-723-2878, 408-952-8200
Sensor Technology Engineering, Inc.	Goleta, CA www.radiationpager.com	HRM	sb_sensor_tech@msn.com 805-964-9507
Technical Associates (subsidiary of U.S. Nuclear Corp.)	Canoga Park, CA www.tech-associates.com	DSI-2GN	tagold@nwc.net 818-883-7043
Thermo Scientific	Franklin, MA www.thermoscientific.com	RadEye GN/GN+, RadEye NL, RadEye SPRD/SPRD-GN	customerservice.rmsi@thermofisher.com 800-274-4212 mark.deacon@thermofisher.com 440-487-6427

5. SUMMARY

PRDs are pocket-sized alarming instruments with user-readable displays that are worn on the body and used to detect the presence of illicit radioactive materials and to indicate the gamma radiation exposure rate. Spectroscopic PRDs are PRDs that can measure the energy spectrum of gamma rays to identify the specific material emitting the gamma radiation. Some PRDs and SPRDs also detect neutron radiation and display the neutron count rate. Neutrons can indicate the presence of a nuclear explosive device or special nuclear materials, such as plutonium, which could be used to make one.

PRDs and SPRDs are small, lightweight, and relatively inexpensive, so they can be worn by large numbers of responders performing their normal duties to conduct continual incidental searches for radiological threats. They can also be used for specific searches for radioactive materials and to measure gamma-radiation exposure rate. Application scenarios include passive monitoring during normal duties such as patrols on foot or in a vehicle, detecting and localizing radioactive sources in cargo, monitoring people passing through an entrance or other chokepoint, and measuring exposure rate to set a safety exclusion area around a radiation source.

This market survey report includes information on ten neutron detecting PRDs and ten neutron detecting SPRDs that are commercially available. A PRD-like instrument that detects only neutrons and an SPRD that is about to become available are also described. The PRDs range in price from about \$3,000 to \$5,500. The SPRDs range in price from about \$4,000 to about \$10,000. Product information on these two types of instruments is given in two separate sections of the report. Specifications are given in two tables. Features common to all or nearly all of the models of each type of instrument are listed, and each model is described and shown in a photograph.

This report also includes information on gamma and neutron radiation and technologies used in PRDs and SPRDs to detect and measure these radiations. All but one of the devices in this report use a scintillator to detect and measure gamma radiation. Five different types of scintillating materials, with various capabilities, are used in the various instrument models. One SPRD uses a CZT semiconductor solid-state detector instead of a scintillator. In SPRDs, the size of the pulses from the gamma-ray sensor is measured to determine the gamma-ray energy spectrum. SPRDs can identify the nuclide that emitted the radiation by comparing the measured gamma-ray spectrum to a stored library of gamma-ray spectra emitted by various radionuclides.

To detect neutrons, some of the instruments use a ^3He gas-filled proportional counter, and the rest use one of several kinds of special scintillators that absorb neutrons and produce a distinctive large light pulse when they do. In addition to ^3He proportional counters, four different types of neutron detecting scintillators are used in the various instrument models.

Emergency responder agencies that may be considering purchasing neutron detecting PRDs or SPRDs should carefully consider the overall capabilities and limitations of each instrument category and each product in relation to their agency's operational needs. Different applications will have different requirements for radionuclide identification, gamma and neutron detection sensitivity, size and weight, ruggedness, battery life, display readability, alarm types, and other specifications and features.