

System Assessment and Validation for Emergency Responders (SAVER)

Radiation Dosimeters for Response and Recovery Market Survey Report

June 2016



Science and Technology

Prepared by the National Urban Security Technology Laboratory



SAVER

System Assessment and Validation for Emergency Responders

The *Radiation Dosimeters for Response and Recovery Market Survey Report* was prepared by the National Urban Security Technology Laboratory for the U.S. Department of Homeland Security, Science and Technology Directorate.

The views and opinions of authors expressed herein do not necessarily reflect those of the U.S. Government.

Reference herein to any specific commercial products, processes, or services by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government.

The information and statements contained herein shall not be used for the purposes of advertising, nor to imply the endorsement or recommendation of the U.S. Government.

With respect to documentation contained herein, neither the U.S. Government nor any of its employees make any warranty, express or implied, including but not limited to the warranties of merchantability and fitness for a particular purpose. Further, neither the U.S. Government nor any of its employees assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed; nor do they represent that its use would not infringe privately owned rights.

The cover photo and images included herein were provided by the National Urban Security Technology Laboratory, unless otherwise noted.

FOREWORD

The U.S. Department of Homeland Security (DHS) established the System Assessment and Validation for Emergency Responders (SAVER) Program to assist emergency responders making procurement decisions. Located within the Science and Technology Directorate (S&T) of DHS, the SAVER Program conducts objective assessments and validations of 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 response 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.

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

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?"

The SAVER Program is managed and executed by the National Urban Security Technology Laboratory (NUSTL). NUSTL is responsible for all SAVER activities, including selecting and prioritizing program topics, developing SAVER knowledge products, coordinating with other organizations, and ensuring flexibility and responsiveness to first responder requirements. NUSTL provides expertise and analysis on a wide range of key subject areas, including chemical, biological, radiological, nuclear, and explosive weapons detection; emergency response and recovery; and related equipment, instrumentation, and technologies. For this report, NUSTL conducted a market survey of commercially available ionizing radiation dosimeters. Three AEL reference numbers pertain to different types of radiation dosimeters described in this report. The AEL reference number 07RD-01-DOSP includes film, thermoluminescent, and optically stimulated luminescent dosimeters. The AEL reference number 07RD-01-DOSS encompasses self-reading dosimeters such as colorimetric devices or pocket ion chambers. The AEL reference number 07RD-01-EPD pertains to electronic personal dosimeters.

Visit the SAVER website at <u>https://www.dhs.gov/science-and-technology/saver</u> for more information on the SAVER Program or to view additional reports on radiation dosimeters and other technologies.

POINT OF CONTACT

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

E-mail: <u>NUSTL@hq.dhs.gov</u>

SAVER website: https://www.dhs.gov/science-and-technology/saver

TABLE OF CONTENTS

For	rewor	rd	i
Poi	nt of	Contact	ii
1.	Intro	oduction	
2.	Rad	iation Dosimeter Overview	
	2.1	Radiological quantities and	units
	2.2	Current Technologies	
		2.2.1 Electronic Personal I	osimeters
		2.2.2 Self-reading Dosimet	ers
		2.2.3 Processed Dosimeter	
	2.3	Applications and Key Featur	es
	2.4	Standards and Testing	
	2.5	Emerging Technologies	7
3.	Proc	luct Comparison Information	
	3.1	Overview and Market Analy	sis
	3.2	Dosimeter Comparison Tabl	es
4.	Indi	vidual Product Descriptions .	
	4.1	Electronic Dosimeters	
		4.1.1 Canberra Industries I	nc. DOSICARD TM and DOSIMAN
		4.1.2 Canberra Industries I	nc. UltraRadiac TM -Plus
		4.1.3 Far West Technology	Inc. Canary II 22
		4.1.4 Far West Technology	Inc. Canary III
		4.1.5 Far West Technology	Inc. Canary IV
		4.1.6 Fisher Scientific Inc.	EPD Mk2+
		4.1.7 Fisher Scientific Inc.	RadEye TM G/G-EX
		4.1.8 Fisher Scientific Inc.	RadEye TM GF/GF-10/GF-EX/GF-10-EX
		4.1.9 Fisher Scientific Inc.	RadEye TM PRD-ER
		4.1.10 Fuji Electric Corpora	ion of America DOSEi
		4.1.11 Fuji Electric Corpora	ion of America NRF50
		4.1.12 Fuji Electric Corpora	ion of America NRF Series (30, 31, 34, 40)
		4.1.13 Ludlum Measuremen	s Inc. Model 25 Series
		4.1.14 Mirion Technologies	Inc. DMC 3000

		4.1.15 Mirion Technologies Inc. RAD-60 (from Laurus Systems Inc.)	27
		4.1.16 Mirion Technologies Inc. RDS-31 (from Laurus Systems Inc.)	28
		4.1.17 Polimaster Inc. PM1211	28
		4.1.18 Polimaster Inc. PM1604A/PM1604B	28
		4.1.19 Polimaster Inc. PM1605-BT	29
		4.1.20 Polimaster Inc. PM1621M/PM1621MA	29
		4.1.21 Polimaster Inc. PM1703MO-1BT	30
		4.1.22 Polimaster Inc. PM1704A-M	30
		4.1.23 Polimaster Inc. PM1904A POLISMART [®] II	31
		4.1.24 RAE Systems by Honeywell GammaRAE II R	31
		4.1.25 RAE Systems by Honeywell DoseRAE Pro	32
		4.1.26 RAE Systems by Honeywell DoseRAE 2	32
		4.1.27 S.E. International Inc. Radiation Alert [®] Sentry EC	33
		4.1.28 Tracero TM PED+ (from Laurus Systems Inc.)	33
		4.1.29 Tracero TM PED Blue (from Laurus Systems Inc.)	34
		4.1.30 Tracerco TM PED-IS	34
		4.1.31 X-Z Lab Inc. RadTarge II D700 (from RadOnc Solutions LLC)	35
		4.1.32 X-Z Lab Inc. RadPavise	35
	4.2	Self-Reading Dosimeters	36
		4.2.1 JP Laboratories Inc. RADTriage50	36
		4.2.2 SE International Inc. PEN Dosimeters	36
	4.3	Processed Dosimeters – User Readable	37
		4.3.1 Landauer RadWatch Dosimeter; Aquila RadLight Reader and RadViewer	37
		4.3.2 Landauer InLight® Dosimeter; MicroStar Reader	37
		4.3.3 Mirion Technologies Inc. Instadose 1 (from Laurus Systems Inc.)	38
		4.3.4 Mirion Technologies Inc. Instadose 2	38
		4.3.5 Thermo Fisher Scientific Inc. Model 8840 TLD	39
	4.4	Processed Dosimeters – from Dosimetry Service Providers	39
		4.4.1 Landauer Escort Wallet Card	39
		4.4.2 Mirion Technologies Inc. REMtrack Wallet Card	40
		4.4.3 Mirion Technologies Inc. Genesis Ultra TLD	40
		4.4.4 PL Medical Co. LLC TLD - Quarterly or Monthly service	40
5.	Ven	dor Contact Information	41

Summary	42	2
	Summary	Summary

LIST OF TABLES

Table 2-1	Radiological Quantities and Units	3
Table 2-2	U.S. Radiation Dosimeter Standards	7
Table 3-1	Electronic Personal Dosimeter Specifications 1	2
Table 3-2	Self-Reading Dosimeter Specifications1	6
Table 3-3	Processed Dosimeters – User Readable 1	8
Table 3-4	Processed Dosimeters from Dosimetry Service Providers	0
Table 5-1	Vendor Contact Information 4	1

LIST OF FIGURES

Figure 3-1	Graphical Co	omnarison o	f Electronic	Personal Dosimeters	C)
Figure 3-1	Orapinear Co	omparison o		i ersonar Dosimeters	······································	<i>'</i>

1. INTRODUCTION

Radiation dosimeters are devices used to quantify the accumulated ionizing radiation dose received by an individual. After a radiological release, workers involved in early response and long term recovery may use dosimeters to track their incurred dose. A variety of dosimeter technologies are available, suitable for different operational scenarios. To provide emergency responders with information on radiation dosimeters, the System Assessment and Validation for Emergency Responders (SAVER) Program conducted a market survey.

This market survey report is based on information gathered between September and October 2015 from manufacturers, vendors, Internet research, industry publications, and a governmentissued Request for Information (RFI) that was posted on the Federal Business Opportunities website. This report covers devices which are designed to be worn to measure the external, whole-body radiation dose from photons (X-rays and gammas rays) received by an individual. Such devices include:

- Electronic instruments that display the wearer's accumulated radiation dose and may alarm at a preset dose limit
- Self-reading passive devices that provide a visual indication of the wearer's accumulated dose without alarm capability, and
- Processed passive devices without a visual display or alarm that store accumulated dose for later readout on an associated reader system.

These devices fall under the Authorized Equipment List (AEL) categories: 07RD-01-EPD, Electronic Personal Dosimeter; 07RD-01-DOSS, Self-Reading Dosimeter; and 07RD-01-DOSP, Personal Dosimeter.

Additional AEL categories for portable radiation detection instruments that address interdiction missions are covered in other SAVER reports. However, some products do not directly align with an AEL category, either because the manufacturer categorizes them differently or because the products' capabilities overlap multiple categories. This report includes such instruments if they are worn on the body and are capable of measuring accumulated dose in fields of 100 milliroentgen per hour (mR/h) or more.¹

Due diligence was performed to develop a report that is representative of products in the marketplace.

2. RADIATION DOSIMETER OVERVIEW

Dosimeters are radiation safety devices worn to quantify an individual's accumulated radiation dose incurred from external sources to evaluate the potential for harmful health effects of

¹ Three interdiction instruments having a secondary capability to measure the user's accumulated dose that did not meet this criterion were submitted in response to this RFI. They will be included in other SAVER market survey reports for personal radiation detectors, handheld survey meters, and radionuclide identifiers as appropriate.

radiation. Dosimeters differ from other radiation detection devices that are designed for the purpose of preventing a radiological release by alerting a responder to the presence of radiation.

Emergency responders could be exposed to radiation from an accidental or intentional release such as a nuclear power reactor accident or the detonation of a radiological dispersal or improvised nuclear device. During the emergency response and later recovery operations, a dosimeter can be used to guide actions to prevent acute injury and to minimize potential longterm health effects.

Commercially available dosimeters range from low-cost, passive devices that store personnel dose information for later readout, to more expensive, battery operated devices that display immediate dose and dose rate information. Readout method, dose measurement range and precision, size, weight, ruggedness, and price are important selection factors. Several types of dosimetry technologies are available that would be appropriate for various response and recovery operations. In this report, instruments have been organized into three main categories:

- Electronic personal dosimeters (EPDs) are battery powered devices that typically have a digital readout displaying real-time accumulated dose and dose rate information to the user. They are worn on the body and most can alarm at preset dose and dose rate thresholds.
- Self-reading dosimeters are field-readable devices worn on the body to measure accumulated dose. These are unpowered devices that do not contain a battery. Devices in this group include pocket ion chambers and self-developing photochemical cards. They display the dose to the wearer using an analog scale or color indicator; they do not have alarm capabilities.
- **Processed dosimeters** are worn on the body and store the accumulated dose for display on a separate reader. They do not alarm or provide real-time information to the wearer, but automatically record it into a database on readout. Reader systems vary among products, therefore processed dosimeters are sorted into two groups: user-operated systems that include field-portable readers, and those that are processed by a dosimetry service.

2.1 Radiological quantities and units

When comparing numerical data on the radiological response of different products, it is necessary to use the same units of measurement. However, the units used in product specifications vary because instruments may be calibrated to measure different radiological quantities, which can be expressed in either traditional or international units (Table 2-1). The definitions of these quantities have distinctions for health physicists who may distinguish between "physical" quantities and dose equivalent "operational" quantities. In routine occupational dosimetry, the operational quantity $H_p(10)$ is used,² but in emergency response applications, any of

 $^{^{2}}$ H_p(10) denotes the deep dose equivalent, defined by the International Council on Radiation Units and Measurements (ICRU 1993) as the personal dose equivalent at a depth of 10 millimeters in ICRU tissue, and identified as the operational quantity to use for assessing and controlling radiation exposure.

the quantities may be used. Therefore, the traditional units of rem, rad, and roentgen (R) are often used interchangeably, meaning that the numerical ranges for products given in these units can be directly compared to each other. In contrast, the international system (SI) of units uses the sievert (Sv) and the gray (Gy) in place of the rem and rad, and it does not have a special unit corresponding to the R. To convert SI units to traditional units, it is necessary to multiply the SI value (in Sv or Gy) by 100 to express it in rem or rad, respectively. For convenient comparison of the numerical range of instruments in the tables and graphs in this report, units of Sv or Gy were multiplied by 100 and the approximation $1 R \approx 1 \text{ rem} \approx 1 \text{ rad}$ is used to express everything in terms of exposure in R. Accompanying text indicates if the product uses dose equivalent quantities for calibration.

Quan	tity	Symbol	Traditional Units	SI Units
Operational Quantities	Personal Dose Equivalent	H _p (10)	rem	Sv
(for health physics)	Ambient Dose Equivalent	H*(10)	rem	Sv
Physical Quantities	Air Kerma	Ka	rad	Gy
(to measure radiation fields)	Exposure	(none)	R	(none)

Table 2-1 Radiological Quantities and Units

The function of a dosimeter is to sum the accumulated dose received by an individual. In addition to measuring the accumulated dose, most EPDs can also display, in real time, the exposure *rate* of the surrounding radiation field, for example in R/h. In comparing the measurement range of different instruments, the exposure rate range is the primary characteristic of interest for electronic dosimeters, because outside of this range, they will not properly measure accumulated dose. In contrast, self-reading and processed dosimeters do not display the rate and their response is not rate dependent; instead, the accumulated dose range is the key characteristic for comparison.

2.2 Current Technologies

2.2.1 Electronic Personal Dosimeters

EPDs are battery powered and most use either a gas-filled Geiger-Mueller (GM) tube or a semiconductor³ in which ionizing radiation releases charges resulting in measureable electric current. Some EPDs use a scintillating crystal such as sodium iodide (NaI) or cesium iodide (CsI) with a photodiode or photomultiplier tube to measure photons released by radiation. EPDs may be capable of measuring a wide radiation dose range from routine (mR) levels to emergency levels (hundreds of R) with high precision, and may display the exposure rate as well as

³ Semiconductor detectors are based on ionization in a solid and include different types of solid-state devices with two terminals called diodes. Product specifications for these types of detectors may use terminology that describes the material of which it is made, such as a silicon diode, or the diode structure, such as a PIN diode (meaning that is constructed of positive-intrinsic-negative layers).

accumulated exposure values. EPDs are typically designed to be clipped to the user's waistband or shirt pocket. Most have visual, auditory, or vibratory alarms that can be set for accumulated dose and dose rate thresholds. Some EPDs have wireless communication capabilities. Of the dosimeter technologies, electronic dosimeters are generally the most expensive, largest in size, and the most versatile.

2.2.2 Self-reading Dosimeters

Self-reading dosimeters are considered passive devices in that they have no on/off switch or internal power supply. They measure only the accumulated dose. These include pocket ion chambers (PICs) and self-developing photochemical (radiochromic) cards. Pocket ion chambers are cylindrically shaped and are designed to be clipped to a shirt pocket. A separate charging device is used to manually zero the reading before use by establishing an initial electrostatic charge on a fiber within the device. The fiber is deflected along a linear scale as radiation ionizes the air around it; the scale is read by looking through a lens at one end toward a source of light. PICs are offered in a variety of scales to span mR or hundreds of R ranges. They are light, relatively inexpensive, and durable. Thousands of these devices were distributed to states as part of civil defense procurements in the 1950s and 1960s in response to concerns about nuclear war. Radiochromic devices have a credit card format, with a radiation-sensitive film that darkens proportionally with radiation exposure. They can be worn on a lanyard or carried in a wallet. A color matching scale printed on the card is used to estimate the dose received, typically emergency dose levels, i.e., 5 R and above. They are relatively inexpensive and durable. The operational lifetime is typically on the order of 1 year and the card may have a printed expiration date. Low-temperature storage may increase the shelf life for stockpiling. Self-reading dosimeters are less precise than electronic dosimeters but would be suitable for applications where real-time dose information is required for large-scale distribution at a lower cost.

2.2.3 Processed Dosimeters

Processed dosimeters are based on thermoluminescence (TL), optically stimulated luminescence (OSL), or direct-ion storage (DIS) technologies. Thermoluminescence dosimeters (TLDs) and OSL materials contain defects in their crystal structure that trap electrons released by exposure to radiation. In TLDs, the trapped electrons are subsequently freed by stimulation with heat, while OSL uses stimulation with light. In both types, after stimulation, the resulting light emission provides a measure of the radiation dose received. Specialized equipment is used for this readout, either by the user with field-portable or lab-based equipment, or by a dosimetry processing laboratory. A commercial dosimetry service can be contracted to supply dosimeters on a regular basis, read out returned dosimeters, and provide dose tracking and record keeping. TLDs and OSL dosimeters are offered in either a clip-on brooch format or identification card style. DIS devices use an analog memory cell inside a small, gas-filled, ionization chamber. Incident radiation causes ionizations in the chamber wall and in the gas, and the charge is stored for subsequent readout. The DIS dosimeter is read at the user's site through connection to a web-based system via a universal serial bus (USB) port or Bluetooth connection to a computer or smart phone. The DIS dosimeter is designed to clip to a breast pocket. Processed dosimeters are also considered passive devices in that they do not have an on/off switch, though DIS devices do contain a small inaccessible battery to maintain their charge or for communications. Processed dosimeters are widely used in health and safety programs for radiation workers such as nuclear

plant workers, X-ray technicians, etc., since they measure a wide dose range from routine through emergency levels with high precision. Processed dosimeters are suitable to applications where a user's dose is tracked over time and real-time information or alarms are not needed.

2.3 Applications and Key Features

The purpose of a dosimeter is for worker protection. The potential hazardous effects of radiation depend on the radiation level. For very high doses (hundreds of R), the effects are immediate ("acute") such as blood and skin damage or infertility, and the severity of the effect increases with dose.⁴ For lower radiation levels, the effects are not immediately life threatening; the long term accumulated dose is of interest because the probability (but not the severity) of effects such as cancer increase with dose.

Radiation dosimeters are routinely used in occupational radiation environments in the nuclear industry and at medical facilities. In contrast, except for some hazardous material response teams, most emergency responders do not routinely use radiation dosimeters. Responders may need dosimeters in the event of a radiological release such as a terrorist attack involving a radiological dispersal devise or an improvised nuclear device. Since emergency response scenarios span a wide range of potential radiation levels that could be initially unknown, many factors must be considered in the selection of a radiation dosimeter.

One of the most important factors influencing selection of radiation dosimeters is the magnitude of radiation levels that an instrument can measure – for example, a very sensitive device with a low minimum range is useful for alerting users to the presence of radiation but may go off-scale and not function in a high radiation field. The operational range of a dosimeter will determine how it can be used during the response, and several guidance documents provide reference values that help define what ranges are applicable. For example, the National Council on Radiation Protection and Measurements (NCRP) defined radiation control zone perimeters for emergency response to nuclear and radiological terrorism, where the "cold zone" is the area where the exposure rate is less than or equal to 10 mR/h, the "hot zone" is an area with exposure rate greater than 10 mR/h, and the "dangerous-radiation zone" is at 10 R/h and higher. Accumulated dose guidelines have also been developed by the Environmental Protection Agency (EPA) and the NCRP to guide tactical emergency response decisions, such as 10 rem for property protection operations and 25 rem and higher to conduct lifesaving missions,⁵ or 50 rad to decide whether to withdraw from a radiation area.⁶

Another, though less important, feature to consider is the minimum photon energy a device can measure. The sensitivity of various radiation detectors typically varies with energy, and the response to lower energy photons is commonly compared to that of 662 kiloelectronvolt (keV) photons from a cesium-137 (Cs-137) source. This feature is more important in specialized

⁴ Whole body doses above approximately 400 R may be fatal.

⁵ Protective Action Guides and Planning for Radiological Incidents, Environmental Protection Agency (2013) <u>http://www.epa.gov/radiation/rert/pags.html</u>

⁶ Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers, NCRP No. 165 (2010)

radiation worker occupations where a specific low energy requirement is based on a known radiation source (e.g., a medical X-ray technician). For emergency response scenarios, the radiation source is not known in advance, but 60 keV is generally used as the standard for the low-energy photon range.⁷ The low-energy response may also be a consideration in situations where measurement readings from different types of dosimeters would be compared during response operations.

The ability to alarm or display instant results may be an important feature to consider in relation to the magnitude of radiation levels. For example, in a dangerous radiation field, a high range electronic device that can measure exposure rates with a real-time display and alarms could help a responder avoid potentially life threatening doses. In a lower radiation field, self-reading and field-readable processed dosimeters could be used to provide near real-time information. In both types of fields and during intermediate and late phase recovery operations, processed personal dosimeters could be used for later verification of field instrument readings and to track accumulated dose for long term health.

The dosimeter format, size, weight, orientation of display, and how it is worn will be factors to consider for compatibility with personal protective equipment and usability in operational conditions. Cost, maintenance, battery life, and shelf life are other considerations, particularly for devices that may not be used routinely. The relative importance of different features depends on the user and the application, and in some cases a combination of technologies may be useful.

2.4 Standards and Testing

Several American National Standards Institute (ANSI) standards that cover radiation dosimetry in various applications are listed in Table 2-2. Of these, ANSI N42.49A and N42.49B, which provide performance specifications for electronic and self-reading Personal Emergency Radiation Detectors (PERDs), may be the most relevant for responders as they were developed for homeland security response applications. However, the acronym PERD is not used in the AEL and was not found in commercial products available at the time of this market survey.⁸

Another standard, ANSI N13.11, provides performance specifications for the National Voluntary Laboratory Accreditation Program (NVLAP), a proficiency test program required for dosimetry providers at Nuclear Regulatory Commission licensed facilities, such as nuclear power plants or medical facilities, and Department of Energy national laboratories. While NVLAP accreditation is not required for emergency responder dosimeters, it is cited in some product descriptions. NVLAP currently provides accreditation for several different types of whole body dosimeters including TLD, OSL, DIS, and EPD. The program is administered by the National Institute of Standards and Technology (NIST) and a list of accredited dosimetry providers, their dosimeters,

⁷ For example, American National Standards Institute (ANSI) standards N42.49A (2011) and N42.49B (2013) require the response at 60 keV to be within $\pm 30\%$ of the response to cesium-137 (Cs-137). Similarly, homeland security standards for radiological equipment used for interdiction missions (N42.32, N42.33) also test to 60 keV.

⁸ A few products described by the manufacturers as survey meters appear to potentially match N42.49A and are therefore included in this report.

and accredited categories may be found at the NIST website.⁹ The N13.11 categories most applicable to emergency response and recovery are Category I (Accident, photons) and Category II (Photons).

The other two standards listed, N42.20 and N322, are limited in scope to EPDs and PICs, respectively. N42.20 addresses active dosimeters in occupational applications, while N322 covers the physical properties of pocket ion chambers.

Additional guidance for emergency responders is being developed. The NCRP Scientific Committee 3-1 is developing an NCRP commentary and report on "Guidance for Emergency Responder Dosimetry," with publication anticipated in February 2017.

Standard Number (year)	Standard Title
ANSI N42.49A (2011)	American National Standard for Performance Criteria for Alarming Electronic Personal Emergency Radiation Detectors (PERDs) for Exposure Control
ANSI N42.49B (2013)	American National Standard for Performance Criteria for Non-alarming Personal Emergency Radiation Detectors (PERDs) for Exposure Control
ANSI N13.11 (2009)	Personnel Dosimetry Performance – Criteria for Testing (2009)
ANSI N42.20 (2003)	Performance Criteria for Active Personnel Radiation Monitors
ANSI N322 (2003)	Inspection, Construction, and Performance Requirements for Direct Reading Electrostatic/Electroscope Type Dosimeters

Table 2-2 U.S. Radiation Dosimeter Standards

2.5 Emerging Technologies

Although the radiation detection technology in many dosimeters has been used for decades, products are continuing to evolve with enhancements in range and readout methods and added features such as global positioning system (GPS) or networking options. In addition, multi-function products are being developed that combine the capability to measure accumulated dose with features used in interdiction missions, such as the high sensitivity and fast response time of personal radiation detectors or spectroscopic functions of radionuclide identifiers.

Some new technologies attempt to use the complementary metal oxide semiconductor (CMOS) electronics contained in mobile phone cameras for radiation detection and are sold as cellular phone applications. Recent evaluations of this technology have demonstrated that the range,

⁹ <u>http://ts.nist.gov/Standards/scopes/dosim.htm</u>

accuracy, and reliability of this technique are not comparable to traditional technologies.¹⁰ Note that this only pertains to using a camera CMOS to detect radiation, and does not apply to the use of a smart phone to interface with a standard detector technology.

3. PRODUCT COMPARISON INFORMATION

3.1 Overview and Market Analysis

The market survey identified 53 radiation dosimeters including 42 EPDs, 2 self-reading dosimeters, 5 processed dosimetry systems designed for user readout (4 of which are portable), and 4 processed dosimeters offered by dosimetry provider services. On the whole, EPDs, as the most complex technology, are also the most expensive, ranging in price from under \$300 to over \$3,000.

Figure 3-1 illustrates functional and physical variations found among EPD products. The product names are listed along the vertical axis followed by the detector type in parenthesis. Products labelled with an asterisk are reported to be intrinsically safe for use in explosive environments. Each product's relative weight is illustrated by the area of the circle next to the product label, ranging from 1.1 to 9.5 ounces. The horizontal axis shows a range of radiation exposure rates from natural background (approximately 10 μ R/h) to dangerously high (1,000 R/h). Background shading denotes the exposure rates for radiation control perimeters, where the cold zone is ≤ 10 mR/h (white), the hot zone is greater than 10 mR/h (light gray) and the dangerous-radiation zone is 10 R/h and higher (dark gray). The horizontal bars depict the dosimeter's operational range and illustrate the importance of matching this range to its intended application. For example, only those products with an upper range greater than 10 R/h, (plotted in the top region of the graph), would be suitable for use in the dangerous-radiation zone.

In contrast to the EPDs, exposure rate operational range is not a characteristic feature of passive dosimeters. Self-reading and processed dosimeters function in all three radiation protection zones since their detectors are not exposure rate dependent and they measure the accumulated exposure rather than rate. Weight is also not a significant consideration since they all weigh about 1 ounce or less. Key features for the passive dosimeters are covered in tables and text in subsequent sections.

¹⁰ See *Radiation Monitoring for the Masses*, by Eric Wagner, Rich Sorom, and Linda Wiles, in Health Physics Journal, Vol. 110, No. 1, pp 37-44, January 2016.



Figure 3-1 Graphical Comparison of Electronic Personal Dosimeters

3.2 Dosimeter Comparison Tables

This section provides four summary tables for comparison of key features of the different types of dosimeters. Subsequent sections provide additional information that describes each product in more detail. Product information presented herein was obtained directly from manufacturers, vendors, and their websites. The information has not been independently verified by the SAVER program. In the tables, "NI" means that no information was available on this feature; "NA" means not applicable; "Y" means that the product has that feature; and "N" means that the product does not have that feature.

Table 3-1 provides product characteristics which are defined as follows, listed in column order:

- **Vendor/Product:** Products are listed in alphabetical order by manufacturer; vendors are also listed where the vendor provided the product data for this report. Some products may be available from multiple vendors.
- **Rate Range (Minimum and Maximum):** The range of exposure rate that the product can measure within an accuracy of $\pm 30\%$. While some instruments are calibrated in dose equivalent quantities $H_p(10)$ or $H^*(10)$, all quantities in this table are expressed in units of R (i.e., of mR/h and R/h) to simplify product comparisons. Quantities have been converted by using the approximation $1 R \approx 1 \text{ rem} \approx 1$ rad. Specifications in Sv were first multiplied by 100 to convert Sv to rem. Note that 1,000 mR/h = 1 R/h.
- **Dose Range (Minimum and Maximum):** The range of accumulated dose or exposure that the product can measure within an accuracy of $\pm 30\%$. For ease of comparison, units of R are used as described above. Note that 1 R = 1,000 mR.
- **Dose/Rate Alarms:** If the product can be set to alarm at one or more accumulated dose levels, and at one or more exposure rate levels, the alarm types are noted as audible (A), visual (V), or tactile (T) (i.e., vibration), followed by the number of thresholds that can be set. "No" means the device does not have alarm features. Except where noted, the alarm options are the same for accumulated dose and rate.
- **Dose Equivalent:** "Y" means that the product is calibrated in a dose equivalent quantity, either personal dose equivalent $H_p(10)$, or ambient dose equivalent, $H^*(10)$, in units of rem or Sv. "N" means that the product is calibrated to read exposure, in units of R. Either is applicable to emergency responder applications, although some may prefer personal dose equivalent. Note that this refers to calibration: most products allow the user to select which units to display on the device and the choice may depend on the user's specific guidelines for protective action or worker dose limits.
- **Min Energy/Relative Accuracy:** The minimum photon energy in units of keV that the product can measure. Where available, the value given in parenthesis quantifies the accuracy at this energy compared to 662 keV.
- **Font**: The font height of the main display numerals in inches, rounded to the nearest 0.1 inch. An entry of "no" means that the device does not have a numeric display.
- Weight: In ounces, rounded to the nearest 0.1 ounce, including batteries.
- **Battery:** Type of battery as reported by the manufacturer or vendor. The designations BR2325, CR2032, CR2450, DL2450, and LIR2450 are coin-type batteries.
- **Environmental Protection:** The protection from dust or liquid. Ingress protection (IP) is a two-digit code for protection against (1) solid objects (dust) and (2) liquids; higher numbers

indicate more protection. First digit: 3 = protected against tools, thick wires, etc.; 5 = function not affected by dust; 6 = dustproof. Second digit: 4 = device not harmed by splashing 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; 8 = not damaged by continuous immersion in water beyond 1 meter. Japan Industrial Standards (JIS) use a 0 to 8 scale for water protection where higher numbers indicate greater protection. JIS 4 refers to protection from splashing water in any direction.

- **Intrinsically Safe:** Indicates certification for use in explosive atmospheres, where US means that certification was obtained in the United States (UL913) and EU means the certification was obtained from the European Union (EU-ATEX).
- **Price:** Approximate manufacturer suggested retail price for one unit, in U.S. dollars; quantity discounts are typically available.

Vendor Product	Rate min (mR/h)	Range max (R/h)	Dose min (mR)	Range max (R)	Dose/Rate Alarms	Dose Equivalent	Min Energy (keV) [Relative Accuracy]	Font (in)	Weight (oz)	Battery	Environmental Protection	Intrinsically Safe	Price (\$)
Canberra Industries Inc. DOSICARD* DOSIMAN*	0.1	100	0.1	1,000	Α, V, Τ	Y	50 [±30%]	NI	2.3	CR2450	IP67		NI
Canberra Industries Inc. UltraRadiac-Plus*	0.1	200	0.0001	999	A, V, T (2)	N	60 [±40%]	NI	9.5	AAA	IP67		NI
Far West Technology Inc. Canary II*	NI	1	0.01	10	no	N	NI	0.2	2.5	BR2325	NI		295
Far West Technology Inc. Canary III*	1.0	100	NI	1,000	A†	N	80 [±30%]	0.2	2.8	BR2325	NI		335
Far West Technology Inc. Canary IV*	0.01	9.9	NI	NI	no	N	80 [±30%]	0.2	7.3	BR2325	NI		420
Fisher Scientific Inc. EPD Mk2+	0.1	100	0.1	1,600	A, V (2)	Y	15 [±50%]	0.3	3.2	AA	IP55		800
Fisher Scientific Inc. RadEye G /G-EX	0.05	10	0.001	1,000	A, V, T (2)	Y	45 [-20%]	0.3	5.6	AAA	IP65	EU	997 1,310
Fisher Scientific Inc. RadEye GF/ GF-10; GF-EX/GF-10-EX	0.1	300	0.1	1,000	A, V, T (2)	Y	45 [-20%]	0.3	5.6	AAA	IP65	EU	1,000 1,300
Fisher Scientific Inc. RadEye PRD-ER	0.001	10	0.001	1,000	A, V, T (>2) ‡	Y	60 [-20%]	0.3	5.6	AAA	IP65		2,500
Fuji Electric Corporation of America DOSEi	0.1	99.9	0.1	99.99	A, V (1)	Y	35	0.3	2.1	CR2450	JIS 4		325 to 400
Fuji Electric Corporation of America NRF 50	0.1	1,000	0.1	1,000	A, V, T (2)	Y	50 [±10%]	0.4	6.0	AA	IP65		NI
Fuji Electric Corporation of America NRF Series (30, 31, 34, 40)	0.1	999.9	0.1	999.99	A, V (1)	Y	50 [±20%]	0.3	3.5	CR123A	IP65		350 to 450

 Table 3-1
 Electronic Personal Dosimeter Specifications

Vendor Product	Rate min (mR/h)	Range max (R/h)	Dose min (mR)	Range max (R)	Dose/Rate Alarms	Dose Equivalent	Min Energy (keV) [Relative Accuracy]	Font (in)	Weight (o2)	Battery	Environmental Protection	Intrinsically Safe	Price (\$)
Ludlum Measurements Inc. Model 25 Series*	2	200	NI	NI	A,V (2)	Y	60	0.5	5.1	DL2450	IP67	US	NI
Mirion Technologies Inc. DMC 3000	0.1	1,000	0.1	1,000	A, V, T (>2)	Y	16	0.4	3.1	AAA	IP67		425
Mirion Technologies Inc. (from Laurus Systems Inc.) Rad-60	0.5	300	0.1	999	A, V (>2)	N	55	NI	2.8	AAA	NI		416
Mirion Technologies Inc. (from Laurus Systems Inc.) RDS-31	0.001	10	0.001	1,000	A, V, T (>2)	N	48	NI	7.8	AA	IP67		1,144
Polimaster Inc. PM1211	0.01	10	1	2,500	A,V	Y	50	0.6	4.2	CR2450	IP54		NI
Polimaster Inc. PM1604A PM1604B	0.1 0.1	500 1,000	0.001 0.001	999 999	A,V (2)	Y	48 [±30%]	NI	3.0	CR2032	IP67		635 728
Polimaster Inc. PM1605-BT	0.01	999	0.001	999	A, V, T (2)	N	48 [±30%]	0.5	9.2	AA	IP68		691
Polimaster Inc. PM1621M PM1621MA	0.01 0.01	10 100	0.001	999	A, V, T (2)	Y	10 [±30%]	0.2	6.5	AA	IP67		665 695
Polimaster Inc. PM1703MO-1BT	0.001	1,000	0.001	999	A, V, T (2)	Ν	33 [±30%]	0.9	6.5	AA	IP65		1,572
Polimaster Inc. PM1704A-M	0.01	1,000	0.01	100	A, V, T (2)	Y	33 [±30%]	0.4	8.8	AA	IP65		3,484
Polimaster Inc. PM1904A Polismart II	0.1	10	0.1	1,000	A,V	Y	60 [±30%]	no	1.1	built-in rechargeable	IP30		299
RAE Systems by Honeywell GammaRAE II R	0.001	600	0.001	999	A, V, T (2)	Y	60 [30%]	0.6	9.5	AA	IP67	US EU	1,360 to 1,600

Vendor Product	Rate min (mR/h)	Range max (R/h)	Dose min (mR)	Range max (R)	Dose/Rate Alarms	Dose Equivalent	Min Energy (keV) [Relative Accuracy]	Font (in)	Weight (oz)	Battery	Environmental Protection	Intrinsically Safe	Price (\$)
RAE Systems by Honeywell DoseRAE Pro	0.001	999	0.001	999	A, V, T (2)	Y	60 [30%]	0.6	4.6	AA	IP54		500
RAE Systems by Honeywell DoseRAE 2	0.001	1140	0.001	1,140	A, V, T (2)	Y	20 [30%]	0.6	1.8	rechargeable LIR2450	IP54		620
S.E. International Inc. Radiation Alert Sentry EC	0.1	15	0.1	65	A, V, T (2)	N	30	no	8.6	9 V	NI		320
Tracero (from Laurus Systems Inc.) PED+	0.001	10	0.001	1,000	A, V (>2)	Y	33	0.2	5.5	rechargeable lithium-ion	IP67		999
Tracero (from Laurus Systems Inc.) PED Blue	0.001	10	0.001	1,000	A, V (>2)	Y	33	0.2	5.1	rechargeable lithium-ion	IP67		695
Tracero PED-IS	0.01	10	0.01	1,000	A, V, T (>2) §	Y	33 [+7%]	0.2	5.6	rechargeable lithium-ion	IP67	US EU	1,149
X-Z Lab Inc. (from RadOnc Solutions LLC) RadTarge II D700	0.001	0.1	0.001	10,000	A, V, T (1)	Y	20	0.3	2.1	rechargeable lithium-ion	IP65		589
X-Z Lab Inc. RadPavise	0.001	0.1	0.001	10,000	A, V, T # (1)	Y	20	0.2	6.7	rechargeable lithium-ion	IP65		1,299

A – Audible alarm; V – Visual alarm; T – Tactile (vibration) alarm

Y – Yes; N – No

NI – No information available

* Product information was obtained from website only; vendor did not reply to request for information.

⁺ The Canary III has an audible alarm for dose rate, but not for accumulated dose.

‡ Two alarm thresholds can be set for accumlated dose, and more than two for dose rate.

§ Two alarms thresholds can be set for rate, and more than two for accumulated dose.

The RadPavise device has an alarm threshold for dose rate, but not for accumulated dose.

Table 3-2 lists product characteristics for self-reading dosimeters. They are defined as follows, listed in column order:

- **Vendor/Product:** Products are listed in alphabetical order by manufacturer. Some products may be available from multiple vendors.
- **Dose Range (Minimum and Maximum):** The range of accumulated dose that the product can measure with an accuracy of $\pm 30\%$. All quantities in this table are expressed in units of R to simplify product comparisons. Quantities have been converted by using the approximation 1 R ≈ 1 rem ≈ 1 rad. Specifications in Sv were first multiplied by 100 to convert Sv to rem. Note that 1 mR = 0.001 R.
- **Dose Scale Increments:** For colorimetric dosimeters, this lists the dose values shown on the color-matching scale. For PIC devices, this is the minor unit marked on the linear scale. All quantities in this table are expressed in units of R to simplify product comparisons.
- **Dose Equivalent:** "Y" means that the product is calibrated in $H_p(10)$ or $H^*(10)$, in units of rem or Sv.
- **Min Energy/Relative Accuracy:** The lowest photon energy in units of keV that the product can measure. Where available, the value given in parenthesis quantifies the accuracy at this energy compared to 662 keV.

Detector Type: Indicates if the system uses photochemical or PIC detection technology.

Use Time/Store Time: Estimated time that the dosimeter is expected to remain within operational parameters under routine use (without damage), or if stored for stockpiling.

Weight: For the dosimeter, shown in ounces rounded to the nearest 0.1 ounce.

Price: Approximate manufacturer suggested retail price for one unit, in U.S. dollars. Quantity discounts are typically available.

Vendor Product	Dose Range min to max (R)	Dose Scale Increments (R)	Dose Equivalent	Min Energy (keV) [Relative Accuracy]	Detector Type	Use Time/ Store Time (years)	Weight (oz)	Price (\$)
JP Laboratories Inc. RADTriage50	2 to 1,000	5, 10, 25, 50, 100, 200, 400	Y	30	photochemical	2 /10†	0.1	10 to 15
S.E. International Inc. PEN-200mR PEN-500mR PEN-2R PEN-5R PEN-20R	0* to 0.2 0* to 0.5 0* to 2 0* to 5 0* to 20	0.01 0.02 0.1 0.2 1	NI‡	16 [±10%]	PIC	NI†	0.7	NI

Table 3-2 Self-Reading Dosimeter Specifications

Y – Yes; N – No; NI – No information available

* The minimum measurable dose was not provided. It depends on detector sensitivity and scale resolution. Instead, the zero value reported by the manufacturer is an indication of lowest value marked on the linear analog scale.

⁺ For long term storage, the RADTriage50 should be kept in a freezer at 5°F, and the PEN dosimeter should be stored at altitudes of less that 50,000 feet.

[‡] The calibration quantity was not provided. Five models of the PEN dosimeter display units of exposure (R). Two additional models, the PEN-2mSv and PEN 5mSv have display scale increments of 0.1 mSv and 0.2 mSv, and maximum ranges of 2 mSv and 5 mSv, which correspond to 200 mR and 500 mR, respectively.

Table 3-3 shows product characteristics for processed dosimeters that may be read out by the user. They are defined as follows, listed in column order:

- **Vendor/Product:** Products are listed in alphabetical order by manufacturer; vendors are also listed where the vendor provided the product data for this report. Some of the products may be available from multiple vendors. For products that require purchase of a separate reader instrument, data for the dosimeter is shown on the first line and that for the reader is shown on the next line.
- **Dose Range (Minimum and Maximum):** The range of accumulated dose that the product can measure with an accuracy of $\pm 30\%$. While most of these instruments are calibrated in H_p(10), all quantities in this table are expressed in units of R to simplify product comparisons. Quantities have been converted by using the approximation 1 R \approx 1 rem \approx 1 rad. Specifications in Sv were first multiplied by 100 to convert Sv to rem. Note that 1 mR = 0.001 R.
- **Portable Readout:** "Y" means that the readout system is portable, "N" means that the readout system is designed to be used in a permanent, indoor location.
- **Dose Equiv.:** "Y" means that the product is calibrated in $H_p(10)$, in units of rem or Sv.
- **Min. Energy/Relative Accuracy**: The lowest photon energy in units of keV that the product can measure. Where available, the value given in parenthesis quantifies the accuracy at this energy compared to 662 keV.
- Detector Type: Indicates if the system uses OSL or DIS detection technology.
- **Temperature Range:** Operational range for the dosimeter and, where applicable, the reader, in degrees Fahrenheit.
- Weight: For the dosimeter, shown in ounces, and for the reader, shown in pounds. (Values are rounded to the nearest 0.1 ounces or pounds.)
- **Intrinsically Safe:** Certification for use in explosive atmospheres, from the European Union (EU-ATEX) or the United States (UL913) for the dosimeter and/or the reader.
- **NVLAP:** The ANSI N13.11 categories in which the dosimeter has received accreditation. Category IA is the general photon accident category, which involves doses from 5 to 500 rad using Cs-137 and M150¹¹ X-rays. Category II is the routine photon category, which spans the range of doses from 50 mrem to 5 rem: IIA uses X-ray energies \geq 20 keV along with a Cs-137 or Co-60 source for the irradiations, while IIC uses medium energy photons (> 70 keV and Cs-137 or Co-60).
- **Price:** Approximate manufacturer suggested retail price for one unit, in U.S. dollars. Quantity discounts are typically available.

¹¹ M150 refers to a National Institute of Standards photon beam technique that uses relatively low density filters to produce broad spectra x-rays with an average energy of 73 keV.

Vendor Product	Dose min (mR)	Range max (R)	Portable Readout	Dose Equiv.	Min Energy (keV) [Relative Accuracy]	Detector Type	Temp Range (°F)	Weight	Intrinsically Safe	NVLAP	Price (\$)
Aquila / Landauer RadWatch Dosimeter RadLight Reader RadViewer	5	3,000	Y	NI	50	OSL	NI -25 to 122* NI	NI 5 lb NI	NI NI NI	IA, IIC	NI 18,000 4,995
Landauer InLight dosimeter MicroStar reader	5	1,000	Y	Y	5	OSL	NI -13 to 104	0.6 oz 17.7 lb	EU	IA, IIA	NI NI
Mirion Technologies Inc. Dosimetry Services Division (Sold by Laurus Systems Inc.) Instadose 1	3	12; 500 ‡	Y	Y	15	DIS	NA	0.6 oz	no	ia, iia, iic	NI
Mirion Technologies Inc. Dosimetry Services Division Instadose 2	5	12; 500 ‡	Y	Y	11 [40%]	DIS	+	1.0 oz	no	NA	NI
Thermo Fisher Scientific Inc. Model 8840 TLD	1	1,000	N	Y	20 [±16%]	TLD	14 to 122	0.8 oz NI	NI	IA, IIA, IIIA, IVAB, VBC	90 NI

Table 3-3 Processed Dosimeters – User Readable

Y – Yes; N – No; NI – No information available

* using external power. Temperatures of 14°F and below reduce battery lifetime by about one-third.

[†] Dosimeter is operational up to 158°F, but must be read out between 57°F and 86°F.

‡ Users may read doses up to 12 R; accumulated doses above 12 R must be returned to the manufacturer for processing.

Product characteristics for processed dosimeters that are read out by a dosimetry service provider are shown in Table 3-4. They are defined as follows, listed in column order:

- **Vendor/Product:** Products are listed in alphabetical order by manufacturer; vendors are also listed where the vendor provided the product data for this report. Some of the products may be available from multiple vendors.
- **Dose Range (Minimum and Maximum)**: The range of accumulated dose that the product can measure with an accuracy of $\pm 30\%$. While these dosimeters are calibrated in H_p(10), all quantities in this table are expressed in units of R to simplify product comparisons with the other tables in this report. Quantities have been converted by using the approximation 1 R \approx 1 rem \approx 1 rad. Specifications in Sv were first multiplied by 100 to convert Sv to rem. Note that 1 mR = 0.001 R.
- **Dose Equiv.:** "Y" means that the product is calibrated in $H_p(10)$, in units of rem or Sv.
- **Minimum Energy/Relative Accuracy**: The lowest photon energy in units of keV that the product can measure. Where available, the value given in parenthesis quantifies the accuracy at this energy compared to 662 keV.

Detector Type: Indicates if the system uses OSL or TLD detection technology.

- **Use Time/Store Time:** Estimated time that the dosimeter is expected to remain within operational parameters under routine use (without damage) or if stored for stockpiling. **Weight:** For the dosimeter, shown in ourses rounded to the parents 0.1 ourses
- Weight: For the dosimeter, shown in ounces rounded to the nearest 0.1 ounce.
- NVLAP: The ANSI N13.11 categories in which the dosimeter has received accreditation. Category I is the general photon accident category, which spans doses from 5 to 500 rad, where IA includes irradiations with Cs-137 and M150 X-rays, and IB uses only a Cs-137 source. Category II is the routine photon category, which spans doses from 50 mrem to 5 rem, with the following subcategories using different irradiation sources: IIA uses X-rays with energies ≥ 20 keV and a Cs-137 or Cobalt-60 (Co-60) source, IIB is high energy, using only Cs-137 or Co-60, and IIC covers medium energy photons, with X-rays > 70 keV and a Cs-137 or Co-60 source. Category III deals with beta particles, category IV covers photon/beta mixtures, and category V deals with neutrons. For more details on these categories see ANSI N13.11.
- **Price:** Approximate manufacturer suggested retail price for one unit, in U.S. dollars. Quantity discounts are typically available.

Vendor Product	Dose min (mR)	Range max (R)	Dose Equiv.	Min Energy (keV) [Relative Accuracy]	Detector Type	Use Time / Store Time (years)	Weight (oz)	NVLAP	Price* (\$)
Landauer Escort	1	1,000	Y	20	OSL	unlimited	0.2	IA	NI
Mirion Technologies Inc. Dosimetry Services Division REMtrack Wallet Card	20	500 — 1,000†	Y	11 [20 to 40%]	TLD	5 / 10	0.2	IB, IIB	NI
Mirion Technologies Inc. Dosimetry Services Division Genesis Ultra TLD	1	500 — 1,000†	Y	11 [20 to 40%]	TLD	5 / 10	0.4	ia, IIa, IIIa, Ivaa, Vca	NI
PL Medical Co. LLC TLD - Quarterly or Monthly Service	1	1,000	Y	10	TLD	1/1	0.1	ia, iia, iiia, ivaa	2 to 120

 Table 3-4
 Processed Dosimeters from Dosimetry Service Providers

Y – Yes; NI – No information available

* Tiered pricing depends on quantity and duration of subscription.
† Manufacturer reported the maximum dose as 1,000 R and noted that it has been tested to 500 R.

4. INDIVIDUAL PRODUCT DESCRIPTIONS

4.1 Electronic Dosimeters

4.1.1 Canberra Industries Inc. DOSICARD[™] and DOSIMAN

The DOSICARD and DOSIMAN are electronic personal dosimeters that use energy compensated silicon PIN diode detectors. They have dimensions of 3.9 x 3.9 x 0.3 inches and are worn in clip-on, transparent vinyl pockets. The DOSIMAN is a special version of the DOSICARD with an on/off switch and without database connection capabilities; it clears information between uses. The DOSIMAN has factory set units while the DOSICARD allows the user to select the display units in Sy or rem. They provide real-time monitoring of personal dose and dose rate and are designed for monitoring personnel in the medical, research, or nuclear industry. Each has a microcontroller with nonvolatile memory, a liquid crystal display (LCD), and audio (buzzer) and visual (flashing light-emitting diode (LED)) alarms. Three touch buttons allow programming and display setup of the current dose, dose rate, and cumulative doses. Dose accumulation modes include daily dose and dose accumulated since a manual start. Two operating modes are available: permanent mode performs a continuous integration of dose, and zone mode integrates dose only within control zones. The zone mode operation is controlled by entrance/exit badge readers connected to the dosimeter through bidirectional infrared (IR) communication. Dose history can be accessed via a badge reader and is password protected. Safe storage is guaranteed via a nonvolatile memory for 10 years without battery. The temperature range of operation is 50 to 140 degrees Fahrenheit (°F) and up to 80 percent relative humidity.

4.1.2 Canberra Industries Inc. UltraRadiac[™]-Plus

The UltraRadiac-Plus is based on a GM detector and has a sensitivity of 0.7 counts per second (cps) at 100 μ R/h for 662 keV photons. It measures 3.9 x 2.6 x 1.2 inches and is ruggedized for use by emergency responders. The device displays both the radiation rate and the total dose received. It is powered by rechargeable or four AAA batteries with a 150 hour battery life. It has a large, backlit, LCD display and a six-button user interface. When user-set dose rate or total dose alarm levels are exceeded, alarms are signaled by a flashing display, audible signal, and vibration. The UltraRadiac-Plus has a "stay time" feature that shows the wearer how much



UltraRadiac Photo: Radiation Dosimeters for Response and Recovery Market Survey Report (January 2010)

time, at the current dose rate, he/she can remain in place before a high dose alarm is reached. An optical RS-232 port enables data transfer to a host computer. The total accumulated daily or weekly dose can be read by a computer and assigned to the user's records. The device performs continual self-monitoring, and logs up to 999 data points. It functions at temperatures from 22°F to 141°F and at 40 to 93 percent relative humidity, with vibrating and audible alarms functional to -58°F. It withstands vibration associated with transport, impacts of dropping in use, and an altitude of 40,000 ft.

4.1.3 Far West Technology Inc. Canary II

The Canary II (model 4080) is based on a PIN diode. The case is anodized aluminum and clips to a pocket, belt, or lanyard. Its dimensions are $1.3 \times 1.0 \times 4.3$ inches and it has a digital display and a built-in beeper. It measures the accumulated dose and beeps every 10 μ R; at background levels this is an average of about 1 beep per hour. The sound can be disabled by removing a replaceable internal jumper. A recessed on/off switch is the only external control. When the instrument is turned on, it resets the display and beeps. The length of the beep indicates the battery condition. It uses two lithium BR2325 batteries with 1,000 hour battery life, and a



Canary II Photo: Radiation Dosimeters for Response and Recovery Market Survey Report (January 2010)

storage life of 10 years. To change the batteries, thumb screws on the top are removed and the old batteries are removed with a provided wooden removal tool (not a metal screwdriver).

4.1.4 Far West Technology Inc. Canary III

The Canary III (model 4083) uses a PIN diode in an anodized aluminum case. It is 4.5 x 1.2 x 0.8 inches in size and can clip to a belt, lanyard, or fit into a pocket. It has an adjustable rate beeper and an adjustable integrated dose alarm. Turning the unit on automatically resets the display. This device uses two non-rechargeable lithium BR2325 batteries with an approximate 2,000 hour battery life. Battery change requires a screwdriver and battery removal tool. The Canary III operates from 32°F to

122°F, and at 20 to 90 percent relative humidity. The Canary III is available in two models, the 4083 with a recessed power switch, and the 4083P with a finger-operated power switch. Mild shocks will have no effect on the device; however, large shocks may increment the display by one mR.

4.1.5 Far West Technology Inc. Canary IV

The Canary IV (model 4084) is an electronic dosimeter based on a PIN diode. It is $3.4 \times 2.3 \times 1.5$ inches in size. It has a removable snap-on clip, or it can be worn on a lanyard. It beeps at every 10 μ R, and the beep function can be turned off. It has an on/off toggle switch and is weather-sealed. The display window is made of polycarbonate. It has a recommended calibration interval of 1 year. The Canary IV requires two BR2325 lithium batteries with an approximate 2,000 hour life. Low battery condition is indicated by a short beep. Battery change



Canary IV Photo: Radiation Dosimeters for Response and Recovery Market Survey Report (January 2010)

requires a screwdriver and a non-metallic removal instrument. The Canary IV operates from 32°F to 122°F. Mild shocks will not affect the reading but large shocks may increment the display by 0.01 mR.



Canary III Photo: Radiation Dosimeters for Response and Recovery Market Survey Report (January 2010)

4.1.6 Fisher Scientific Inc. EPD Mk2+

The EPD Mk2+ electronic personal dosimeter uses a silicon chip detector with gamma sensitivity of 1 count per 0.1 mrem. It has been available since 1999. The dosimeter's dimensions are $3.4 \times 2.5 \times 1.2$ inches and it is worn on a belt clip. It is suitable for use as a single, stand-alone dosimeter, or as a component of a dosimetry management system. A low battery condition is indicated by a visual display and audible chirps. The device has a liquid-crystal display and user-activated backlight. The display functions are controlled by a single button on the front of the unit, recessed to prevent inadvertent use. The device is powered by one AA size Lithium Thionyl Chloride (LTC) or Alkaline battery with

a 5-month or 50-day life for LTC and alkaline, respectively. No special tools are required to access the battery compartment. Self-checks include detector and battery tests and may be initiated upon startup, on demand, or over an IR communications link as part of a dosimetry management system. The device's nonvolatile memory stores up to 579 dose transition records, the total dose and peak dose rates, and time of occurrence. Calibration is expected to last at least 1 year in routine use, and indefinitely in storage. The dosimeter has operating ranges of 14°F to 122°F and 20 to 90 percent relative humidity. It is drop tested to 1.5 meters.

4.1.7 Fisher Scientific Inc. RadEye[™] G/G-EX

The RadEye G and G-EX use GM detectors with gamma sensitivity of 17 cps/mR/h for Cs-137. The RadEye G-EX is the intrinsically safe version of the RadEye G. They have been available since 2006. The device measures 4.1 x 2.6 x 1.4 inches and can be worn using its holster and clip. It is powered by rechargeable or two AAA batteries with a 500 hour battery life. A low-battery condition is indicated by a low battery symbol, a text "low batt" warning, and an audible alarm. No tools are required to access the battery compartment. The display has a backlight feature that stays on for 10 seconds after any button press or can be locked on. The device has a self-check feature, and no maintenance is required apart from battery replacement

and regular response checks. Calibration is expected to last 10 years under routine use or in storage. Data is stored in flash memory. The device maintains a history of 1,600 data points and 250 log book entries. Communication between the device and a computer can be done via IR or Bluetooth; a Wi-Fi option is also available. The device has operating ranges of -4°F to 122°F and 10 to 90 percent relative humidity. It is drop tested to 1.5 meters.



EPD Mk2+ Image courtesy of Fisher Scientific Inc.



RadEye G and G-EX Images courtesy of Fisher Scientific Inc.

4.1.8 Fisher Scientific Inc. RadEyeTM GF/GF-10/GF-EX/GF-10-EX

The RadEye GF models are designed for higher-range dose rates than the RadEye G/G-EX products described in section 4.1.7. The RadEye GF series products use GM detectors with gamma sensitivity of 1.3 cps/mR/h. They have model designations GF, GF-10, GF-EX, and GF-10-EX. The GF-10 models report the ambient dose equivalent; the "-EX" designation indicates intrinsically safe certification to the European Union standard (EU:ATEX). The GF and GF-10 have been available since 2009. The devices measure 3.8 x 2.4 x 1.2 inches without case and holster, and approximately 4.3 x 2.8 x



4.1.9 Fisher Scientific Inc. RadEyeTM PRD-ER

The RadEye PRD-ER is an extended-range personal radiation detector designed for both interdiction and response missions. It has been available since 2009. It has a NaI detector with gamma sensitivity of 1.5 cps/ μ R/h for Cs-137. Proprietary circuitry allows energy compensated dose and dose rate measurements with a single detector. The device measures 3.8 x 2.4 x 1.2 inches without case and holster, and approximately 4.3 x 2.8 x 1.6 inches with case and holster. It is worn using the holster's clip. It is powered by rechargeable or two AAA batteries with greater than 800 hour battery life. A low-battery condition is indicated by a low battery symbol, a text "low batt" warning, and an audible chirp. No tools are

required to access the battery compartment. The display has a backlight feature that stays on for 10 seconds after any button press or can be locked on. A heartbeat graphic shows the status of the device's self-check for detector, voltage, electronics, and data. Calibration lasts 2 to 3 years under routine use and 3 to 5 years in storage. Data is stored in flash memory, and consists of 1,600 data points and 250 log book entries. Data communication is through cable, IR, and Bluetooth, with Wi-Fi as an option using an external device. The device operates within -4°F to 122°F, 20 to 90 percent relative humidity, and passes a 1.5 meter drop test.



RadEye GF and GF-10-EX *Images courtesy of Fisher Scientific Inc.*



RadEye PRD-ER Image courtesy of Fisher Scientific Inc.

4.1.10 Fuji Electric Corporation of America DOSEi

The DOSEi is a lightweight electronic dosimeter that uses a Si chip detector. It has been available since 2008. The device measures approximately 1.8 x 4.3 x 0.5 inches and can be worn on a lanyard or clip. It has a four-digit display with a backlight. The DOSEi is powered by a coin-type lithium battery (CR2450) with greater than 720 hours battery life; no tools are required to access the battery compartment. Visual and audible indicators signal a low battery condition. The device performs continuous self-monitoring and a self-check when powered up. Calibration lasts over a year under



DOSEi Image courtesy of Fuji Electric Corporation of America

routine use or in storage. It can store 600 data points of dose measurement and uses IR for external communication. The operating range for the dosimeter is -4°F to 104°F and up to 90 percent relative humidity. The DOSEi meets Japanese standards for drop testing.

4.1.11 Fuji Electric Corporation of America NRF50

The NRF50 electronic personal dosimeter uses a Si chip detector with gamma sensitivity of 0.1 cps/mrem/h (10 cps/mSv/h). It has been available since 2015. It measures 2.4 x 4.1 x 1.1 inches and can be clipped to the body or worn with a lanyard or holster. It is powered using a rechargeable or standard AA battery with 2,500 hour battery life. The battery compartment can be opened using a coin. A low-battery condition is signaled with a visual indicator and audible alarm. It has a backlit monochrome LCD (128 x 48 dot) display and flashing LEDs, vibration, and audible indicators for alarms. It also has an emergency call button that can be used to



NRF50 Image courtesy of Fuji Electric Corporation of America

notify on-site facility managers of incidents that require assistance. The NRF50 includes integral communications via IR, Bluetooth, Wi-Fi, or existing radio remote monitoring systems. Connection to peripheral devices via Bluetooth allows workers to continuously monitor their dose. The device's self-check monitors low battery voltage, calibration status, or errors of internal LEDs, memory, or clock. The NRF50 can retain 4,000 history data points. Calibration lasts over a year either in routine use or in storage. The device's operating range is 14°F to 122°F and up to 95 percent relative humidity. It is drop tested to 1.5 meters.¹²

 $^{^{12}}$ A 1.5 m (4.9 ft) drop on to concrete is a standard drop test.

4.1.12 Fuji Electric Corporation of America NRF Series (30, 31, 34, 40)

The NRF Series of electronic dosimeters use Si chip detectors. The NRF30 measures gamma; NRF31 measures gamma, thermal neutrons, and fast neutrons; NRF34 measures gamma and beta; and the NRF40 is a ruggedized model of the NRF30. The devices have been available since 2005 and measure 2.4 x 3.1 x 1.1 inches (excluding clip). They can be worn by lanyard, clip, or holster. They are powered using rechargeable or CR123A batteries with up to 2,000 hours battery life. The battery compartment can be opened using a coin. The LCD display has a backlight. A self-check



NRF40 Image courtesy of Fuji Electric Corporation of America

is initiated on start-up and runs continuously during use. Calibration lasts over a year under routine use or in storage. Data retention includes 600 records of trend data and 500 records of access data. Configuration and calibration information can be communicated via cable and IR. The operating range for these dosimeters is -4°F to 122°F and relative humidity up to 95 percent. The NRF40 is drop tested to 2 meters on a steel plate.

4.1.13 Ludlum Measurements Inc. Model 25 Series

The Model 25 Series Personal Radiation Monitor uses an internal energy-compensated GM detector. It is 3.0 x 2.1 x 0.7 inches in size and designed to be worn on a belt, lanyard, or armband. It can be set for 2 alarm levels each for exposure rate and accumulated dose, distinguished by the words "alert" and "alarm" and different durations of audible beeps. It uses a single frequency tone that is distinguishable from the personal alert safety system alarms typically worn by firefighters. The LCD display normally shows exposure rate, but can be set to display total accumulated dose and time remaining to dose alarm

limit as well. In an alarm situation, the display (automatically backlit if light levels are dim) rotates every two seconds among the three displays: exposure rate, accumulated dose, and time remaining. Thus, in an emergency situation, a responder can be warned of the radiation level and informed of the time remaining before their maximum allowed dose is reached. Setup of the instrument is accomplished through the front panel buttons.

The Model 25 Series includes four designations: Model 25 displays in units of R, Model 25-1 displays in units of Sv, and both are available with intrinsically safe certification, denoted 25-IS and 25-IS-1, which are certified in the U.S. (UL913, Class I Division I Group A, B, C, and D). All versions of the Model 25 personal radiation monitor require two DL2450 lithium batteries and have an approximate 6,000 hour life. A low battery condition is indicated by an icon on the display screen. Battery change requires a coin or screwdriver. The Model 25 operates from -40°F to 150°F.



Model 25 *Photo: Radiation Dosimeters for Response and Recovery Market Survey Report (January 2010)*

4.1.14 Mirion Technologies Inc. DMC 3000

The DMC 3000 electronic radiation dosimeter provides dose and ambient dose rate readings for deep dose equivalent $H_p(10)$. It uses a Si chip detector with gamma sensitivity of 180 cps/R/h. It has been available since 2012. The device measures 3.3 x 1.9 x 0.7 inches and has options for being clipped to a pocket, belt, or lanyard. It is powered with rechargeable or AAA batteries with a battery life of up to 2,500 hours of continuous use. A Torx T8 screwdriver is needed to access the battery. Audible and visual indicators signal a low battery condition. The device has a backlit, eight-digit LCD



DMC 3000 Image courtesy of Mirion Technologies Inc.

display; two-button navigation; and visual LED, audible, and vibrating alarm indicators. Continuous self-diagnostics include battery voltage, optical detector diode test, and background counts. Calibration is expected to last 9 months under routine use and 2 years in storage. Data is stored in nonvolatile memory. The operating range for the dosimeter is from 14° F to 122° F and up to 90 percent relative humidity. It is drop tested to 1.5 meters. The DMC 3000 has optional external modules that expand the device's detection and communication capabilities. These include a beta module that provides Hp(0,07) for beta radiation measurement; a neutron module that provides Hp(10) neutron radiation measurement; and a telemetry module that allows transmission of data to an external station.

4.1.15 Mirion Technologies Inc. RAD-60 (from Laurus Systems Inc.)

The Rad-60 is a personal alarming dosimeter that uses a Si chip detector. It has been available since 1995. It measures 3.1 x 2.6 x 0.9 inches and is worn by holster, pocket, or lanyard. The device is powered by a single AAA alkaline battery with 1,800 hour battery life (in dose mode, in a background field). Visual and audible alarms signal low-battery conditions, and no tools are needed to change the battery. The dosimeter has a digital display, six preset alarm levels, a selfcheck, and a nonvolatile memory. The RAD-60 can be integrated into an access control system to track personnel radiation dose records and



RAD-60 Image courtesy of Laurus Systems Inc.

generate reports with an external dosimeter reader. Calibration lasts 4 years under routine use and 6 years in storage. The device can communicate over IR. Its operating range is -4°F to 122°F, up to 90 percent relative humidity, and it is drop tested to 1.5 meters.

4.1.16 Mirion Technologies Inc. RDS-31 (from Laurus Systems Inc.)

The RDS-31 is a multi-purpose radiation survey meter that uses a GM detector. It has optional alpha, beta, and gamma external probes. It has been available since 2011. It measures 3.9 x 2.6 x 1.3 inches and can be handheld, or worn by pocket, belt clip, or pouch. It has a five-digit, backlit, LCD display. It is powered by two AA alkaline or rechargeable batteries with a 4-month battery life. No tools are needed to access the battery compartment. It has configurable buttons and a self-check feature. The RDS-31 can communicate over USB cable or RF. Calibration lasts 2 years under routine use or in storage. The device's operating range is -40°F to 131°F, up to 85 percent relative humidity, and it passes drop testing of 1.5 meters.



The PM1211 uses a GM detector and is designed for search and continuous monitoring. It has a gamma sensitivity of 25 cps/mrem/h for Cs-137 and is commercially available in 2016. It measures 5.1 x 2.0 x 0.8 inches, and can be worn on a lanyard or pocket. The device is powered by a single, non-rechargeable, CR2450 battery with battery life of approximately 2 years. Partial and critical low battery conditions are indicated on the device's LCD screen. The PM1211 features two-button operation, audible and visual alarms, and clock and calendar functions. Up to 2,000 data points are stored in nonvolatile memory. Different versions are available with GPS capability, and data export via USB or



4.1.18 Polimaster Inc. PM1604A/PM1604B

The PM1604A and PM1604B electronic personal dosimeters use GM detectors with gamma sensitivity of 3 cps/mrem/h for Cs-137. The PM1604A measures exposure rate up to 650 R/h whereas the PM1604B measures an extended range up to 1,300 R/h. They have been commercially available since 2003. Each dosimeter measures 2 x 3.5 x 0.8 inches, has a configuration similar to a stopwatch, and can be worn by clip or PM1604A/B Image courtesy of Polimaster lanyard. Each is powered by a single CR2032 lithium battery with a 9-month battery life. Low battery is indicated by partial and critical warnings on the LCD screen. Up to 1,000 records are

stored in a nonvolatile memory and data can be transmitted via IR to a computer or external device. The devices operate from -4°F to 158°F, up to 98 percent relative humidity, and they are drop tested to 1.5 meters.

28



RDS-31 Image courtesy of Laurus Systems Inc.



PM1211 Image courtesy of Polimaster Inc.

Inc.



4.1.19 Polimaster Inc. PM1605-BT

The PM1605-BT uses a GM detector and has been available since 2015. It measures 4.5 x 2.4 x 0.8 inches (without clip) and can be worn with a belt clip, web loop, or holster. It has a backlit LCD display screen and twobutton control. It is powered by rechargeable or AA alkaline batteries with a 9-month battery life. A flathead screwdriver is used to access the battery compartment. Visual and audible indicators signal low battery conditions. The self-check is initiated after powering on. Calibration lasts 10,000 hours under routine use and 8 years in storage. Up to 4,000 data points are stored in its nonvolatile memory. The device can communicate via USB cable and Bluetooth, and can exchange data with a user's mobile device in real time. The dosimeter's



PM1605-BT Image courtesy of Polimaster Inc.

operating range is -22°F to 149°F and up to 98 percent relative humidity. It is drop tested to 1.5 meters.

4.1.20 Polimaster Inc. PM1621M/PM1621MA

The PM1621M and PM1621MA are personal radiation dosimeters that include an algorithm for detection and location of radioactive materials. The PM1621M measures exposure rates up to 20 R/h and the PM1621MA has an extended rate range of up to 200R/h. The "M" in the model number signifies that these devices contain a vibration alarm (two additional models by this manufacturer, the PM1621 and PM1621A, are identical with the exception of the vibration alarm). The dosimeters use GM detectors with a gamma sensitivity of



PM1621M Image courtesy of Polimaster Inc.

30 cps/mrem/h. They have been commercially available since 2005. They measure $3.4 \times 2.8 \times 1.4$ inches and can be worn by clip or holster. Each is powered by one AA battery with a 12-month battery life. A low battery condition is indicated on the LCD screen. The device has data retention of 1,000 records and IR communication. The dosimeters' operating range is -40°F to 140°F and up to 98 percent relative humidity. The 1621M and 1621MA are drop tested to 0.7 meters.

4.1.21 Polimaster Inc. PM1703MO-1BT

The PM1703MO-1BT uses CsI and GM detectors with gamma sensitivity of 0.85 cps/(μ R/h) for Cs-137 and 1.0 cps/(μ R/h) for Am-241. It has been available since 2015 and is designed to be used for both gamma radiation detection and dose rate measurement. It measures 2.8 x 1.3 x 3.4 inches and can be worn by belt clip or with a web loop holster. It is powered by a rechargeable or alkaline battery with 1,000 hour battery life. The PM1703MO-1BT also has an optional vehicle mounting cradle for charging and installation on a vehicle dashboard. Visual and audible indicators signal a low-battery condition. The LCD has a backlight. A self-test and background calibration are initiated on startup.



PM1703MO-BT Image courtesy of Polimaster Inc.

Calibration is expected to last 8 years under routine use and eight years in storage. The device retains 2,000 data points and can communicate through an IR interface and Bluetooth for real-time exchange of data with a user's mobile device. The dosimeter's operating range is -22°F to 122°F and up to 95 percent relative humidity. The device is drop tested to 0.7 meters.

4.1.22 Polimaster Inc. PM1704A-M

The PM1704A-M uses CsI and GM detectors with gamma sensitivity of no less than 1 cps/ μ rem/h (100 cps/ μ Sv/h). It has been available since 2015 and combines radiation detector, radioisotope identifier, and dosimeter capabilities. It measures 4 x 3.5 x 2 inches and is equipped with a removable belt clip or a web loop holster. It can be powered by a rechargeable or AA alkaline battery with battery life of 300 hours. Visual and audible indicators signal a low battery condition. The display screen is a transflective LCD with backlight. The device has a self-check, and calibration lasts 6 months under routine use or in storage. The device can



PM1704A-M Image courtesy of Polimaster Inc.

store up to 1,000 gamma spectra and up to 15,000 events in nonvolatile memory. Communication is via cable and Bluetooth, and data can be exchanged in real time with a user's mobile device. The instrument has an operating range of -4°F to 122°F, up to 98 percent relative humidity, and it is drop tested to 1.5 meters.

4.1.23 Polimaster Inc. PM1904A POLISMART® II

The PM1904A POLISMART II uses a GM detector with gamma sensitivity of 3 cps/mrem/h for Cs-137. It measures 2.3 x 1.5 x 0.7 inches and can operate independently or with a user's smart phone or mobile device. It has been commercially available since 2014. Autonomously, it records all measurements in nonvolatile memory at preset intervals. With a mobile device, it exchanges data in real time using Bluetooth. The software app installed on the user's mobile device allows recording tracks marked with DER and DE values using the ability of GPS positioning of user's mobile device. The associated software allows integration with GPS for mobile tracking. It allows iPhone users to continuously monitor environmental radiation background and individual radiation exposure. Visual LED and audible alarms activate when preset thresholds are exceeded. It is powered by a rechargeable battery with up to 2,000 hour battery life at background conditions or up to 300 hours with Bluetooth

activated. A flashing light indicates a low battery condition. The device's operating range is 4° F to 122° F and up to 95 percent relative humidity. In its PVC case, it is drop tested to 1.5 meters.

4.1.24 RAE Systems by Honeywell GammaRAE II R

The GammaRAE II R is designed for detection and dosimetry and has been available since 2007. It uses CsI and PIN detectors with gamma sensitivities of $1 \text{ cps/}\mu\text{R/}h$ and about 0.2 cps/mR/h, respectively. The base unit measures 4.9 x 2.7 x1.4 inches and is worn by clip. It is powered by rechargeable or two AA batteries with battery life of 600 hours. A screwdriver is used to open the battery compartment, and a low-battery condition is visually indicated. The device has a backlit display and self-diagnostics. Calibration is expected to last 2 years under routine use and 3 years in storage. The device retains 30,000 data points and can communicate via cable or Bluetooth. Remote command center software is included for real-time threat monitoring. The operating range is -

4°F to 122°F and up to 95% relative humidity. It is intrinsically safe and drop tested to 1.5 meters.



Image courtesy of RAE Systems by

Honeywell



PM1904A Polismart II Image courtesy of Polimaster Inc.

4.1.25 RAE Systems by Honeywell DoseRAE Pro

The DoseRAE Pro is an electronic dosimeter that uses CsI and PIN detectors. It has been available since 2012. Its gamma sensitivity is 4 to 5 cps per 100 μ R/h. The DoseRAE Pro measures 2 x 3.5 x 0.9 inches and is worn by clip. It is powered by a single AA battery with a battery life of 750 hours, and has a visual low-battery indicator. A screwdriver is used to open the battery compartment. It has a backlit display and two button interface. It also has a stay-time countdown feature that warns users when they have exceeded a preset time in a radiation area. Calibration is expected to last 2 years under routine use and 3 years in storage. The device retains 3,000 data points and can communicate via cable or wirelessly using near-field communication with an entire designed of the start of the store of



DoseRAE Pro Image courtesy of RAE Systems by Honeywell

optional dosimeter reader. The dosimeter's operating range is -4°F to 122°F and up to 95 percent relative humidity. It is drop tested to 1.5 meters.

4.1.26 RAE Systems by Honeywell DoseRAE 2

The DoseRAE 2 is a compact, badge-style dosimeter that is worn by lanyard. It has been available since 2009. It uses CsI and PIN detectors with gamma sensitivities of 4 to 5 cps per 100 μ R/h and 1-2 cps per 100 mR/h. The dosimeter measures 3.3 x 2.2 x 0.4 inches and uses a LIR2450 rechargeable battery with a 200 hour battery life between charges. A visual indicator signals a lowbattery condition, and a screwdriver would be needed to access the battery. It comes with a dock, USB connector, and software. The display screen has a backlight, and alarm types include audible, visual, and vibration. Calibration lasts 2 years under routine use and 3 years in storage. The DoseRAE 2 has self-diagnostics and data



DoseRAE 2 Image courtesy of RAE Systems by Honeywell

retention of 3,000 data points. The dosimeter's operating range is -4°F to 12°F and up to 95 percent relative humidity. It is drop tested to 1.5 meters.

4.1.27 S.E. International Inc. Radiation Alert[®] Sentry EC

The Radiation Alert Sentry EC is a personal alarming dosimeter and ratemeter that uses a GM

detector with gamma sensitivity of 1.5 cps/mR/h for Co-60. It has been available since 2008. It measures 4.2 x 2.7 x 1.1 inches and can be worn using its steel belt clip. It is powered with a rechargeable or alkaline 9-volt battery with a 1,500 hour battery life. Visual and audible alerts signal a low-battery condition, and a screwdriver is required to change the battery. The Sentry does not have a display screen; rather, visual, audible, and vibration alarms are used to alert the user that dose or dose rate thresholds have been exceeded. An audio switch allows the user to choose between audible clicks for each count received or a silent mode that can be augmented with the use of headphones. Built-in memory records 1,024 data points and data communication is via USB cable. Associated software allows the user to download the accumulated dose data along with time, date, and other



Radiation Alert Sentry EC Image courtesy of S.E. International Inc.

identifiers for analysis. The device has a self-check feature. Calibration lasts 1 year under routine use or in storage. The dosimeter's operating range is -4°F to 122°F and up to 90 percent relative humidity. It is drop tested to 1.5 meters.

4.1.28 Tracero[™] PED+ (from Laurus Systems Inc.)

The PED+ Personal Electronic Dosimeter is designed to be used as both a dosimeter and a handheld dose rate survey meter. It uses a GM detector and has been available since 2012. It measures 3.9 x 2.3 x 0.8 inches and can be worn by clip or lanyard. The PED+ is powered by a rechargeable lithium-ion battery with 300 hour battery life. It has a low-battery indicator and can be charged by a micro USB cable to a PC. The display features a color-coded graphic of a person that fills with color depending on accumulated radiation exposure. The PED+ incorporates self-



PED+ Image courtesy of Laurus Systems Inc.

diagnostics, a 125,000 data point nonvolatile memory capacity, GPS, and communication through IR or Bluetooth. The dosimeter's operating range is -4°F to 122°F and up to 95 percent relative humidity. It is drop tested to 1.5 meters.

4.1.29 Tracero[™] PED Blue (from Laurus Systems Inc.)

The PED Blue Personal Electronic Dosimeter uses a GM detector. It has been available since 2012. It measures 3.9 x 2.3 x 0.8 inches and can be worn by clip or lanyard. The PED Blue is powered by a rechargeable lithium-ion battery with 300 hour battery life. A low-battery condition is signaled by an audible and visual alarm and the device can be charged by a micro USB cable. The display features a color-coded graphic of a person that fills with color depending on accumulated radiation



PED Blue Image courtesy of Laurus Systems Inc.

exposure. The PED Blue incorporates self-diagnostics, a 125,000 data point nonvolatile memory capacity, and communication through cable or IR. The dosimeter's operating range is -4°F to 122°F and up to 95 percent relative humidity. It is drop tested to 1.5 meters.

4.1.30 Tracerco[™] PED-IS

The PED-IS has the same design and features as the PED Blue, but is a heavier weight, intrinsically safe model. It has been available since 2011. It uses a GM detector with gamma sensitivity of 480 cpm/mR/hour for Cs-137. It measures $4.1 \ge 2.5 \ge 1.0$ inches and is worn by clip, lanyard, or pouch. It is powered by a nonreplaceable, rechargeable, lithium-ion battery with 300 hour battery life between charges. A visual battery indicator on the display depicts battery condition; the number of hours of charge left can be found in the battery menu. The LED display features a color-coded graphic of a person



PED-IS Image courtesy of Tracerco

that fills with color depending on accumulated radiation exposure and a traffic light system to simplify radiation monitoring. LED, vibration, and sound checks are initiated on start-up, and self-diagnostics include a detector check for counts on the GM tube. Calibration lasts 2 years under routine use or 3 years in storage. An on-board flash chip retains 120,000 data points including dose, dose rate, and time/date stamp. A docking station is used for data transfer and battery charging. The dosimeter's operating range is -4°F to 122°F and relative humidity up to 95 percent. The PED-IS passes a drop test two times on each face onto concrete from 1.5 meters.

4.1.31 X-Z Lab Inc. RadTarge II D700 (from RadOnc Solutions LLC)

The RadTarge II D700 is an alarming, electronic dosimeter with dose-equivalent rate and accumulateddose functions. It uses a Si photomultiplier and a Yttrium Orthosilicate (YSO) scintillator with gamma sensitivity of 340 cps/mrem/h for Cs-137. It has been available since 2015. It measures 2.7 x 1.8 x 0.7 inches and is worn by clip. It is powered by a rechargeable lithium-ion battery with 200 hour battery life. It has a visual low-battery indication. It has a backlit LCD display screen. Calibration lasts 5 years under routine use and 10 years in storage. A flash chip stores 43,800 data points and 5,000 work log



RadTarge II D700 Image courtesy of RadOnc Solutions LLC

items. Communication is via microUSB cable or radiofrequency identification (RFID) system. The device's operating range is -4°F to 122°F, and up to 90 percent relative humidity. It is drop tested to 1.5 meters.

4.1.32 X-Z Lab Inc. RadPavise

The RadPavise is designed to function as a dose equivalent rate meter, accumulated dose meter, radiation survey meter, and radiation source locator. It uses a Si photomultiplier and YSO scintillator with gamma sensitivity of 340 cps/mrem/h for Cs-137. It has been available since

2012. It measures 4.4 x 2.8 x 0.9 inches and is handheld, with an optional case for clip attachment to the user. It has an organic lightemitting diode (OLED) display and uses a rechargeable lithium-ion battery with 240 hour battery life between charges. A low-battery condition is signaled by an icon on the display screen. The device performs a self-check upon start up. Calibration lasts at least a year under routine use or in storage. Up to 43,800 data points and 5,000 work log items can be stored in flash memory. Data transfer may be through USB or RFID depending on the version of the device chosen. The instrument's operating range



RadPavise Image courtesy of X-Z Lab Inc.

is -4°F to 122°F and up to 95 percent relative humidity. It has been drop tested to 1 meter on each face onto concrete covered by a 4 millimeter hard rubber sheet.

4.2 Self-Reading Dosimeters

4.2.1 JP Laboratories Inc. RADTriage50

The RADTriage50 is a credit card sized, instant color developing emergency dosimeter. It is designed for monitoring exposure in a radiological incident for medical treatment triage and to minimize worry and panic. It measures medically significant doses ranging from 2 R (20 mSv) through about 1,000 R (10,000 mSv). It requires no reader, batteries, or maintenance. The RADTriage50 has a service life of 2 years at room temperature and can be stockpiled for 10 years in a freezer. It also has an indicator to monitor the service life and any false signals. The operating



RADTriage50 Image courtesy of JP Laboratories Inc.

temperature range is -4°F to 140°F, and it is not affected by humidity. It can be worn on a clip, lanyard, or carried in a pocket or wallet.

The sensor of the RADTriage50 is a coating of radiation sensitive solid compounds called diacetylenes which polymerize to form colored plastics. The sensor instantly develops noticeable color above 1 R (10 mSv) and intensifies with increasing dose. The color development is cumulative and irreversible. The dose is estimated by matching the color of the sensor with its adjacent color reference bars. Each card has its own unique barcode on the back. Available since 2003, its dimensions are $3.3 \times 5.4 \times 0.04$ inches.

4.2.2 SE International Inc. PEN Dosimeters

The PEN direct reading dosimeters are rugged, precision instruments available since 1995. They measure and directly read, at any time, accumulated dose for gamma and X-ray exposure. PEN dosimeters are designed to satisfy military specifications (RADIAC METER IM-264/PD) and ANSI N322 requirements. A metal clip attaches the dosimeter to a pocket or any object to monitor total radiation exposure. They are hermetically sealed and immersible. Neither the dosimeter nor the charger requires a battery; the charger is used to zero the



PEN Dosimeter and Charger *Image courtesy of SE International Inc.*

dosimeter. PEN dosimeters are dose rate independent and available with different ranges and scale increments, where the number in the product designation indicates its maximum range.

Their operational temperature range is from -4°F to 122°F, and the dimensions are 4.5 inches long with a diameter of 0.6 inches.

4.3 Processed Dosimeters – User Readable

4.3.1 Landauer RadWatch Dosimeter; Aquila RadLight Reader and RadViewer

The RadWatch dosimeter contains three OSL elements behind different filters to assess the dose from photons and neutrons and to indicate the photon energy. It also contains an RFID chip that stores the dosimeter serial number, calibration data, and dose results from the most recent analysis. The RadWatch is designed to be worn on the wrist or chest, and read out using the portable RadLight Reader manufactured by Aquila. The RadLight Reader uses four AA alkaline batteries or alternating current (AC) power and



RadWatch Dosimeter, RadLight Reader, and RadViewer Images courtesy of Landauer and Aquila

incorporates an Apple iPad Mini for the user interface. Dosimeters to be read are inserted into the reader's drawer assembly, which automatically positions their built-in sensors for analysis by the photo-optical engine. All analytical data is stored in the RadLight Reader for later download to a computer via a USB connection, facilitating additional analysis and reporting. Data reports may also be emailed to multiple command sites directly from the RadLight reader. Using battery power, the RadLight reader can operate for 21.5 hours in the temperature range of 64°F to 122°F, and for shorter times at low temperatures that affect battery performance. (For example, the operational time is reduced to about one-third for -4°F to 14°F). It takes about 27 seconds to process a dosimeter, which allows about 144 to be processed per hour. Also, a central processing lab can provide a final NVLAP accredited dose of record analysis after use. By this method, the RadWatch and RadLight system can provide a legal dose of record for dose reconstruction, risk mitigation, and legal defense. The RadWatch dosimeter measures 1 x 1 x 0.5 inches and the reader is 9 x 7 x 7 inches. The system has been available since 2013.

The RadViewer is used to manage RadWatch dosimeter assignments to responders to establish a chain of custody. It uses an Apple iPod Touch as the primary user interface and can also be used to view the last dose reading that was assigned to the dosimeter.

4.3.2 Landauer InLight® Dosimeter; MicroStar Reader

InLight® dosimeters provide X-ray, gamma, and beta radiation monitoring with OSL technology. They are uniquely bar coded with serial numbers for chain of custody and sensitivity identification. Inlight dosimeters offer reanalysis capabilities, precision with a wide dynamic range of measurement, and long term stability. InLight dosimeters can be returned to Landauer for accredited analysis or, with the purchase of a MicroStar reader, dosimeters can be read on-site for an in-house accredited dosimetry program. This system can be used for personnel, area/environmental and emergency



InLight dosimeter and MicroStar Reader Image courtesy of Landauer

response monitoring, or any radiation assessment application. The portable reader is applicable for in-field use or in locations requiring immediate analysis, such as emergency response activities. It is appropriate for less than 10,000 participants. Readout takes 13 seconds, allowing a throughput of approximately 180 readouts per hour. The nondestructive OSL readout allows for reanalysis. It works with a laptop computer and can be networked with additional MicroStar readers. The reader measures 4.3" x 12.9 x 9.1 inches.

The InLight system has been available since 2003 and is NVLAP accredited in Categories IA and IIA.

4.3.3 Mirion Technologies Inc. Instadose 1 (from Laurus Systems Inc.)

The InstadoseTM uses DIS technology and is smaller than a flash drive, with a built-in clip to attach to clothing. It provides an instant readout when connected to a computer with internet access via a USB connector and logging in to a secure online account. Unlimited online readings and access to each user's current and historical exposure readings are included in the subscription price.

A built-in memory chip stores each wearer's identity using an embedded unique serial code. Once a user receives Instadose, they must first register the device, whereby the Instadose driver and client are installed on the user's computer and the device is initialized for use.

The accumulated dose stored on Instadose is processed through a proprietary algorithm. This fully automated transfer of data minimizes the chance of human error and misidentification. Once complete, a graphical representation of the current dose (since the last readout) will load on the screen. Users can also select an option to view their cumulative dose level. The Instadose dosimeter can be read for cumulative doses of up to 12 rem. If the cumulative dose exceeds 12 rem, the dosimeter must be sent in for processing and reporting; doses up to 500 rem can be read. The Instadose dosimeter can be used or stored for 2 years. It is NVLAP accredited in categories IA, IIA, and IIC. Available since 2011, its dimensions are approximately 0.5 x 1.0 x 3.0 inches.

4.3.4 Mirion Technologies Inc. Instadose 2

The Instadose 2 uses the same DIS detector technology as the Instadose 1 but does not require a USB connection for readout. Instead, dose information can be automatically transmitted to an Instadose-enabled communication device using Bluetooth Low Energy (BLE) technology. Readouts occur automatically according to a user-configured calendar, or manually by pressing a button on the back of the dosimeter in the vicinity of the enabled device. The Instadose-enabled

device can be an iPhone or iPad, a personal computer with BLE or an accessory called the instaLink-USB attached to the computer's USB port, or another accessory called the instaLink



Instadose 1 Image courtesy of Laurus Systems Inc.



Instadose 2 Image courtesy of Mirion Technologies Inc.

hotspot station. A dose reading consists of two parts; the detector is read and then the dose is communicated to Mirion Technologies' server. If communication does not occur, the badge will attempt to communicate every hour for 24 hours. If the dosimeter cannot communicate with Mirion's server, the dose reading is stored on the dosimeter. The data remains stored on the dosimeter until a successful connection can been established.

The badge can be worn by clip or lanyard. It contains a lithium battery for data communication. With every successful communication, a status check on the battery is performed. The battery lasts 5 years under typical conditions. The Instadose 2 can be used or stored for 5 years, and its dimensions are $2 \times 2 \times 1$ inch. The Instadose 2 is becoming available in 2016.

4.3.5 Thermo Fisher Scientific Inc. Model 8840 TLD

The Model 8840 TLD is designed to be read out using a laboratory-based reader as part of an in-house dosimetry service. The personal dosimeter is capable of deep dose, shallow dose, eye dose, and neutron dose equivalent measurements. It is worn using a strap clip or belt loop. The dosimeter uses high sensitivity lithium fluoride LiF:Mg,Cu,P TLD material and measures 2.7 x 1.6 x 0.6 inches. It is waterproof to depths of 66 feet. The Model 8840 TLD may be read on any of the Thermo Fisher Scientific hot gas TLD readers which are not portable. Data is stored within the personal computer that is part of the dosimetry system, allowing nearly limitless storage



Model 8840 TLD Image courtesy of Thermo Fisher Scientific Inc.

capacity. This system has received NVLAP accreditation in categories IA, 2A, 3A, IIIA, IVAB, and VBC, and has been available since 2000.

4.4 Processed Dosimeters – from Dosimetry Service Providers

4.4.1 Landauer Escort Wallet Card

Escort dosimetry service provides radiation monitoring for emergency responders who may accidentally be exposed during a radiation incident. The laminated, wallet-sized card can be worn by clip or lanyard. It measures radiation exposure using Landauer's Luxel+ OSL material. The Escort dosimeter can be customized with graphic, color, and packaging design options. Landauer's full service provides automatic exchange of dosimeters for each wear period, accredited dose of record processing and analysis, data management, reporting of exposure results, and customer service and technical support programs. In addition, many ancillary services are available including direct computer access via the internet to Landauer's database for exposure reports, shipment tracking, and account maintenance transactions.



Escort wallet card *Image courtesy of Landauer*

The Escort is NVLAP accredited in category IA. It has been available since 1998 and measures 2.4 x 3.4 inches. It is expected to remain within operational parameters for 5 years under routine use and for 10 years in storage.

4.4.2 Mirion Technologies Inc. REMtrack Wallet Card

The REMtrack[™] wallet cards are designed for use by counter-terrorism operations, law enforcement, and other personnel who encounter radiation emergency situations. REMtrack consists of a natural LiF TLD chip positioned between high quality paper and polyethylene laminate material, and it is optionally available with a second LiF chip. Its bar code identification system displays an individual's name, unique card number, issue and expiration dates, and offers chain-of-custody through the analysis process. The REMtrack's credit card style can be customized with a company logo. It is available in a choice

of wallet card or clip-on badge. The REMtrack is expected to remain within operational parameters under routine use for 5 years and for 10 years in storage. Available since 1990, it is NVLAP accredited in categories IB and IIB. Its dimensions are 3.25 x 2 x 0.06 inches.

4.4.3 Mirion Technologies Inc. Genesis Ultra TLD

The Genesis Ultra TLD contains 4 TLDs to respond accurately to beta, gamma, X-ray, and neutron radiation. The response of each TLD element is corrected by the application of a unique element correction factor and allows for reporting of deep, lens of eye, and shallow doses. The badge can be worn by clip or lanyard. It is permanently bar-coded for user identification and tracking. The TLD is returned for processing with wear period options from 1 week to 1 year. It is expected to remain within operational parameters for 5 years under

normal use or in storage for 10 years. The Genesis Ultra TLD is NVLAP accredited in categories IA, IIA, IIIA, IVAA and VCA. It has been available since 2006 and its dimensions are 1.9 x 1.5 x 0.75 inches.

4.4.4 PL Medical Co. LLC TLD - Quarterly or Monthly service

PL Medical Co. LLC offers TLDs and accredited dosimetry services to industries in which radiation monitoring is desired or mandated by state or federal regulator guidelines. There are no account maintenance or set-up fees. Flexible wear periods are offered, with automatic dosimeter replacement every 3 months for 1 year. Computer generated reports are sent to the customer within 2 to 3 weeks of receiving dosimeters. This dosimetry service is applicable for homeland security, medical offices, and

TLD Image courtesy of PL Medical Co., LLC





Genesis Ultra TLD

Image courtesy of Mirion Technologies Inc.



REMtrack Wallet Card Image courtesy of Mirion Technologies Inc.

universities. The whole body TLD clips to clothing with the supplied hanger and is resistant to mechanical impact, and permanently bar coded for user identification and tracking. Online account access is provided to view past and present dosage reports. Available since 1993, the dosimeter dimensions are 1.0 x 0.5 inches and they may be used or stored for 12 months. They are NVLAP accredited for categories IA, IIA, IIIA, and IVAA.

5. VENDOR CONTACT INFORMATION

Additional information on the radiation dosimeters included in this market survey report can be obtained from the vendors listed in Table 6-1. Products may be available from multiple vendors.

Manufacturer/Vendor	Address/Phone Number	Website/E-Mail Address		
Aquila (Yamasato, Fujiwara, Higa & Associates Inc. dba Aquila)	8401 Washington Place, N.E Albuquerque, NM 87113 (505) 923-3155	www.aquilagroup.com kadner@aquilagroup.com		
Canberra Industries Inc.	800 Research Parkway Meriden, CT 06450 (800) 243-3955	www.canberra.com customersupport@canberra.com		
Far West Technology Inc.	330 S. Kellogg Ave Suite DGoleta, CA 93117(805) 964-3615	www.fwt.com info@fwt.com		
Fisher Scientific Inc.*	300 Industry Drive Pittsburg, PA 15275 (800) 556-2323	www.thermoscientific.com customer.service.rmsi@thermofisher. com		
Fuji Electric Corporation of America50 Northfield Avenue Edison, NJ 08837 (732) 560-9410		www.americas.fujielectric.com/syste ms/radiation/personal-dose- monitoring		
JP Laboratories Inc.	120 Wood Avenue Middlesex, NJ 08846 (732) 469-6670	www.jplabs.com gnpatel@jplabs.com		
Landauer	2 Science Road Glenwood, IL 60026 (800) 561-2708	www.landauer.com sales@landauerinc.com		
Laurus Systems Inc. (vendor for Mirion Technologies Inc., and Tracerco)	3460 Ellicott Center Drive Ellicott City, MD 21043 (410) 465-5558	www.laurusSystems.com		
Ludlum Measurements Inc.	P.O. Box 810 Sweetwater, TX 79556 (800) 622-0828	<u>www.ludlums.com</u> ludlum@ludlums.com		

Table 5-1 Vendor Contact Information

Manufacturer/Vendor	Address/Phone Number	Website/E-Mail Address		
Mirion Technologies Inc.	5000 Highlands Parkway, Suite 150 Smyrna, GA 30082 (800) 251-3331	www.mirion.com info@mirion.com		
PL Medical Co. LLC	117 West Dudley Town Road Bloomfield, CT 06002 (860) 243-2100 x14	www.plmedical.com		
Rad Onc Solutions LLC (vendor for X-Z Lab Inc.)	70 SE 4th Ave Delray Beach, FL 33483 (561) 926-5121	www.radonc-solutions.com/radiation- detection office@radonc-solutions.com		
RAE Systems by Honeywell	3775 North First Street San Jose, CA 95134 (877) 723-2878	www.raesystems.com		
S.E. International Inc.	436 Farm Road Summertown, TN 38483 (800) 293-5759	www.seintl.com radiationinfo@seintl.com		
Thermo Fisher Scientific Inc.*	27 Forge Parkway Franklin, MA 02038-3135 (800) 251-3331	www.thermoscientific.com customerservice.rmsi@thermofisher.c om		
Tracerco	4106 New West Drive Pasadena, Texas, 77507 (281) 291-7769	http://www.tracerco.com/		
X-Z Lab Inc. 2440 Camino Ramon, Ste. 264 San Ramon, CA 94583 (925) 359-6908		www.x-zlab.com contact@x-zlab.com		

*Fisher Scientific is a subsidiary of Thermo Fisher Scientific Inc. Fisher Scientific holds the U.S. General Services Administration (GSA) schedule.

6. SUMMARY

Commercially available radiation dosimeters for response and recovery range from simple, low cost, radiochromic cards to multifunctional electronic devices. Prices range from less than \$20 to more than \$3,000. Dosimeters are used to track the personal dose received by responders for radiation safety from immediate or longer term hazards of radiation. Selection of a dosimeter technology is based on the intended operational scenario. This market survey identified 53 dosimeters from 16 companies: 42 EPDs, 2 self-reading dosimeters, and 5 processed dosimeter systems that allow user readout – 4 of which are portable – and 4 processed dosimeters from dosimetry services.

Electronic personal dosimeters are applicable to situations with a potential for high dose levels where precise real-time information is needed to make tactical decisions and avoid acute effects. Of the EPDs identified:

- Most are capable of operating across a wide range of gamma-radiation fields, typically from at least 100 μ R/h to 10 R/h. Some can measure down to natural background radiation levels (e.g. 5 to 10 μ R/h) and/or to up to hundreds of R/h. Eight instruments have a maximum range of about 1,000 R/h.
- All but two EPDs have audible alarm capabilities. Twenty eight have audible and visual alarms that can be set for both dose rate and accumulated dose at two thresholds. Seven of these offer more than two threshold settings for rate, accumulated dose, or both. Twenty five have vibration alarms.
- Many are dust and water resistant and thirteen are immersible in water.
- Six EPD models are certified for use in explosive environments.
- All but four EPDs can communicate with a computer, reader, or smart device. Most have an IR capability; 15 have Bluetooth.
- Two EPD products have built-in GPS capability, and one other EPD is designed to integrate with GPS data from the user's smart mobile device.
- Products' weight ranged from about 1 ounce to 9.5 ounces.
- Costs range from about \$300 to \$3480.

Self-reading dosimeters are less precise devices applicable to situations where real-time information may be needed to make tactical decisions but where electronic dosimeters are not practical, such as for large scale dosimeter stockpiling. Of the two self-reading dosimeters identified in this report:

- One is a colorimetric device in the format of an identification card, spanning doses from about 5 R to 400 R. Cost is \$10 to \$15, depending on quantity.
- The other is a cylindrical pocket ion chamber which comes in various models to measure doses in the mR, R, and 20 R levels on an analog scale. (Cost information was not available.)

Processed dosimeters are applicable to situations where real-time information is not needed, but precise accumulated dose monitoring records are desired for comparison to field measurements or for assessing the potential for long term health effects. The four user-readable processed dosimeters identified in this report are manufactured by three companies:

- Two are based on OSL technology and span accumulated doses from 5 mrem to 1,000 rem. They are designed to be read out with different types of field portable readers, and one is certified for use in explosive environments. Both systems also offer an option for a subsequent NVLAP accredited readout by the manufacturer (accident and routine categories).
- Two are based on DIS technology and use different configurations of internet based systems to read or record the dose. They allow the user to read out doses from 3 mrem to 12 rem, while doses up to 500 rem can be read by sending the dosimeter to

the manufacturer. These systems are NVLAP accredited in routine and accident categories.

- One processed dosimeter system was identified which would require the user to set up a dedicated indoor laboratory for processing and obtain NVLAP accreditation as an in-house dosimetry service.
- Costs for most systems are based on the quantity of dosimeters and/or duration of subscription.

Three dosimetry service providers were identified, which contract to exchange and read dosimeters on a regular basis and track the dose measured. All are NVLAP accredited. Four different dosimeters are offered:

- One is an OSL based dosimeter in a wallet card format designed for emergency responders. It measures doses from 1 mrem to 1,000 rad and is NVLAP accredited in an accident category.
- Another is a TLD based dosimeter in a wallet card format designed for emergency responders. It measures doses from 1 mrem to 500 rad and is NVLAP accredited in an accident and a routine category.
- Two are TLD based dosimeters in brooch format designed for occupational radiation workers and NVLAP accredited in multiple categories.
- Costs for all dosimetry providers depend on dosimeter quantity and the service contract.

Radiation dosimeter products identified in this market survey cover a wide range of features which could potentially be useful to emergency response and recovery applications. Emergency responder agencies that consider purchasing radiation dosimeters should carefully research each product's overall capabilities and limitations in relation to their agency's operational needs.