Mobile Radiation Detection Systems

Market Survey Report

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FOREWORD

The National Urban Security Technology Laboratory (NUSTL) is a federal laboratory within the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T). Located in New York City, NUSTL is the only national laboratory focused exclusively on supporting the capabilities of federal, state, local, tribal, and territorial responders to address the homeland security mission. The laboratory assists responders with the use of technology to prevent, protect against, mitigate, respond to, and recover from homeland security threats and incidents. NUSTL provides expertise on a wide range of subject areas, including chemical, biological, radiological, nuclear, and explosive detection, personal protective equipment, and tools for emergency response and recovery.

NUSTL manages the System Assessment and Validation for Emergency Responders (SAVER) program, which provides information on commercially available equipment to assist response organizations in equipment selection and procurement. SAVER 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 works with responders to conduct objective, practitioner-relevant, operationally-oriented assessments and validations of commercially available emergency response equipment. Having the right tools provides a safer work environment for responders and a safer community for those they serve.

NUSTL is responsible for all SAVER activities, including selecting and prioritizing program topics, developing SAVER knowledge products, and coordinating with other organizations to leverage appropriate subject matter expertise. NUSTL conducted a market survey of commercially available mobile radiation detection systems. This equipment falls under the AEL reference numbers 07RD-04-SGND titled "Detector, Radiation, Standoff" and 07RD-03-DRHS titled "Detector, Radionuclide, High Sensitivity."

SAVER reports are available at www.dhs.gov/science-and-technology/saver-documents-library.

Visit the NUSTL website at www.dhs.gov/science-and-technology/national-urban-security-technology-laboratory or contact the lab at NUSTL@hq.dhs.gov.

U.S. Department of Homeland Security

SAVER

System Assessment and Validation for Emergency Responders

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EXECUTIVE SUMMARY

Mobile radiation detection systems are used for the detection and measurement of photon – and optionally neutron – radiation for the purposes of detection, interdiction, and hazard assessment.

Between July 2021 and November 2022, the Systems Assessment and Validation for Emergency Responders (SAVER) program – run by the Department of Homeland Security (DHS) Science and Technology Directorate (S&T) National Urban Security Technology Laboratory (NUSTL) – conducted a market survey of commercially available Mobile Radiation Detector Systems. This market survey report covers detector systems that are designed to take geo-referenced measurements while carried in manned, moving ground-based, maritime, or aerial vehicles. This report does not include detectors on unmanned systems, radiation backpacks, body-worn or handheld instruments, or air sampling systems.

This market survey describes 24 mobile radiation detection products from 16 manufacturers. In some cases, the product is designed for use in a single platform environment (land, water, or air) while in other cases it can be configured for different environments. Most vendors offer flexible options for customization based on the user's needs. While prices are therefore highly dependent on the selected options, they range from approximately $33,000 to $414,800. Most systems consist of modular components, with some configurations designed to be integrated semi-permanently in a vehicle and others to be easily removed from or transferred between vehicles. Vendors may include vehicle integration or offer this service at an additional charge.

For gamma detection, all the products included in this report use sodium iodide scintillators with volume of at least one liter and are capable of radionuclide identification. Three products also offer large volume organic plastic scintillators to enhance the low range of detection sensitivity. Eleven systems rely on Geiger-Mueller detectors to increase the upper range capability for measurement of high exposure rates. Twenty-one of the mobile radiation systems are capable of measuring exposure rates up to 1 Roentgen per hour (R/h) or higher; nine of those have an upper range of 100 R/h or greater. All systems offer options for neutron detection capability, with neutron detector types and sizes varying greatly.

Most of the land-based systems can display real-time maps of exposure rate and offer options for left/right directionality. Some systems also include features like 360-degree geometry, video cameras, source localization, isotope-specific alarms, and data output compatibility with RadResponder.[1]

The purpose of this market survey is to provide information that will guide emergency response agencies in making operational and procurement decisions. Such decisions require consideration of capabilities, limitations, and technical specifications of each product in relation to operational needs, as well as impacts associated with information technology infrastructure, data management, concept of operations, and required maintenance. Information included in this report has not been independently verified by NUSTL.

[1] RadResponder is a federally funded software platform that can collect, map, and manage radiological data from various types of equipment during an emergency. This report goes into additional detail about the usefulness of this compatibility on page 17.

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1.0 INTRODUCTION

Emergency responders use mobile radiation detector systems to sense, measure, or characterize radiation from illicit transport of material or an accidental or intentional release. The mobile radiation detector systems covered in this report are used on a vehicular platform such as an automobile, boat, or aircraft and are designed to make geo-referenced radiation measurements while the vehicle is in motion.[2] The National Urban Security Technology Laboratory (NUSTL) System Assessment and Validation for Emergency Responders (SAVER) program conducted this market survey to provide information to aid emergency response organizations in equipment selection.

Between July 2021 and November 2022, SAVER conducted a market survey of commercially available vehicle-borne mobile radiation detector systems. This market survey report is based on information gathered from manufacturer and vendor websites, internet research, industry publications and a government-issued request for information (RFI) that was posted on the System for Award Management website at (https://sam.gov/opp/c776709ce0d849089e3a8f664a5b8240/view). The U.S. Department of Homeland Security (DHS) Science and Technology Directorate's (S&T's) Technology Scouting Group also contributed to the market research used in the development of this report.

Due diligence was performed to develop a report that is representative of products in the marketplace. For inclusion be included in this report, a mobile radiation detection system was required to:

- Be designed to be mounted on, or carried within, a land, air, or maritime vehicle and ruggedized to function in the corresponding operational environment
- Include a large volume gamma-ray detector (e.g. one or more detectors having a combined volume of at least 1 liter for sodium iodide or the equivalent for other materials) that is sensitive to photon energies from 50 keV to 2.7 MeV
- Be capable of detecting radiation encountered while the vehicle is in motion and tracking geo-referenced coordinates of radiation measurements (with internal GPS receiver or software to accept coordinates from a user-provided device)
- Be able to detect small changes in radiation field above background and alert the user to changes corresponding to alarm thresholds
- Analyze the gamma radiation spectrum and identify radionuclides

Although radiation detection backpacks may meet the above criteria, they are not included in this report. Likewise, this market survey does not cover detectors designed for use on unmanned aerial or ground-based systems,[3] nor air sampling devices.

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[2] While some applications involve taking measurements while the vehicle is temporarily parked (or docked), systems designed solely for stationary applications are not included here.

[3] Radiation detectors mounted on unmanned systems are typically much smaller and therefore less sensitive than the detectors covered here.

2.0 MOBILE RADIATION DETECTION SYSTEMS OVERVIEW

Mobile radiation detector systems integrate radiation and spatial location data. They are used by law enforcement and incident response personnel to find lost, stolen, illegal, or potentially threatening radiological sources, and may be used for hazard assessments in emergency response missions. The mobile radiation detection systems covered in this report are based on large, sensitive, vehicle-borne gamma-ray detectors that allow responders to survey a wide area. Deployed on land-based vehicles they can search a particular route or area of interest, or temporarily be parked to monitor passing vehicle and pedestrian traffic. Detectors on maritime vessels can monitor radiation from boat traffic at ports and harbors or detect radiation from material dispersed by fires or explosions on land nearby. Detectors deployed on helicopters or airplanes can cover a larger geographical region, take measurements over a potentially hazardous area, or detect radiation from radioactive material released in atmospheric plumes.

The starting point for selection of any radiation detection equipment is to match a product's radiological capabilities to the requirements of the intended mission and operations. For example, discovery and interdiction missions require the capability to quickly detect small changes in the ambient radiation field, while additional abilities to perform gamma spectroscopy and detect neutrons can help identify threats. In contrast, incident response operations require the capability to function in higher radiation fields and to measure exposure rates; while radionuclide identification may be informative, neutron detection is not called for in response missions. Radiological capabilities and how they apply to homeland security missions are detailed in sections 2.1.1 through 2.1.3. Other use-cases, such as detectors installed on ground-based vehicles for characterizing contamination during cleanup operations are beyond the scope of this report.

2.1 Key Features of Mobile Radiation Detection Systems

Vendors offer various system configurations consisting of multiple detectors or combinations of different types of detectors. Some systems are designed to be integrated into the mechanical and power systems of the vehicle carrying them; others are made up of self-contained components that are more easily transferable between vehicles. Some products are designed for use in a specific environment (i.e., land, water, air); others can be used in two or more environments. Associated hardware includes the power supply, data processing and storage device, data communication module, and protective fittings and housings. Some systems may have additional optional sensors such as video camera systems. Software includes data collection, analysis, and user interfaces for data displays such as real-time spatial maps. Key features and selection considerations for mobile radiation detection systems are discussed in sections 2.1.1–2.1.6.

2.1.1 Gamma Ray Detectors

Gamma rays are penetrating radiation emitted by atomic nuclei in radioactive decay. They can be detected as individual photons and are the radiation most often detected at distances beyond a few feet from radioactive material. Gamma detectors may be used to indicate if radiation is present, to identify the source radionuclide(s) to determine if it is a threat, and to measure the radiation exposure rate. The gamma detectors used in mobile systems typically include scintillation detectors and gas-filled detectors, and some systems might include a semiconductor detector.

Scintillation detectors consist of a material that emits a light pulse when radiation is absorbed and a device, such as a photomultiplier tube, that converts the light pulse into an electrical pulse. Scintillation materials may be crystalline solid, amorphous solid (plastic), liquid, or gas.[4] A detector's sensitivity increases with its size. Scintillators composed of plastic such as polyvinyl toluene (PVT) can be made in large sizes at relatively low cost, allowing mobile radiation detectors to be very sensitive, capable of detecting small changes in the count rate of background radiation using detection algorithms with thresholds that may be set by the user. Crystal scintillators are smaller and more expensive to produce than plastic scintillators but have approximately four times higher counting efficiencies per volume.[5] Since plastic scintillators can be made larger, they can achieve comparable sensitivity to the smaller crystals due to their larger size.

In scintillation detectors made with crystals of materials such as thallium-doped sodium iodide (NaI(Tl)) or cesium iodide (CsI(Tl)), the size of the scintillation pulse may be used to determine the incident gamma energy to identify the radioactive source material. These detectors measure the gamma-ray energy spectrum, which is the number of counts in each gamma energy range plotted against energy. The measured spectrum typically shows peaks corresponding to the energies of the detected gamma rays. Radionuclide identification software then matches the measured peaks to a library of radionuclides and may assign a threat level based on whether it is a naturally occurring, medical, industrial, or special nuclear material (SNM) that has been detected. Proprietary identification algorithms may result in performance differences between systems with the same detector type. The energy resolution of plastic scintillators is typically too poor to use for spectroscopy to identify specific radionuclides, but the approximate size distribution of the scintillation pulses is sometimes used to indicate whether the gamma radiation is from naturally occurring radioactive materials (NORM). Other solid scintillation materials used in gamma spectroscopy include lanthanum bromide ($LaBr_3$:Ce) and cesium lanthanum lithium bromochloride (CLLBC). (Lithium inclusion in CLLBC detectors allows for neutron detection in addition to gamma spectroscopy.)

Gamma count-rate measurements are used for detecting the presence of radiation. Some gamma detectors are calibrated to convert gamma count rates to an exposure rate or dose rate in order to quantify the effects of radiation and allow comparisons between measurements made at different times, locations, or by different detection systems. Scintillation detectors may be calibrated to measure low levels of exposure rate or dose rate as required in interdiction missions, but the sensitive crystals used in mobile radiation systems typically overload in radiation fields greater than several milliroentgen per hour (mR/h).

Gas-filled radiation detectors can be designed to measure higher exposure rates, up to hundreds or thousands of Roentgens per hour (R/h).[6] In gas-filled radiation detectors (such as Geiger-Mueller (GM) detectors, proportional counters, or ionization chambers), high voltage is applied between two electrodes in a container filled with an inert gas or air. Radiation is detected as it ionizes the gas and creates measurable pulses of current. Gas-filled gamma detectors are sometimes incorporated into mobile radiation systems, where they are used to measure the exposure rate in high radiation fields that may be encountered in response missions that would overload scintillation detectors.

[4] Commercial mobile systems generally use solid scintillators.
[5] Plastic detectors have lower counting efficiency than crystals because they are made from elements with a lower atomic number which have fewer electrons, and it is the electrons that interact with the gamma rays which get counted.
[6] A Roentgen. a unit of exposure in the field of radiation dosimetry, has the value of 2.58×10^{-4} C/kg.

Solid-state semiconductor detectors can measure gamma-ray energies with higher resolution than scintillation detectors can but have drawbacks for use in mobile detection systems. For example, high-purity germanium (HPGe) solid-state detectors have extremely good energy resolution, but they must be cooled to near the temperature of liquid nitrogen and are expensive in the large sizes needed for mobile detection systems.[7] Cadmium zinc telluride (CZT) is a semiconductor detector material that works at room temperature and has better energy resolution than scintillators, but it is limited to small detector sizes. One product included in this report uses a CZT detector to image the direction of strong or close sources.

Additional gamma-ray detector specifications that users may encounter in product descriptions are explained below:

- **Detector size**: a larger detector offers a larger cross-sectional area which will capture a larger number of gamma-ray photons; a thicker detector is more likely to absorb all of the energy from high-energy gamma rays. Manufacturers may sometimes bundle multiple smaller detectors to achieve a large cross-sectional area.
- **Counting efficiency:** Count rate above background is the quantity typically used in search operations. Detectors with a higher counting efficiency will register more counts for the same number of incident photons, and therefore have higher detection capability. Counting efficiency is typically expressed in terms of percentage (e.g., 5% counting efficiency) and refers to the number of counts registered by the instrument for a given number of gamma rays of a specified energy striking the detector.[8]
- **Energy Range:** Detector efficiency varies with the energy of the gamma ray, so products typically specify the range of gamma ray energies they can detect in terms of keV or MeV. The natural radiation background spectrum including thorium decay products would be sufficiently covered by systems capable of detecting gamma rays with energies in the range from 50 keV to at least 2.7 MeV. (All the systems included in this report are specified by the manufacturers to cover at least that range.)
- **Exposure or dose rate range:** while count rate measurements are useful for source detection, a measurement of the exposure or dose rate is needed to compare measurements taken at difference locations and times, and for radiation safety during response operations. Detectors capable of measuring low exposure rates, i.e., less than 10 micro R/h (μR/h), can measure radiation near background levels. For use after a radiological incident, detectors capable of measuring higher levels would be needed to establish radiation control perimeters and inform response activities. For use in the “hot zone” or “dangerous radiation zone” as defined by the National Council for Radiation Protection and Measurements, detectors would need to be capable of measuring radiations fields greater than 10 mR/h or 10 R/h, respectively.
- **Energy resolution:** for products capable of radionuclide identification, the energy resolution is expressed as a percentage, where a lower value corresponds to a better capability of distinguishing sources. For NaI detectors the resolution is about 7–8%.
- **Energy calibration and stabilization:** a known source of radiation is used to provide a reference energy to calibrate and stabilize the detector’s energy response as the temperature changes.

[7] While systems using HPGe detectors were not included by vendors responding to the Request for Information for this report, they may be available. For example, see www.ortec-online.com/products/nuclear-security-and-safeguards/mobile-detection-systems.
[8] The 662 keV gamma-rays of ^{137}Cs are conventionally used in product specifications of gamma-ray detection efficiency.

Most systems self-calibrate during startup and check periodically (or monitor for temperature changes) by calibrating on the detection of ^{40}K, one of the isotopes of naturally occurring potassium, that is present in the environment. Since ^{40}K is primarily found in rocks and soils, systems that rely on it may stabilize more slowly if the instrument is already airborne or on the water when first turned on. Instead, an embedded radioactive source (such as potassium chloride (KCl) or sodium-22, (^{22}Na)) may be used for marine applications, or source-less gain stabilization based on thermal management and software stabilization algorithms may be applied.

2.1.2 Neutron Detectors

Neutrons are uncharged particles that are emitted during nuclear fission and by industrial neutron sources. Some radionuclides, particularly californium-252 (^{252}Cf) and plutonium-240 (^{240}Pu), can fission spontaneously, emitting neutrons. Since the special nuclear material (SNM) plutonium always contains some ^{240}Pu, it emits a significant number of neutrons. Consequently, detection of neutrons in quantities above background indicates a possible threat, including the possible presence of a nuclear weapon.

Neutron detection may be applicable in discovery/interdiction missions, but it is not typically required for incident response. This can be true even if the event involves dispersal of material from an industrial neutron source, since neutron emitters also emit gamma radiation, which is easier to measure.

Responders may want to have high sensitivity neutron detectors in mobile systems for discovery and interdiction missions to aid in detecting and identifying such threats. To be most useful for such missions, relatively efficient cylindrical detectors, such as ^{3}He proportional counters, should have minimum dimensions similar to 2” diameter x 20” long, cross-sectional area totaling at least 40 in^2 (approximately 260 cm^2) or a volume of at least 1 liter, and a sensitivity of at least 170 counts per neutron/cm^2. Planar detectors such as ^{6}Li+ZnS scintillators should have at least as large an active area, 40 in^2 or more, to have a similar sensitivity. Neutron detection is optional for mobile radiation detection systems included in this report, and some of the products included may not have sufficiently sensitive neutron detection capability to be useful in discovery and interdiction missions.

Neutron detection has two main difficulties and one big advantage. One difficulty is that neutrons tend to interact with most materials much less frequently than gamma rays do, so they make fewer detectable pulses in a detector. The other difficulty is distinguishing the ionization pulses produced by neutrons from the much more frequent pulses produced by gamma rays. The advantage is that very few materials emit neutrons, so there are far fewer nuisance alarms, and the neutron background is much lower than the gamma background.

The most common and efficient way to detect neutrons is to first slow them down from fission energies (fast neutrons) to very low energies (thermal neutrons) by passing them through a moderating material such as high-density polyethylene (HDPE). They can then be readily captured by certain materials such as helium-3 (^{3}He), lithium-6 (^{6}Li), and boron-10 (^{10}B), which absorb thermal neutrons thousands of times more effectively than most other materials. When these materials capture neutrons, their atomic nuclei fragment into highly ionizing charged particles. In scintillators or gas-filled detectors, the charged particles from neutron capture produce a large signal that can be distinguished from the smaller signal produced by gamma rays. In some detectors, the pulses produced by the charged particles from neutron capture have a different duration than the pulses produced by gamma rays and pulse-shape discrimination electronics is used to further distinguish neutrons from gamma rays.

The effectiveness of a neutron detector has two aspects. The first is the sensitivity of the detector – how many neutrons it can detect in a given neutron fluence (neutrons per unit area) – which depends on the area of the detector and its efficiency in detecting the neutrons that pass through it.[9] Typical units for neutron sensitivity are counts per neutron per area (cm^2). A system's neutron sensitivity may also be specified in terms of its ability to detect a source with a given neutron emission rate and moderation passing by at a specified distance and speed. To meet the neutron detection part of the Institute of Electrical and Electronics Engineers (IEEE) N42.43 "Standard for Mobile Radiation Monitors Used for Homeland Security," [1] a mobile detection system must produce a neutron alarm when a source emitting 20,000 fission neutrons/s and surrounded by a 4 cm thick HDPE moderator passes by the system at a speed of 2.2 m/s (4.9 miles/h) at a distance of 3 m (9.8 feet).

The other aspect of neutron detector effectiveness is how well the neutron detector rejects counts produced by gamma rays or from vibration. To meet the IEEE N42.43 standard [1] (additional information in section 2.3), a detection system must not produce a neutron alarm in a 10 mR/h gamma radiation field and must pass its neutron detection sensitivity test in the presence of a 10 mR/h gamma radiation field.

The most common type of neutron detector in use is the ^3He proportional counter. A proportional counter is a gas-filled detector similar to a GM counter but operated at a lower voltage so the size of the current pulse from each particle detection is proportional to the number of ions produced in the gas. Helium-3 proportional counters are particularly effective due to their high sensitivity to neutrons and low sensitivity to gamma rays. Parameters used to characterize proportional counters include volume and pressure, where higher volumes or higher pressures would be expected to be more sensitive. Helium-3 is a rare isotope of helium. Its widespread use in neutron detectors led to a supply shortage and the development of alternate technologies using ^6Li and ^{10}B, which are used in many of the systems described in this report.

Thin layers or coatings of ^6Li and ^{10}B can be used in proportional counters or on scintillators to make efficient neutron detectors. The charged nuclear fragments from neutron capture can travel only a few micrometers (μm) in solid matter before they lose their energy and stop, so the layer of neutron-absorbing material must be thin to allow the charged particles to escape into the gas or scintillator. To make a sensitive neutron detector, the area of the detector must be large to compensate for the thinness of the neutron absorbing material. One way to achieve a large area of coating in the traditional cylindrical proportional counter shape is to use many long, thin (4 mm diameter) proportional counters bundled together into a larger tube that can replace a ^3He proportional counter. Boron-10 carbide ($^{10}B_4C$) is used as the coating material in such "boron-coated straw" detectors. Another way to achieve a large area in a proportional counter is to use a planar array of many charge-collecting wires in parallel—a multi-wire proportional chamber. A thin foil of ^6Li is used as the other electrode to make a large area neutron-detection panel. Lithium-6 and boron-10 can also be used to make large area neutron detectors by coating the material on to a silver-doped zinc sulfide (ZnS(Ag) or just ZnS) scintillator, which emits blue light in response to the charged nuclear fragments from neutron capture. The ZnS scintillator is not transparent to the light it emits, so the coated scintillator is itself coated onto a transparent sheet of glass or plastic or dispersed in a transparent medium to transmit the light to a photomultiplier. Lithium-6 can also be incorporated into transparent scintillators, including NaI crystals and panels of scintillating glass fibers.

[9] Although the size of the moderator can influence the effective area of a detector, specifications of the active area of a thermal-neutron detector typically do not include the moderator.

Large lithium- and boron-based neutron detectors that are rugged enough to use in mobile systems can be manufactured at relatively low cost.

Neutron Detection Sensitivity: The products covered in this report use different types of neutron detectors, and their vendors specify neutron detection sensitivity in different ways, making it difficult to compare the sensitivity of their neutron detectors with one another. The American National Standards Institute (ANSI)/IEEE N42.43 standard [1] specifies minimum performance requirements for neutron detection, but neutron detection is optional in the standard, so a manufacturer may legitimately claim a system meets the standard (based on its gamma-ray detection) even though its neutron detection has not been tested. Potential customers should ask for verification of what tests in the standard the product has passed.

For products whose neutron detectors have not been tested to the standard, some manufacturers give the neutron detector sensitivity in counts per neutron/cm^2 or in the same units expressed as "cps/nv."[10] Use of the latter expression implies that the given sensitivity is for a thermal-neutron detector detecting thermal neutrons. Some manufacturers just give the dimensions of the neutron detector, with or without its moderator. For a given efficiency of neutron detector, the sensitivity is proportional to the active cross-sectional area. While different types of detectors, for example ^{3}He proportional counter vs. ^{6}Li+ZnS scintillator, cannot be directly compared, active area can provide a rough proxy for relative neutron sensitivity, where larger areas would be expected to be more sensitive. Active volume can also be used to compare relative sensitivity for detectors with sensitivity throughout their volume, such as ^{3}He proportional counters.

2.1.3 Detection Distance

In using mobile radiation detectors to search for potential nuclear and radiological threats, one of the most important characteristics is how far away the system can detect and identify a threat source. There is no single answer for the detection distance of a system because it depends on the amount of radioactivity in the source as well as the sensitivity of the detectors and the identification software. This is analogous to asking how far away someone can hear and understand a sound—the answer is farther for a shout than for a whisper.[11] Detection distance also depends on the time the system is near the source, the energy spectrum of the gamma rays emitted by the source, and the level of background radiation. A further complication is that radiation detection is fundamentally a random statistical process—under the same conditions, the system may alarm some of the time and not alarm some of the time—so tests actually measure the probability of detection, not just yes or no.

People evaluating mobile systems often want to know the detection "range" or "stand-off distance." Using these terms for detection distance can cause confusion. When people ask to know a system's detection range, they might mean detection distance, but "range" also means the span of values of a capability or environmental condition. For example, mobile radiation detectors need to measure a range of exposure rates, detect a range of gamma-ray energies, and operate over a range of temperatures. "Standoff distance" has also been used to mean detection distance, but sometimes, especially the maritime realm, it means simply whatever distance is between vessels.

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[10] "cps/nv" is another way to express neutron sensitivity in counts per (thermal) neutron flux. In typical units, it is equivalent to cps/(neutrons/cm^2 s). The "v" is for velocity (mean velocity of the neutrons in cm/s), and "n" is the neutron density in neutrons per cm^3, so "nv" is (neutrons/cm^3)(cm/s) = neutrons/cm^2 s. Expressing neutron sensitivity as "cps/nv" only really makes sense for thermal neutrons, where the mean velocity is known.

[11] This is illustrated by an experience that one of the authors of this report has observed: a system detected an unshielded 100 curie industrial radiography source from a distance of over 1½ miles but did not detect a nearby 1 microcurie source within a lead shield at a distance of about 16 feet.

As described in section 2.3, the ANSI/IEEE N42.43 [1] and the DHS Domestic Nuclear Detection Office (DNDO) Technical Capability standards for aerial [2] and vehicle-mounted [3] mobile detection systems describe tests to detect specific radioactive sources at source-to-detector distances that are intended to represent distances in typical applications.

2.1.4 Location tracking

The ability to associate spatial location with radiation measurement is a defining feature of the mobile radiation detection systems covered here. A global navigation satellite system such as the U.S. GPS provides the geolocation to a GPS receiver. Some mobile radiation systems have the receiver integrated into the detectors or provide an external antenna attached via cable, while others use the GPS receiver embedded in the associated user-interface tablet or a smart phone which may also be used for vehicle navigation. The position data may be stored or used in real time, as discussed in section 2.1.5.

2.1.5 User Interface, Data Analysis and Display

All the vehicle-borne systems in this report include software that collects data from the detectors and monitors their functioning. A user interface allows the user to control the system and to monitor and interpret survey results. Data may be monitored in real time or saved for later review. The data display may include the dose or count rate and alarms for rates above user-set thresholds. In addition to alarm indications to vehicle occupants, they may also transmit alarms to a remote command center or a handheld device. Some data analysis systems for airborne measurements are capable of calculating the corresponding measurements at ground level.

Rising and dropping count rate levels encountered while the detector system is moving (e.g., when driving past a radiation source) may be displayed on a histogram, that is, a visual data representation where line length corresponds to the numerical value of the data. In some systems the geolocation data is stored for later mapping, while others can generate maps in real time. Real-time mapping can help users to see "hot spots," to ensure thorough coverage of the survey area, and to note trends in environmental radiation exposure rates. This information is typically displayed through color-coded dot maps (sometimes called "breadcrumbs"). The dots' colors indicate relative radiation exposure rates and their location on a map shows the path surveyed. These breadcrumbs can help the operator (and those reviewing the survey) to see "holes" in the survey pattern, as well as to identify locations that have already been adequately checked. Some systems generate contour maps or smoothed "heat maps," that, like the dot maps, use color-coding to display relative radiation exposure rates. Thus, even if the radiation exposure rate never rises high enough to cause an alarm, the operator can still see locations exhibiting elevated radiation levels that might warrant a closer examination.

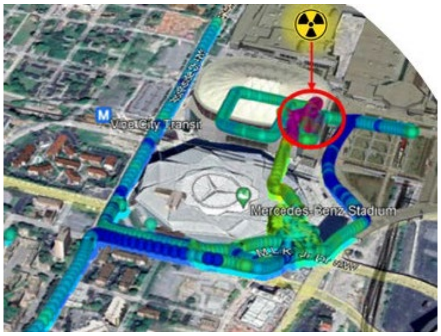

Figure 2-1 Example of breadcrumbs map
Image credit: Radiation Solutions Inc.

For systems with radionuclide identification capabilities, the software analyzes the data to produce a spectrum, identifies peaks and compares them with radionuclides contained in the system's nuclide library. The data display might include the gamma spectrum detected in the last data integration period (usually 1 second) and nuclide identifications and attributions (e.g., industrial, medical, natural, etc.). It may also show a "waterfall" display, where constantly changing rows of dots, color-coded by energy, show the relative number of counts the detector picked up at different energies.

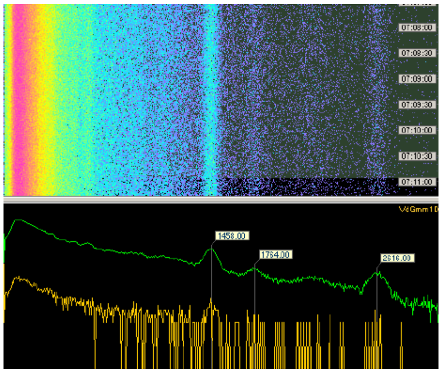

Figure 2-2 Example of spectrum (bottom) and waterfall (top).
Image credit: Radiation Solutions Inc.

The user interface is typically accessible on a laptop, tablet or other mobile device located within the vehicle. The device may be connected to the detector modules through a wired or wireless connection. System data may also be transmitted to a remote monitoring location or to "reachback" using the device's communication method (e.g., 3G/4G LTE)[12], or an alternate transmission method. The system's software may export data in multiple formats for different uses or in the format specified in ANSI/IEEE N42.42-2020 "American National Standard Data Format for Radiation Detectors Used for Homeland Security" [4] (see Section 2.3).

Some mobile radiation detection systems may be configured to send data to RadResponder, a federally funded software platform that can collect, map, and manage radiological data from various types of equipment during an emergency.[13] This platform is designed to be the national standard for management of data and resources during a multijurisdictional response to a radiological or nuclear emergency by facilitating information sharing at all levels of government. RadResponder is provided free to all federal, state, local, tribal, and territorial response organizations and can be accessed on smartphones and tablets (iOS, Android, Windows) and via the web at www.radresponder.net. RadResponder collects and stores continuous exposure rate data for up to a year and can provide alerts for exceeded exposure rate thresholds. It includes an option for mobile survey data for integration with vehicle-borne detectors. The RadResponder website provides a list of equipment that is integrated with RadResponder, as reported by the manufacturers.[14] Agencies that require system integration with RadResponder should verify its implementation with the manufacturer or vendor and test the equipment before purchasing.

2.1.6 Mounting Systems

The mobile radiation detection systems covered in this report can be used in a variety of configurations on land, sea, and air. Each operating environment involves unique considerations for positioning of the detector.

Some mobile radiation detection systems are mounted directly into the vehicle, boat, or aircraft in which they will be used and while system components can be removed for repair or replacement, the process may be laborious and require special tools or mounting fixtures.

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[12] "Reachback" is a capability in which spectra are sent to experienced personnel for analysis.
[13] RadResponder resulted from collaboration between the Federal Emergency Management Agency, Department of Energy National Nuclear Security Administration, the Environmental Protection Agency, the Defense Threat Reduction Agency, and the DHS Science and Technology Directorate.
[14] See www.radresponder.net/#about/equipment. When checked on 01/03/2023, the list of integrated equipment did not include any mobile radiation systems. Additional information may be available by contacting support@radresponder.net.

An airborne system is typically designed to be mounted temporarily rather than built into the aircraft but must be tightly fixed in place to keep the detectors from shifting during flight.

Other systems are designed to be highly portable and configurable (including adding or removing detectors for different missions) and can easily be moved from vehicle to vehicle without the need for special tools or mounts other than rope or straps.

When mounted in (or on) cars, trucks, or boats, detectors placed on each side of a vehicle can help the operators understand which side of the vehicle a source is on. Vehicle-borne systems might have lower sensitivity to sources directly ahead or directly behind the vehicle due to the small cross-sectional area of the detectors from the front and back, (e.g., for a 2-inch x 4-inch x 16-inch detector mounted on the left, compare 8 square inches for detection in front of the vehicle versus 64 square inches to the left side). Systems that use two or more detectors on each side of a vehicle may stack one detector above the other with the broad side facing outwards in order to maximize the cross-sectional area facing potential sources. Placing the detectors at the same level, one behind the other, would reduce detection effectiveness as the outboard detector partially shields the inboard device. Mounting one or more detectors on each side of a vehicle can give some directional information as the detector on the same side of the vehicle as the source would have a slightly higher count rate due to its relative proximity compared to the detector(s) further away. However, this effect is not always reliable (e.g., in the case of a distant source or when a source is directly in front of or behind the vehicle).

Material between the detector and the radiation source (e.g., the detector enclosure and the side of the vehicle for detectors that are carried internally) can reduce the strength of the radiation field, reducing detector sensitivity. Therefore, to the extent it is practical, detectors are mounted to minimize shielding from the vehicle itself, its engine, batteries, or other components. The denser the intervening material the more the radiation field will be reduced. In addition, high atomic number materials such as iron or tungsten interfere more than do low atomic number materials such as aluminum or carbon fiber. This effect is especially noticeable when trying to detect and identify radionuclides that emit low-energy gammas, such as Am-241. Because of this, manufacturers often use low atomic number materials for detector enclosures to permit detection and identification of low-energy gammas. Detectors may also be mounted on top of the vehicle.

When mounted in maritime vessels, detectors are subject to vibration, water, and corrosion. They require shock mounting, water-tight and saltwater spray-resistant cabinets, instrument cases and cable connections, and frequent inspections to minimize instrument damage. The hull of the vessel performing the survey and of vessels being surveyed, and the water between them, can attenuate radiation. Mounting maritime detectors well above the deck can minimize such shielding to facilitate monitoring of suspect vessels. Some systems may be temporarily installed for short-term missions or mounted in the boat interior as they are not hardened for long-term external deployment.

The presence of strong electromagnetic fields and/or electromagnetic radiation (e.g., radio or radar signals) can interfere with the accurate collection and processing of the electrical pulses that are produced by the normal operation of many radiation detectors. This interference can cause spurious “extra” counts, elevating radiation dose rate readings. Given the prevalence of radar and radio usage in the maritime environment, systems intended for maritime use typically take measures to reduce this interference. This may include shielding with electrically conductive materials, using coaxial cables, grounding the system, use of electronic filters, or other noise- and interference-reduction methods. The detector(s) and system cables should be mounted out of the primary beam of the vessel’s radar if possible.

2.2 Standards

Several standards that specify minimum performance and other criteria for mobile radiation detection systems used for homeland security are listed below. Many manufacturers cite compliance with one or more of these standards. The standards describe tests to detect specific radioactive sources at source-to-detector distances that are intended to represent distances in typical applications. For example, the test distance specified in IEEE N42.43-2021 for a vehicle-mounted mobile system is 3 meters from the outside surface of the vehicle.[15] To pass the radiological tests at a 3-meter distance of closest approach, the system must detect sources of several radionuclides, moving at a relative speed of 2.2 meters/second in 117 trials out of 120 [1]. The Technical Capability Standard for Vehicle Mounted Mobile Systems specifies about the same test distance, with adjustment for weaker or stronger test sources [3]. In the Technical Capability Standard for Aerial Mounted Radiation Detection Systems, the airborne test distance (altitude above ground) is 100 feet directly above the test source, and the SNM test source is equivalent to 400 grams of weapons-grade plutonium [2].

- IEEE N42.43-2021, "IEEE Standard for Mobile Radiation Monitors Used for Homeland Security." This standard includes performance criteria for tests of the detection and/or identification of radionuclides, and indication of the presence of neutron radiation. It also includes tests and requirements associated with the expected electrical, mechanical, and environmental conditions while in use, such as temperature, humidity, moisture and dust, electromagnetic interference, electrostatic discharge, vibration, and impact. It covers land-based systems but does not address boat or aerial platforms.
  Available at https://ieeexplore.ieee.org/document/9650801
  This is a revision of ANSI 42.43-2016, "American National Standard Performance Criteria for Mobile and Transportable Radiation Monitors Used for Homeland Security." Products in this report indicating compliance with N42.43 may be referring to the 2016 version of this standard.

- "Technical Capability Standard for Vehicle Mounted Mobile Systems," Domestic Nuclear Detection Office, Document#: 500-DNDO-119430v0.00 (August 2013). This standard sets minimum requirements for vehicle-mounted mobile systems for the detection of radioactive material. It covers radiological, climatic, mechanical, electric and electromagnetic, and documentation requirements and the associated test methods.
  Available at www.dhs.gov/sites/default/files/publications/vehicle-mms-tcs-08-2013.pdf.

- "Technical Capability Standard for Aerial Mounted Radiation Detection Systems," Domestic Nuclear Detection Office, Document#: 500-DNDO-119430v0.00 (February 2017). This standard covers testing of aerial detection and identification capabilities for gamma-emitting radioactive material to establish detection performance requirements. It includes environmental and mechanical requirements which may affect the performance of the radiation detector systems while flying, including radio frequency interference, vibration, and temperature.
  Available at www.dhs.gov/sites/default/files/publications/aerial-mrs-tcs-02-2017.pdf.

[15] In partnership with the DHS, selected IEEE/ANSI standards are provided at no cost through the IEEE GET Program, at https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=83

- IEC 63121, “Radiation Protection Instrumentation – Vehicle-Mounted Mobile Systems for The Detection Of Illicit Trafficking Of Radioactive Materials is an international standard published by the International Electrotechnical Commission.
  Similar to IEEE N42.43, it applies to land-based systems and does not address aerial or maritime systems. It sets minimum requirements for vehicle-mounted mobile systems for the detection of radioactive material and establishes radiological, climatic, mechanical, electric and electromagnetic, and documentation requirements, and the associated test methods.
  Available at https://webstore.ansi.org/standards/iec/iec63121

While the standards listed above are those most relevant to mobile radiation detection systems, a few of the products included in this report cite compliance with other homeland security radiation detection standards, namely N42.33 “American National Standard for Portable Exposure Rate Meters for Homeland Security” [5] and N42.34 for “Hand-held Instruments for the Detection and Identification of Radionuclides.” [6]

The following standards provide specifications for data formatting and environmental enclosures.

- ANSI/IEEE N42.42-2020, “American National Standard Data Format for Radiation Detectors Used for Homeland Security.” [4] This document specifies a standard Extensible Markup Language (XML) data format for both required and optional data that is generated by radiation measurement instruments. Data display and analysis software tools that are available at laboratories and reachback centers are designed to read ANSI N42.42-compliant data files. The use of a standard data format allows many software tools to read data from the radiation measurement instruments of all vendors that comply with the standard.
  Available: https://ieeexplore.ieee.org/document/9264644
- ANSI/International Electrotechnical Commission (IEC) IEC 60529-2020, “Degrees of Protection Provided by Enclosures” (IP Code) [7]. Many vendors report ingress protection (IP) ratings for the enclosures used in their systems. The rating is specified as “IP” followed by two numbers that are codes for the degree of dust protection and water protection, respectively. Most products in this report specify an IP rating with a first digit of 6 (dustproof). For the second digit regarding water protection:
  - 5 means protection from low pressure water jets from any direction
  - 6 means protection from high pressure water jets
  - 7 means protection from temporary water submersion to a depth of up to 1 meter
  - 8 means protection from continuous submersion in water to depth beyond 1 meter

  Available: https://webstore.ansi.org/standards/nema/ansiiec605292020
- The National Electrical Manufacturers Association (NEMA) standard NEMA 250 “Enclosure Types” [8] uses an alpha-numeric designation (different from the IP Code) to define types of enclosure ratings and addresses other requirements including corrosion resistance and the effects of icing. Appendix A provides more information on this standard.
  Available: www.nema.org/standards/view/nema-250-enclosure-types

3.0 PRODUCT INFORMATION

This report provides information on 24 mobile radiation systems from 16 manufacturers. Most are customizable and would be configured to user specifications. Prices are dependent on user-selected options, ranging from about $33,000 to $414,800. The products are listed alphabetically by manufacturer in Table 3-1, summarizing key specifications. Additional information on each product is provided in the pages that follow. Product information was obtained directly from manufacturers, vendors, and their websites from July 2021–November 2022 and has not been independently verified by the SAVER Program.

Product features – listed in column order as shown in Table 3-1 – are defined as follows:

Company and Product: manufacturer (or vendor) in bold font and the product name or model number.

Platform: type(s) of vehicle on which the system is designed to be mounted or integrated, where "L" means land, "W" means water, and "A" means air. This report does not include systems designed for unmanned vehicles.

Gamma Detectors: number and types of gamma detectors that may be included with the system (NaI, CZT, LaBr, CLLBC, or PVT), with detector volume in liters (L) shown in parenthesis. If provided, the modular weight and cost is also listed.

High-Range Gamma Detector: additional gamma detector (GM, ion chamber (IC), or small PVT) available to extend the system's measurement range for use in response operations. If provided by the manufacturer, the price is listed also.

Upper Range Exposure or Dose Rate: the highest gamma radiation field that the system is capable of measuring. This value corresponds to the maximum range of the secondary gamma detector, where available. If a system has two options for secondary detectors, two values are listed. If no secondary detectors are available, the upper range exposure or dose rate for that system corresponds to that of the gamma detector(s) listed in the third ("Gamma Detectors" column. Values are reported in R/h, rad/h, or rem/h for ease of comparison.[16]

Neutron Detector: type of neutron detectors available: ^{3}He proportional counter (volume in liters); ^{6}Li + scintillator (volume in liters or dimensions of active area in inches). Where the number of neutron detectors is specified, the detector type is preceded by a number. When available, the modular weight and cost are also listed. If the dimensions of a proportional counter were provided in inches, the volume in liters was calculated by NUSTL

RadResponder: compatibility with the information-sharing software developed as the national standard for managing data and resources during a multijurisdictional response to a radiological or nuclear emergency. The letter "Y" denotes the product is readily compatible with RadResponder, while "Y" in parentheses "(Y)" indicates this capability is available on request. The letter "N" indicates that RadResponder capability is not currently available.

Additional Information: other features that are included or optionally available (i.e.,) real-time radiation mapping, other sensors, algorithmic source localization, specific isotope alarms or calculations) and, when available, the weight and approximate cost of selected options as noted.

[16] For gamma rays it is common to approximate that units of R, rad and rem are roughly equivalent, though they correspond to different radiation quantities (exposure, air kerma, and personal dose equivalent, respectively.)

Table 3-1 Product Comparison Matrix

Manufacturer and Product	Platform(s)*	Gamma detectors (volume) Module weight Cost	High Range Gamma Detector Cost	Upper Range Exposure Rate or Dose Rate†	Neutron Detector (volume) Module weight Cost	Rad-Responder	Additional Information
Arktis Detection Systems Inc. MODES Mobile Detection System	L	NaI (2-L, 4-L) 55 lb PVT (≥10-L) 66 lb	GM more options	500 rem/h	^{6}Li+^{4}He (14-L) 88 lb	N	Real-time radiation map Daylight color camera, Distance measurer, Night camera License plate recognition $70,000–$300,000
Berkeley Nucleonics Corp. SAMmobile 150 (RD-150) Mobile Radiation Detection System	L, W, A	NaI (2-L, 4-L) $44,000 (2-L) $57,000 (4-L)	GM	10 rem/h	^{3}He (0.08-L, 0.14-L) $13,800 (0.08-L) $19,600 (0.14-L)	Y	Module weight 44 lb, includes gamma and neutron detectors
Bubble Technology Industries FlexSpec X8400 4 GN Mobile	L	≤ 14 NaI (2-L) 4 NaI (2-L) 235 lb	GM	500 rem/h	≤ 14 ^{6}Li+ZnS (5”x4”x1”) 4 ^{6}Li+ZnS	(Y)	Module weight 59 lb Real-time radiation map $185,000 (4 gamma + neutron modules)
Bubble Technology Industries FlexSpec X8400 2GN Maritime	W	2 NaI (2-L)	GM	500 rem/h	2 ^{6}Li+ZnS (5”x4”x1”)	(Y)	Includes 2 modules Total weight 125 lb
Bubble Technology Industries FlexSpec X8400 4GN Airborne	A	4 NaI (2-L)	GM	500 rem/h	4 ^{6}Li+ZnS (5”x4”x1”)	(Y)	4 detector modules in an externally mounted pod Total weight 215 lb Internal mounting options available
CAEN Technologies GAMON Mobile	L, W, A	NaI (2-L, 4-L) 62 lb (4-L) $56,155 (4-L)	GM	100 1000 rem/h	^{6}Li+ZnS (3.5-L)	Y	Real-time radiation map Isotope alarm thresholds $75,000 for 4-L NaI + GM + neutron
Gamma Reality Inc. LAMP-Mapper	L	NaI (1-L) 20 lb CZT (0.02-L) 10 lb CLLBC (1-L) 30 lb	GM	1000 R/h	CLLBC (1-L)	(Y)	Real-time radiation map Lidar and visual camera 3D visualization $110,000 for LAMP

Manufacturer and Product	Platform(s)*	Gamma detectors (volume) Module weight Cost	High Range Gamma Detector Cost	Upper Range Exposure Rate or Dose Rate†	Neutron Detector (volume) Module weight Cost	Rad-Responder	Additional Information
Mirion Technologies Inc. SPIR-Ident Mobile Advanced Spectroscopy Platform	L, W, A	≤ 4 NaI (2-L,4-L) $45,000 (2-L)	GM	1 rem/h	1 ^{10}B+ZnS (2”x28”) 55 lb	N	Total weight 77 lb (two 2-L +GM) Real-time radiation map Calculates surface radiation dose rate and select nuclide concentration $45,000–$105,000
NUVIA Dynamics Inc. (JWG International, Ltd) RADPatrol-SO	L, W, A	2 NaI (4.2-L) 139 lb	GM	1 R/h	^{6}Li+ZnS (1.5-L) 55 lb	N	Real-time radiation map Calculates radioisotope activity $133,000–$150,000
Ortec RadEAGLE Mobile Search System	L, A	NaI (1-L and 2-L) 22 and 38 lb PVT (10-L)	N	100 rem/h	^{6}Li+ZnS (4”x8”) 18 lb	Y	Real-time radiation map $100,000–$150,000
Physical Sciences Inc. (PSI) PERM-M	L, W	1 NaI (2-L) 39 lb $33,200–$34,860	N	1 R/h	1 ^{6}LiF+ZnS (21”x12”) 94 lb $40,404–$42,420	N	Real-time radiation map Optional contextual video $15,200–$15,960
Physical Sciences Inc. (PSI) PERM-Mobile	L	2 NaI (2-L)	N	1 R/h	2 ^{6}LiF+ZnS (21”x12”) 94 lb	N	Total weight 425 lb Real-time radiation map $183,000–$192,152 L/R video contextual assessment Video $15,200–$15,960 IR-camera option $21,400–$22,470
Physical Sciences Inc. (PSI) Mobile Urban Radiation Search (MURS) 2.0	L	6 NaI (2-L)	N	1 R/h	2 ^{6}LiF+ZnS (21”x12”) 94 lb	N	Real-time radiation map Optical, infrared thermal sensors Algorithm for automated source attribution bounding box on source carrier $384,431–$414,158 Vehicle integration $30,000–$33,000

Manufacturer and Product	Platform(s)*	Gamma detectors (volume) Module weight Cost	High Range Gamma Detector Cost	Upper Range Exposure Rate or Dose Rate†	Neutron Detector (volume) Module weight Cost	Rad-Responder	Additional Information
Radiation Solutions Inc. (RSI) RS600	L, W, A	NaI (2-L, 4L) 19-50 lb $35,000–$40,000	GM $2,500–$3,500	25 rem/h	^{3}He (0.5-L, 1-L, 1.6-L) 18–50 lb ^{6}Li+ZnS (9.4-L) 60–125 lb 30–40 ^{10}B straws 50–64 lb $30,000–$100,000	Y	Real-time radiation map RadResponder alarm forwarding Source localization Visual object tracking 360° directionality
Rapiscan Systems Inc GMS-4x4-Fixed	L	4 NaI (2-L) 50 lb	‡	2 R/h	4 ^{6}Li+ZnS (10.5-L total)	(Y)	Real-time radiation map Permanent van-installed detector panels
Rapiscan Systems Inc. GMS-4x4-Conf	L, W, A	4 NaI (2-L) 50 lb	‡	2 R/h	4 ^{6}Li+ZnS (10.5- L total) 50 lb	(Y)	Real-time radiation map Modular format $30,000–$300,000
Scienta Envinet MONA	L, W, A	NaI (1-L, 2-L, 4-L) 42 lb (1-L) 46 lb (2-L) 64 lb (4-L) $39,000–$47,450 (4-L)	GM $5,750	1000 rad/h	^{3}He (1.5-L) 40 lb ^{6}Li+Scint (1.5-L) 19 lb, no moderator 70 lb, with moderator $10,550	Y	Real-time radiation map Calculates total gamma dose rate and dose rate for each identified nuclide
Symetrica Inc. Discovery Mobile 3x3+NNS	L	3 NaI (1-L total)	Small PVT	50 rem/h	1 ^{6}Li+ZnS	(Y)	Total weight 57 lb Real-time radiation map $98,000
Symetrica Inc. Discovery 180	L, W§	2 NaI (2-L)	Small PVT	50 rem/h	2 ^{6}Li+ZnS	(Y)	Total weight 270 lb Real-time radiation map Optional lead shielding for increased directionality $148,500

Manufacturer and Product	Platform(s)*	Gamma detectors (volume) Module weight Cost	High Range Gamma Detector Cost	Upper Range Exposure Rate or Dose Rate†	Neutron Detector (volume) Module weight Cost	Rad-Responder	Additional Information
Symetrica Inc. Discovery Mobile 360	L	6 NaI (2-L)	Small PVT	50 rem/h	4 ^{6}Li+ZnS	(Y)	Real-time radiation map 360° day/night video cameras for radiation visualization $289,000 includes Ford Ranger vehicle
Technical Associates MoRad Mobile Radiation Detection System and Super MoRad	L	≤ 6 NaI (1-L, 4-L) ≤ 7 NaI (1-L, 4-L)	IC $3,325	1000 R/h	^{10}B:ZnS (0.1-L) $4,405	Y	Total weight 120lb Real-time radiation map $75,000–$125,000 for MoRad
Textron (TerraTracker) ARAM (Adaptable Radiation Area Monitor) (standard model specs)	L, W, A	2 NaI (2-L)	N	–	2 ^{3}He (0.22-L) 25 lb	Y	1 module with 1 gamma and 2 neutron detectors, weight 75 lb 2 modules, each contains 1 gamma, 2 neutron detectors, weight 150 lb Real-time cps radiation map (not exposure or dose rate) $150,000
Thermo Fisher Scientific, Inc. Thermo Scientific Matrix Mobile ARIS	L	2 NaI (2-L) 50 lb ea + 2 PVT (7-L)	N	–	^{3}He (1.65-L)	(Y)	Total weight 350 lb Realtime radiation map $60,000–$70,000
Thermo Fisher Scientific, Inc. Matrix Maritime RADspec	W	NaI (2-L) 50 lb	N	10 mrem/h	^{3}He (0.022-L)	(Y)	Real-time radiation map $150,000–$250,000

Notes: * In this column, **A** indicates an air-based platform; **L,** a land-based platform; **W,** a water-based platform.

† R/h is an exposure rate; rad/h, a dose rate, and rem/h , a personal dose equivalent rate.

‡ Products from this vendor use the neutron detector to measure gamma exposure rate up to 2 R/h; GM option available upon request.

§ Customized modular systems for maritime deployment are not specified here but are available

– Indicates information was not available

N Indicates product does not have this feature

Y Indicates system is currently ready or compatible with RadResponder

(Y) Indicates capability available on request

3.1 Arktis Detection Systems Inc. MODES Mobile Detection System

PLATFORM: LAND

The MODES system is a modular, customizable gamma and neutron detection system that may be permanently installed or temporarily fitted in a land-based vehicle. A rooftop luggage carrier option is available. A single detection module can contain one or more types of detectors, and multiple modules can be arranged to achieve the desired performance. A typical two-sided configuration has four gamma, eight neutron, and one control module.

Figure 3-1 MODES
Image credit: Arktis Detection Systems

Gamma Detectors:
NaI(Tl): 2- or 4-liter volume
Photon energy: 30 keV–3 MeV
Calibration stabilized to natural ^{40}K
Directionality: Left–right
Module weight: 55 lb

PVT: 10-liter or larger
Module weight: 66 lb including shielding

High Dose Rate GM:
Upper range: 5 Sv/h
Module weight: 2.2 lb
(Other options available)

Neutron Detector: M800
^{6}LiF + ^{4}He scintillator: 14-liter active volume (non-Helium-3)
Cylindrical: 912 mm length x 144 mm
Module weight: 88 lb

Detection Capability Standards:
(ANSI)/IEEE N42.43
IEC 63121-2020A

Connectivity:
Detectors to user interface: wired or Wi-Fi
Data to remote server: GSM (encrypted) 3G/4G (SIM card required but not included), Wi-Fi, Ethernet
Data export: ANSI N42.42-compliant
RadResponder: not included

User Interface
Hardware: ruggedized laptop (included)
Software: gamma energy spectrum analysis, NORM rejection (optional)

Data Display and Analysis
Gamma measurement count rate in (cps)
Dose rate in µSv/h (other units possible)
Mapping: real-time dose rate color-coded dots overlaid on maps
Central alarm system: separate interface for live data from multiple streams, visual and acoustic alarms, and collective view of stored scans

GPS
Included, with internal or external antenna

Other Sensors
Included: daylight color camera, distance measurer
Optional: night camera with infrared (IR) floodlight, license plate recognition system

Power Options
Power over Ethernet
90-250 VAC, 47–63 Hz
12V DC
Optional Li-ion and spare battery pack with 4–8 hr operating time (~33 lb)

Environmental
IP45–IP65
Operating temperature: -22°F–122°F

Price
$70,000–$300,00 depending on configuration

3.2 Berkely Nucleonics Corp. SAMmobile 150 (RD-150) Vehicle Mounted Radiation Detection System

PLATFORM: LAND | WATER | AIR

Figure 3-2 SAMMobile RD-150
Image credit: Berkely Nucleonics

The SAMmobile 150 Vehicle Mounted Radiation Detection System consists of large volume gamma and optional compressed Helium-3 neutron detectors with shock-absorbent packaging in rugged plastic enclosures. Modules can be moved from one vehicle to another and positioned for optimized detection geometry or clandestine monitoring. The system is scalable with multiple detector options for land, water, or air vehicles. To provide electromagnetic shielding for maritime applications, the detector is surrounded by mu-metal shielding, and electronics are housed in an aluminum case.

Gamma Detectors
NaI(Tl): 2- or 4-liter volume
Photon energy: 20 keV–3.0 MeV
Calibration stabilized to natural ^{40}K
Directionality: Left–right
Upper range: 10 mrem/h
Module weight: 44 lb (2-liter)
Module size: 41” x 11” x 11.4”

High Dose Rate GM
Upper range: 10 rem/h
Included in SAMmobile RD-150 detector module

Neutron Detector
^{3}He: 0.08 liters, 3.5 atmosphere (atm) pressure, 17 counts per neutron/cm^2
Optional: 0.14 liters, 10 atm pressure, 34 counts per neutron/cm^2
Detector weight: <1 lb
Module weight: 44 lb (gamma and neutron detector)

Detection Capability Standards
Nuclide identification according to ANSI N42.34

Connectivity
Detector to user interface: wireless (Bluetooth (BT) or Wi-Fi)
Data to remote center: 5G or internet
Data export: ANSI N42.42-compliant
Immediate push-to-reachback function
RadResponder compatible

User Interface
Hardware: Windows-based tablet or smartphone
Software: Windows-based SAM III PeakGo

Data Display and Analysis
Isotope ID, classification, color-coded peaks and bar graphs
Real-time dose rate, count rate, live spectra, isotope ID, full spectroscopic reports and identification details
GPS-coordinate tagged reports
Color-contoured mapping (not in real time)
Photo/video reports append
Isotope help

GPS
Integrated in tablet or smartphone

Other Sensors
Camera, video and voice recording via wireless tablet, files can be appended to spectrum files

Power Options
Internal Li-ion battery: 8 hrs. continuous operation
Vehicle (12V)
Tablet Li-ion battery: 4 hrs. continuous or 8 hrs. intermittent operation

Environmental
IP65
Operating temperature: 5°F–122°F

Price
2x4x16 NaI (RD-150-2G1): $44,000
4X4X16 NaI (RD-150-4G1): $57,000
Optional ^{3}He (0.08-liter): $13,800
Optional other neutron (0.14-liter): $19,600

3.3 Bubble Technology Industries FlexSpec X8400

PLATFORM: LAND | WATER | AIR

Three models are available. The FlexSpec X8400 is a modular gamma and neutron detection system that can be mounted and transferred between land vehicles, while systems intended for use on boats or aircraft are provided with enclosures and mounting appropriate for maritime and aviation use but are not meant for transfer. Each detector module contains one 2-liter NaI(Tl) gamma detector and an array of ^{6}Li+ZnS neutron detectors. A single system can contain up to 14 gamma and neutron modules, which can be arranged to indicate the direction (left/right) of a source. Models include:

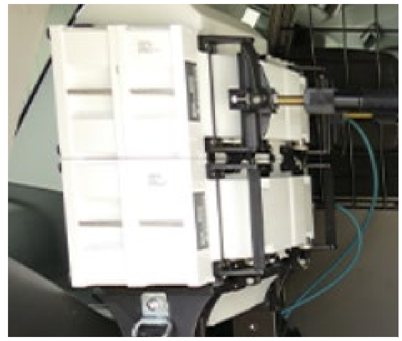

Figure 3-3 Detector Module
Image credit: Bubble Technologies

4GN Mobile for land vehicles, includes four detector modules, weighs 235 pounds

2 GN Maritime includes two detector modules, weighs 125 pounds

4 GN Airborne includes four detector modules in an externally mounted pod (internal mounting options also available), weighs 215 pounds

Gamma Detectors
NaI(Tl): up to 14, 2-liter volume
Photon energy: 20 keV–3000 MeV
Calibration stabilized to natural ^{40}K
Directionality: Left–right
Upper range: 1 mrem/h (10 µSv/h)
Module weight: 59 lb (one gamma and neutron module)

High Dose Rate GM
Upper range: 500 rem/h (5 Sv/h)
Weight: 1 lb

Neutron Detector
^{6}Li+ZnS: two arrays (each 5”x4”x1”) per detector module

Detection Capability Standards
(ANSI)/IEEE N42.43

Connectivity
Detectors to controller: Ethernet cable
Controller to user interface: wired, wireless
Data to remote server: 3G, 4G LTE, Wi-Fi (802.11), wired network
Data export: ANSI N42.42-compliant
Auto-populates key fields for reachback reports
RadResponder: not available (capability expected in 2023)

User Interface
Hardware: Toughbook laptop (included)
Connects to tablet or smartphone (optional or user-provided)

Data Display and Analysis
Gamma dose rate in µrem/h and µSv/h
Mapping: real-time color-coded point values, lines, heat map, additional mapping tools for presentations
Exports to remote location in real time
Visualizations: waterfall, spectrum, isotope identification

GPS
Integrated GPS

Power Options
10 to 30 VDC (vehicle battery)
Li-ion with 3 hr. run time for 4 detector modules
115 VAC

Environmental
IP66
Operating temperature: -22 F–122°F

Price
~$185,000 (with four gamma and four neutron modules)

3.4 Caen Technologies Inc. GAMON-Mobile

PLATFORM: LAND | WATER | AIR

The GAMON-Mobile is a modular detection system designed to perform radionuclide identification from moving vehicles on land, in water, or air. The system is composed of gamma spectrometric and dosimetric units; an optional neutron counting unit is also available. Each module, with the detectors and integrated control/analysis microprocessor, is housed in a ruggedized transportable case that can be moved from one vehicle to another or permanently mounted. Multiple modules can be mounted in the same vehicle and monitored separately or in combination to provide left–right directionality and improved sensitivity.

Figure 3-4 GAMON-Mobile
Image credit: Caen Systems

Gamma Detectors
NaI(Tl): One 2-or 4-liter per module
Photon energy: 30 keV–3 MeV
Calibration stabilized to natural ^{40}K plus ~20 g of embedded KCl for marine applications. Dynamic correction for temperature
Directionality: Left–right (two detectors)
Upper range: 500 µSv/h (50 mrem/h)
Module Weight: 62 lb for 4-liter NaI, (40”x16”x6”)
88 lb for 4-liter NaI + Neutron + extended range dosimeter (40”x16”x 16”)

High Dose Rate GM
Upper range: 100 rem/h (1 Sv/h)
Optional extended: 1000 rem/h (10 Sv/h)
Photon energy range: 50 keV–3 MeV
Dosimetric compensation for 50 keV–1.3 MeV

Neutron Detector
^{6}Li+ZnS dispersed in transparent medium**:** 3.5-liter volume (14.5” x 6.5” x 2.24”)
Thermal neutron sensitivity: 40 counts per neutron/cm^2
0.8” polyethylene moderator on both faces

Detection Capability Standards
(ANSI)/IEEE N42.43

Connectivity
Detector module to user interface: wired (RJ45 Ethernet, USB 2.0), or Wi-Fi
Data to remote server: 3G/4G/5G LTE, radio, LoRa™
Data export: ANSI N42.42-compliant
RadResponder compatible

User Interface
Hardware: tablet (included or user-supplied)
Software: proprietary software in detector module microprocessor (access via browser)

Data Display and Analysis
Dose rate in Sv/h (rem/h available)
Mapping: real-time color-coded point values on mapped route, heat map
Auto-generated reports (hourly and daily)
Other: isotope-related alarm thresholds
Real-time count rates, spectrum, nuclide ID and categorization (natural, medical, industrial, nuclear), nuclide-specific dose rates
Visualizations: waterfall display, histograms

GPS
Integrated receiver in each detector module

Other Sensors
Internal temperature sensor

Power Options
Vehicle battery, 5 to 12 VDC
110-220 VAC/DC
Internal Li-ion, 8 hrs. run time
Optional spare battery, hot swappable
Power consumption <5 W

Environmental
Components: IP67
Full system: IP65.
Operating temperature: -40°F–140°F

Price
$56,155 per module with 4-liter NaI detector
$75,000 per module with 4-liter NaI + neutron detector + extended range dosimeter

3.5 Gamma Reality LAMP-Mapper

PLATFORM: LAND

The Localization and Mapping Platform “LAMP” fuses radiation information with camera, GPS, and lidar sensors to create real-time 3D maps. Additional hardware is required to mount the device. The base model for the LAMP-Mapper includes gamma detectors capable of detecting up to 50 mR/h and for the LAMP Imager, about 1 R/h. Additional gamma detectors (NaI and CLLBC) are available as separate detector modules that would also need to be mounted on the vehicle. The LAMP system includes 3D mapping hardware that is separate from the detectors. Optional neutron and high dose rate detectors are also available, separately.

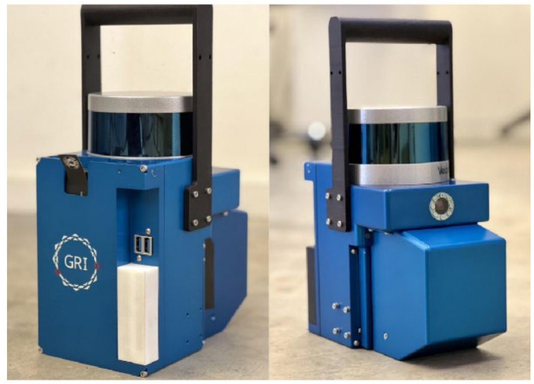

Figure 3-5 LAMP-Mapper base model (Detector modules not shown)
Image credit: Gamma Reality

Gamma Detectors
NaI(Tl): 1 liter
Photon energy: 50 keV–3 MeV
Automatic gain stabilization using temperature sensing
Directionality: none
Module weight: 20 lb

CZT: 0.02 liter
Upper range: 1 R/hr
High energy resolution with Compton imaging
Module Weight: 10 lb (including LAMP)

CLLBC: 1-liter
Photon energy: 30 keV–3 MeV
Automatic gain stabilization
Directionality: 360° imaging capability
Module weight: 30 lb

High Dose Rate GM
Upper range: 1000 R/h

Neutron Detector
CLLBC: 1 liter

Connectivity
Detector to user interface: wired or WiFi
Data export: N42.42-compatible
RadResponder: not included (available by customer request)

User Interface
Hardware: included
Software: browser-based

Data Display and Analysis
cps and dose rate or exposure rate in Sv/h or mR/h
Spectra, and isotope identification/alarms shown in user interface
Real-time GPS or 3D lidar maps with radiation data overlay to localize source
Augmented reality radiation data view overlay on camera feed and isotope-specific 3D radiation map (isotope specified by user)
Multiple LAMPs create a single combined map

GPS
Integrated receiver

Other Sensors (optional)
Camera
Lidar
Inertial measurement unit (for 3D mapping and tracking)

Power Options
External or vehicle power
Single Li-ion 98 watt-hour battery
2 hr battery runtime for active mapping

Environmental
IP65
Operating temperature: -40°F–122°F (detector dependent)

Price
Base price:$110,000 for the LAMP
(includes batteries, tablet, case)

3.6 Mirion Technologies Inc. SPIR-Ident Mobile

Figure 3-6 SPIR-Ident
Image credit: Mirion

PLATFORM: LAND | WATER | AIR

SPIR-Ident Mobile is a flexible, modular gamma and neutron detection system that can be reconfigured or moved from one vehicle to another. It can consist of up to four four-liter gamma detectors and one neutron detector housed in low-atomic number cases. Different combinations of neutron detectors and two- or four-liter gamma detectors are available, including two gamma and two neutron detectors; four gamma and two neutron detectors; or four gamma and four neutron detectors. Survey maps and data can be viewed on the vehicle or can be exported to a supervisory system, which in turn can monitor multiple systems on a single display.

Gamma Detectors
NaI(Tl): up to four 2-liter or 4-liter volume per detector (one detector per module)
Photon energy: 25 keV–3 MeV
Automatic calibration stabilized to natural ^{40}K
Directionality: Left–right (2 detectors), 360º (4 detectors)
Module weight (with two 2-liter + GM): 77 lb

High Dose Rate GM
Upper range: 1 rem/h

Neutron Detector
^{10}B+ZnS: 2.5” diameter x 27.6” length (detector)
17 cm x 19 cm x 58 cm (moderator)
Module weight: 55 lb

Detection Capability Standards
(ANSI)/IEEE N42.43
CEI 62438
IAEA NSS1
IAEA TECDOC 1363

Connectivity
Detectors to controller: wired
Controller to user interface: wired
Data to remote server: LTE, Wi-Fi
RadResponder: not available

User Interface
Hardware: laptop (included)
Data export to remote computer, smartphone, or tablet
Software: SPIRView
(part of SPIR-Ident Mobile Suite)

Data Display and Analysis
Gamma dose rate in Sv/hr, rem/hr
Real-time playback, export to supervisor
Visualizations: heat maps, breadcrumbs, waterfall, spectrum, isotope identification
Calculates surface radiation dose rate and nuclide concentration (for user-selected nuclides)

GPS
Included, with external GPS antenna

Power Options
Vehicle
POE
5 VDC, 8 hrs. run time

Environmental
IP65
Operating temperature: -4°F–122°F

Price (includes laptop and software)
$45,000 for one 2-liter gamma system
$75,000 for two 2-liter gamma system
$105,000 for two 2-liter gamma + one neutron system
Other combinations available

3.7 NUVIA Dynamics RADPatrol-SO

PLATFORM: LAND | WATER | AIR

The RADPatrol-SO Stand-Off Integrated Radiation Information System is a modular gamma spectroscopy system with neutron detection capabilities that can be configured for various vehicles. The system can be customized with different detector sizes and mountings. Smaller volume detectors are available upon request. Detectors are contained in aluminum housing with shock mount isolators.

Figure 3-7 RADPatrol-SO
Image credit: Nuvia Dynamics and JGW International

Gamma Detectors
NaI(Tl): two 4.2-liter with options for 0.3-liter to 8.4-liter total volume
Photon energy: 50 keV–3 MeV
Calibration stabilized automatically to natural peaks (e.g., ^{40}K)
Directionality: Left–right
Module weight: 139 lb

High Dose Rate GM
Upper range: 1 R/h
Photon energy range: 50 keV–1.3 MeV
Module weight: 2–4 lb

Neutron Detector
$^{6}Li+ZnS$: 1.5-liter volume with integrated moderators.
Sensitivity: 170 cps/nv for thermal neutrons
Module weight: 55 lb

Detection Capability Standards
(ANSI)/IEEE N42.43

Connectivity
Connection to user interface: wireless (Bluetooth or Wi-Fi)
Data to remote server: via email
Data export: ANSI N42.42-compliant
RadResponder: not available

User Interface
Hardware: ruggedized laptop (included)
Software: Windows-based suite

Data Display and Analysis
Exposure rate in mGy/h
Real-time calculation of activity of isotopes, and radionuclide identification
Real-time acquisition and visualization software with 2D color-dot maps
Mapping: Shaded contaminated area, radionuclide
Review, replay, reprocess, visualize, and export data
Displays spectrum in waterfall display for the last 120 seconds.

GPS
Integrated GPS receiver, antenna, and altimeter

Power Options
6-40 V DC, 4 hr. battery life
Vehicle power

Environmental
IP64
Operating temperature: -22 °F–131 °F

Price
$133,000 for two 4.2 L NaI + neutron + GM detectors
Prices vary by configuration up to ~$150,000

JGW International Ltd is a US Authorized dealer of the product, which is manufactured by NUVIA Dynamics.

3.8 Ortec RadEagle Mobile Search System (RaMSS)

PLATFORM: LAND | AIR

The RaMSS is user-configurable, with options for gamma and neutron detectors. Gamma detectors of different scintillation materials, PVT and NaI, are available in multiple detector sizes. The detectors are housed in various sized Pelican-style cases designed to be transferable between vehicles. The system is designed for minimal operator interaction with integrated self-diagnostics and verification routines. The system stores data in an internal database and can also stream data to the cloud in real-time.

Figure 3-8 RAMSS
Image credit: Ortec

Gamma Detectors
NaI(TI): 1-liter and 2-liter
Photon energy: 15 keV–3 MeV
Calibration automatically stabilized to algorithm for multi-peak gain stabilization, temperature characterized
Directionality: Left–right
Upper range: 1 Sv/h (100 rem/h)
Module weight: 22 lb and 37.5 lb

PVT: 10-liter or larger
Module weight: 66 lb including shielding

Neutron Detector
^{6}Li+ZnS: 4” x 8” active area
Module weight: 17.5 lb

Detection Capability Standards
(ANSI)/IEEE N42.33

Connectivity
Detectors to user interface: wired or wireless
Data to remote server: integrated 4G receiver, 3G support
Data export: ANSI N42.42-compliant
Reachback functionality
RadResponder compatible

User Interface
Hardware: ruggedized tablet (included)
Software: Android app, web interface

Data Display and Analysis
Dose rate in Sv or rem and count rate in cps
Real-time user control and mapping,
Mapping: position and radiation overlays, spectrum, heatmap, review mode
Audible and visible alarms (selectable thresholds)
Rolling background acquisition
ID algorithm uses multiple techniques (e.g., template-matching, peak search, and multi-agent analysis) to identify shielded or masked nuclear threat sources

GPS
Integrated

Power Options
POE (for each detection system, for power and data)
Central power supply with battery: 12 hours run time
Charging options: 110/230V mains or 12/24V automotive
Solar

Environmental
IP67
Detector operating temperature: -40°F to 122°F

Price
Depending on exact configuration (includes all necessary hardware and software):
$100,000–$150,000 for 2 gamma detector packages + 1 neutron detector package

3.9 Physical Sciences Inc. PERM M, PERM-Mobile, and MURS 2.0

PLATFORM: LAND | WATER (PERM-M)

Three models are available. The PERM-M, PERM-Mobile, and Mobile Urban Radiation Search (MURS) 2.0 are mobile radiation detection systems based on combinations of modular gamma detectors, neutron detectors, and an optical module The optical module, called Optical Warning and Localization (OWL), provides visible (or optionally, thermal infrared) data feeds that are coupled to the gamma detector. The OWL uses on-board attribution algorithms to associate object tracks with real-time source identification and displays a bounding box in the user interface associated with the potential source carrier.

PERM-M uses the letter M to designate that it is modular, where the modular building blocks are the PERM gamma detector, Local Area Neutron CountER (LANCER) neutron detector, and OWL video camera module for contextual attribution. The gamma detector and electronics are enclosed in an IP67-rated housing. The system can be mounted to a boat, all-terrain vehicle, or strapped into the back seat of a vehicle. It can connect to optional peripheral devices such as the OWL contextual video system, and/or a LANCER neutron detector. The system includes an internal cellular modem, Wi-Fi router, and GPS transceiver.

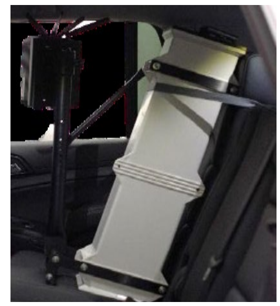

Figure-3-9 PERM-M

PERM-Mobile includes two PERM gamma modules and 2 LANCER neutron modules. It is a configurable system that can be installed in most full and midsized sport utility vehicles (SUV) with rear seats collapsed. Optional OWL modules can be used for left-right contextual assessment of the source carrier.

Figure 3-10 PERM-Mobile

Mobile Urban Radiation Search (MURS) 2.0 is a land vehicle system with six PERM gamma modules, two LANCER neutron modules, and 360-degree contextual system (visible and near infra-red) that provides source detection, identification, tracking and localization.

Figure 3-11 MURS 2.0

Image credit: Physical Sciences Inc.

Gamma Detectors (PERM)

NaI(Tl): 2-liter
Photon energy: 45 keV–3 MeV
Calibration stabilization algorithm (proprietary) using naturally occurring radionuclides.
Upper range: 1 R/h
Weight: 39 lb

Neutron Detector (LANCER)
^{6}LiF+ZnS: 21” x 12” active area
Module weight 94 lb

Detection Capability Standards
(ANSI)/IEEE N42.43
DNDO Technical Capability Standard

Connectivity
Detection unit to PC: Wi-Fi or optional hardwire
Detector module includes internal cellular modem, Wi-Fi router, and GPS transceiver
Optional modules to gamma detection unit: wired, with IP67 connectors.
Network connection: cellular
Data export: ANSI N42.42-compliant
RadResponder: not offered

User Interface
Hardware: tablet PC included
Software: Map-focused graphical user interface.

Data Display and Analysis
Dose rate in either μR/hr or μSv/hr (user-selected)
Real-time visual and audio alarms
Map overlay with detector position and dose rate
Contextual imagery when coupled with optional OWL module

GPS
Integrated GPS transceiver

Other Sensors
Optional visible and thermal IR cameras in the OWL contextual module
Coupled gamma detector for automated source attribution
Chemical sensors

Power Options
Universal AC or 12 VDC vehicle power
Power consumption: 10 W average, 80 W peak

Environmental
IP67
NEMA 6
Detector operating temperature: -22°F to 131°F

Price
Includes software, tablet, and case:
PERM-M: $33,200–$34,860
LANCER: $40,400–$42,420
OWL: $15,200–$15,960 (no IR camera)
OWL: $21,400–$22,470 (IR-camera)
PERM-Mobile $183,300/$192,152
(without OWLs, no vehicle, comes with frame ready to mount; contextual-ready PERM-Mobile would have two OWLs added; see OWL unit price, above)
MURS 2.0: $394,431- $414,158
(without vehicle or vehicle integration; vehicle integration typically $30K; law enforcement package is $33K)

3.10 Radiation Solutions Inc. (RSI) RS-600 Series

PLATFORM: LAND | WATER | AIR

Figure 3-12 RS-600
Image credit: Radiation Solutions Inc.

The RS-600 is a modular gamma and neutron detection system that can be expanded to multiple modules with up to 5 detectors (gamma and/or neutron) per module. Enclosed in low-atomic number carbon fiber cases, the modules can be permanently mounted or moved between platforms (e.g., from helicopter to SUV). Modules can also be mounted on a vehicle roof or interior; helicopter interior or exterior pods; on the roof of a boat's superstructure, inside the hull, or on top of the hull. A Pelican case version is also available. The RS-600 can be used with an optional Visual Object Tracking and Detection System that synchronizes video with radiation data to associate a vehicle or person with the source. These images can be transmitted to reachback.

Gamma Detectors
NaI(Tl): 2-liter and 4-liter
Photon energy: 15 keV–3 MeV
Calibration stabilized automatically to natural ^{40}K and other natural gamma-emitters
Directionality: Left–right, 360°
Upper range: 0.2 mSv/hr (20 mR/hr)
Module weight: 19-50 lb

CsI(Tl) and **LaBr:** multiple sizes, from 0.013–4 liters per crystal.

High Dose Rate GM
Upper range: 250 mSv/hr (25 rem/hr)
Module weight: 1 lb

Neutron Detectors
^{3}He: up to 4 tubes: 2" diameter, and 9" (0.5 L), 20" (1 L), or 32" long (1.6 L), 2.7 atm pressure
Module weight: 18–50 lb
^{6}Li+ZnS: 8" x 36" x 2" (9.4 liters)
Module weight: 60–125 lb
Boron straws: 30–40 straws
Module weight: 50–64 lb

Detection Capability Standards
(ANSI)/IEEE N42.43

Connectivity
Detectors to controller: Ethernet
Controller to user interface: wired, Wi-Fi, Bluetooth
Data to remote server: cellular, relay server
Data export: ANSI N42.42-compliant
RadResponder compatible for forwarding alarm information

User Interface
Hardware: Toughbook laptop (included)
tablet or smartphone (optional or user-provided)
Software: RadView, MapAssist, Synthetic Aperture Gamma Array (SAGA) directional system (for source localization using 4 or more detectors)
RadMobile smartphone app

Data Display and Analysis
Dose rate in Sv/hr, rem/hr
Mapping: real-time color-coded breadcrumbs or heat maps
Visualizations: Spectrum, waterfall, isotope ID, histogram, dose rate
Remote-controlled display
Playback of data collection
Video associated with radiation data

GPS
Integral or external GPS antenna and receiver.

Other Sensors
Visual object tracking and detection system
Options for other sensors (e.g., air pressure)

Power Options
10–18 VDC
115–220 VAC
Vehicle battery, boat or aircraft power
Optional $LiFePO_4$ battery: 50 hrs. operation for console and 1 gamma detector

Environmental
IP66/IP67; NEMA 4X
Operating temperature: -40°F–122°F

Price varies with options; approximately:
$35,000–$40,000 per gamma detector $2,500–$3,500 for GM detector
$30,000–$100,000 per neutron detector

3.11 Rapiscan Systems Inc. GMS-4X4-Fixed and GMS-4x4-Conf

PLATFORM: LAND | WATER | AIR

The GMS-4x4 is available in two models. In the "Fixed" model, gamma and neutron detectors are housed together in four panels, with two panels on each side of a frame installed in a van. The "Conf" version is a configurable and modular system that can be used in land, water, and air vehicles. The detectors are contained in six cases: four of which contain one gamma detector each. The other two cases each contain two neutron detectors. A control box houses a computer and two hot-swappable batteries. An optional modular frame is available for the Conf model. Options are available for an additional gamma detector in the Fixed model and an additional neutron detector in the Fixed or Conf models.

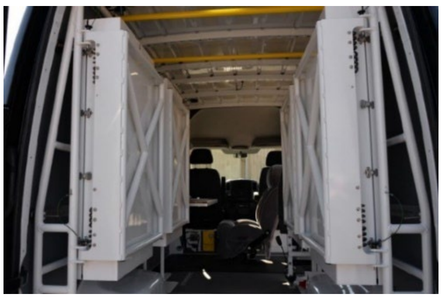

Figure 3-13 GMS-4x4-Fixed
Image credit: Rapiscan Systems Inc.

Figure 3-14 GMS-4x4-Conf
Image credit: Rapiscan Systems Inc.

Gamma Detector
NaI(Tl): four 2-liter volume
Fixed model: two detectors per side
Conf model: four detectors, one per module
Photon energy: 30 keV–3 MeV
Calibration stabilized to naturally occurring ^{40}K and ^{232}Th when available
Directionality: Left–right, 360°
Upper range: 2 R/h
Module weight: 50 lb

High Dose Rate
Uses neutron detector
Upper range: 2 R/h
GM on request

Neutron Detector
Li+ZnS: 10.5-liter total volume
Fixed model: 2 detectors per side
Conf model: 4 detectors, 2 per module
Module weight: 50 lb

Detection Capability Standards
(ANSI)/IEEE N42.43

Connectivity
Detection unit to control box: wired, up to six detector modules
Control box to user interface: wired, wireless
Data export: LTE, Wi-Fi (802.11) or both, ANSI N42.42-compliant
Reachback capable
RadResponder: not included (available by customer request at no charge)

User Interface
Hardware: laptop, tablet, Android, iPhone
Software: Mobile Mission or Mobile HQ

Data Display and Analysis
Cps and exposure or dose rate in R/h or Sv/h (user-selected)
Mapping: Windows-mapping software, real-time color-coded point values, heat maps (generated after survey completed)

GPS
Integrated receiver and external antenna provided

Power Options
12–24 VDC
Vehicle battery

Environmental
IP65
Operating temperature: -4°F–140°F

Price
Approximate range $30,000–$300,000

3.12 Scienta Envinet MONA

PLATFORM: LAND | WATER | AIR

Figure 3-15 MONA
Image credit: Scienta Envinet

MONA is a modular radiation detection system that can be used in land, maritime, or aerial vehicles. It consists of a self-contained detection unit in a weatherproof plastic case that pairs wirelessly with a mobile PC. The detection unit is powered by an internal, rechargeable battery and has two operating modes: tracking (mobile use) and recording (stationary use). The system can be transferred between vehicles. In land vehicles, the detection unit can either be installed inside the vehicle or integrated into an inconspicuous rooftop carrier. MONA comes standard with a 4-liter sodium iodide gamma detector with the option to extend the system with up to three additional gamma detectors. Various configurations with optional neutron detectors are also available.

Gamma Detectors
NaI(Tl): 1-, 2-, and (standard) 4-liter
Photon energy: 30 keV–3 MeV
Calibration stabilized to natural ^{40}K
Directionality: Left–right
Module dimensions: 40” x 17” x 7”
Module weights: 42 lb (1-liter), 46 lb (2-liter), 64 lb (4-liter)

High Dose Rate GM (optional)
Upper range: 10 Sv/h (1000 rad/h)
Weight: 2 lb

Neutron Detector (optional)
^{3}He: 0.02 liter or 1.5-liter effective volume, 2 atm pressure
Weight: 40 lb
^{6}Li scintillation detector: 1.5 liter
Weight: 19 lb (without moderator), 70 lb (with moderator)

Connectivity
Detection unit to PC: Wi-Fi
Mobile PC to remote center: LTE (4G). Satellite options available.
Remote control/display via remote desktop.
Data export: ANSI N42.42-compliant, CSV, KML
RadResponder compatible

User Interface
Hardware: mobile PC (included)
Software: web-based local data display with integrated GIS and local database
Remote monitoring center software based on Scientia Envinet’s NMC server application

Data Display and Analysis
Gamma dose rate H*(10) in μR/hr, mR/hr, μSv/hr, mSv/hr
Calculates the total gamma dose rate as well as the dose rate for each identified nuclide
Mapping: GPS data assigned to location
Map server with preinstalled OpenStreet maps and support for shapefiles
Visualizations: real-time color-coded tracks on a map, linked to spectra, waterfall diagrams, graphs, tables, and 2D sectional views
Remote monitoring software displays multiple survey vehicles simultaneously.

GPS
Integrated GPS receiver

Power Options
Integrated rechargeable battery (~24 hrs. runtime)
10–16 V (minimum 4A for charging)

Environmental
IP66
Operating temperature: -4 °F–140 °F

Price
Varies depending on configuration:
$47,450 for MONA-100-301L with 4-liter NaI(Tl) detector
$10,550 for MONA-500-M Integrated Neutron Detector
$39,000 for MONA-100-010L: Auxiliary Unit 4-liter NaI(Tl) detector
$5,750 for MONA-500-G High Dose Rate GM

3.13 Symetrica Inc. Discovery Mobile Three 3X3+NNS, Mobile 180, and Mobile 360

PLATFORM: LAND | WATER

Symetrica Inc.’s gamma and neutron detectors are available in flexible configurations, either as modular components or as a fully integrated system in an included vehicle. Three example configurations of small, medium, and large systems for land vehicles are described here. Modular systems for maritime deployment are also available.

Figure 3-16 Discovery Mobile Three 3X3 & NNS
Image credit: Symetrica

Figure 3-17 Discovery Mobile 180 modules
Image credit: Symetrica

Figure 3-18 Discovery Mobile 360
Image credit: Symetrica

Discovery Mobile Three 3x3 & NNS consists of three small (3”x 3”) NaI gamma detectors and one ^{6}LiF+ZnS-based neutron detector in a Pelican case. The total NaI volume is 1.05-liter per module. The detectors are paired with a separate control and communication electronics case that also contains the GPS receiver. The total weight is 57 lb.

Discovery Mobile 180 includes two 2-liter NaI gamma and two ^{6}LiF+ZnS-based neutron detectors in aluminum cases, with a separate case for the electronics, GPS receiver, and battery. This configuration has left–right directionality and optional lead shielding available on the side of the NaI detectors facing toward the vehicle’s interior (inboard) to improve directionality. The total weight of all the components is 271 lb. In this example configuration, one NaI and one neutron detector are contained in each of the modules, but other possible configurations include having two 2-liter NaI per case, with the module weight for that two 2-liter NaI configuration at 108 lb.

Discovery Mobile 360 includes six 2-liter NaI gamma detectors and four ^{6}LiF+ZnS-based neutron detectors. The detectors are fully vehicle-integrated to achieve 360° area monitoring. Two neutron detectors are on each side for dynamic detection sensitivity described as detection of a 20,000 n/s ^{252}Cf source at 9.8 ft distance while moving at 4.9 mph. This system includes the vehicle (a Ford Ranger) and 360° video cameras with night vision capabilities. The vision system interface offers a radiation dose overlay that allows the operator to see the direction of the radiation source. The total weight of this detector system (excluding vehicle-related components) is 1,113 lb.

Gamma Detectors
NaI(Tl): 0.35- or 2-liter
Photon energy: 25 keV–3 MeV
Calibration stabilized automatically using an encapsulated 27 nCi ^{22}Na source (Digitally separated tagged calibration spectrum records in parallel with observed external spectrum)
Upper range: 100 mrem/h (1 mSv/h)

High Dose Rate:
Small organic scintillator Included in gamma detector module
Upper range: 50 rem/h

Neutron Detectors
^{6}LiF+ZnS: NNS:FP 8.7” x 8.7” active area or NNS:2000 34.3” x 7.9” active area
Sensitivity: 0.4 cps (FP) and 1.75 (2000) per ng ^{252}Cf moderated with 2.5 cm HDPE at 2 m from center of detector

Detection Capability Standards
(ANSI)/IEEE N42.43 for 360 model only

Connectivity
Detectors to control module: wired
Control to user interface: Wi-Fi, Bluetooth, and 4G cellular
Data export: ANSI N42.42-compliant
Reachback capable
RadResponder compatible (available at extra cost)

User Interface
Hardware: controller that contains processor, laptop (included)
360 model: touchscreen tablet controller in cab and ruggedized laptop (included)

Data Display and Analysis
Gamma dose rate in rem/h or Sv/h (user selects)
Real-time dose mapping and vehicle tracking at reachback
Spectra and nuclide ID
Mapping: color-coded breadcrumb trail of count rate measurements
Dynamic background management
Email automatically generated reports by Wi-Fi or 4G

GPS
Integrated in electronics case
(180 and 360 models use external antenna)

Other Sensors
360 model: multiple video cameras that including night vision

Power Options
12V DC vehicle power
230/115 V AC power supply
Three 3x3 & NNS model: Li-ion battery, 8- or 16- hr runtime, hot swappable
180 and 360 models: non-spillable lead-acid battery, 8 hr runtime; optional shore power and/or solar panels

Environmental
Detector enclosures: IP65
The 360 system: IP54
Operating temperature: -4 °F–122 °F

Price
Three 3x3 + NNS: $98,000
180: $148,500
360: $289,000 (includes vehicle)

3.14 Technical Associates MoRad and Super MoRad

PLATFORM: LAND

Technical Associate makes two available models of mobile detection system. The MoRad includes up to six individual detectors connected by cables to the electronics unit, which connects to the user's laptop. The MoRad electronics unit weighs six pounds, and the weight for a MoRad system with four individual detectors (two 4-liter gamma detectors, a high-rate detector, and neutron detector) and moderator is about 120 pounds. The Super MoRad is a self-contained unit with up to seven detectors and a built-in computer.

Figure 3-19 MoRad
Image credit: Technical Associates

Figure 3-20 Super MoRad
Image credit: Technical Associates

Gamma Detectors
NaI(Tl): 1- or 4-liter
Photon energy: 50 keV–2.7 MeV
Automatic stabilization using natural ^{40}K
Directionality: Left–right (for two detectors)
Upper range: 1 mR/h (4-liter), 3 mR/h (1-liter)
Weight: 12 lb (1-liter), 48 lb (4-liter)

High Dose Rate (optional)
Ion chamber: Upper range of 1,000 R/h
GM: Upper range of 10 mR/h

Neutron Detectors
PNS-20mo: thermal neutron probe using ^{10}B+ ZnS scintillator, 0.1-liter active volume, plus moderator, 1.0 cps per neutron/cm^2 s
PNS-19mo: fast-neutron dosimetry probe, 0.1-liter active volume, 0.4 cps per neutron/cm^2 s
Weight (either): <2 lb without moderator

Connectivity
Detectors to control box: BNC cables, MHV optional
Control box to user interface: RS-232, USB, Ethernet; WiFi or cell phone optional
Data export: serial output, RS-232 standard, USB optional,
Not N42.42-compliant
RadResponder compatible

User Interface
Hardware: MoRad laptop, user-supplied or option to include
Super MoRad laptop, included
Software: proprietary TAquire software

Data Display and Analysis
Display units: R/h, cps, cpm, or user selection (via software)
Mapping: GPS tagged overlay on a satellite map, radiation levels as color-coded point values
Optional custom data displays.
Optional multi-channel analyzer for isotope identification
Audio and visual alarms with user-determined thresholds
Optional vehicle dashboard alarm light

Power
Vehicle, battery, or AC
Batteries: included 12V, 4.8 amp-hour built-in Li-ion rechargeable battery, AC charger optional
Optional 44 or 92 amp-hour Li-ion battery pack
Battery Life: 24–40 hrs; up to 700 hrs. with optional battery pack

Other Sensors
Optional hazardous chemical sniffers
Optional HD camera ($1,800)
Optional airborne particulate monitor for alpha, beta, and gamma particulates ($5,700)

GPS Technology
MoRad GPS receiver optional or user-supplied
Super MoRad GPS receiver included

Environmental
Detector enclosures: IP63.
Operating temperature: 32°F–122°F

Price
MoRad systems: $75,000–$125,00 (with one or two 4-liter NaI detectors and nuclide ID, depending on options)

3.15 TerraTracker Adaptable Radiation Area Monitor (ARAM)

PLATFORM: LAND | WATER | AIR

The ARAM is configurable for automobiles, maritime vessels, or aerial systems. The standard mobile configuration includes two modules, each containing one gamma and two neutron detectors, with a total weight of 150 lb. The system can be configured for specific dimensions and performance requirements. The detectors can be housed in aluminum, composite (carbon-fiber and fiberglass) or high-density polyethylene (HDPE) low-atomic number material enclosures. Modules are mounted to custom-made brackets and can be moved to a similar vehicle with the same mounting system, or they can be configured to fit a generic mounting system.

Figure 3-21 ARAM Aerial
Image credit: TerraTracker

Figure 3-22 ARAM vehicle
Image credit: TerraTracker

Figure 3-23 ARAM maritime
Image credit: TerraTracker

Gamma Detectors
NaI(Tl): One 2-liter crystal per enclosure
Photon energy: 10 keV–3 MeV
Calibration stabilized to natural ^{40}K (additional nuclides added at customer's request)
Directionality: Left–right with two modules
Weight: 75 pounds (one module containing one gamma and two neutron detectors)

Neutron Detector

^{3}He: 0.22 liter each, 4 atm pressure
Weight of neutron module with 4 moderated detectors and associated hardware: 25 lb

Detection Capability Standards
(ANSI)/IEEE N42.38

Connectivity
Detector to control box: wired USB and Ethernet
Control box to user interface: USB, Ethernet, Wi-Fi
Data export: ANSI N42.42-compliant
Reachback capable via Wi-Fi, LTE
RadResponder compatible

User Interface
Hardware: controller containing processor, laptop or tablet (included, user's choice)
Software: TerraTracker app (works with user-supplied smart phone)

Data Display and Analysis
Gamma measurement count rate (cps)
Real-time mapping and vehicle tracking at reachback
Spectra and nuclide ID
Map interface with color-coded breadcrumb trail of count rate measurements
Event list with isotope ID

GPS
External GPS (internal GPS optional)

Other Sensors
Radiological data can fuse with data from other user-supplied sensors (e.g., video, thermal)

Power Options
12V DC
Vehicle power

Environmental
Detector enclosures: IP66
Operating temperature: 5 °F–131 °F

Price
$150,000

3.16 Thermo Scientific Matrix Mobile ARIS™ Detection System

Figure 3-24 Matrix Mobile ARIS
Image credit: Thermo Scientific

PLATFORM: LAND

The Matrix Mobile ARIS is a system for radiation survey, patrol, and isotope identification that is permanently mounted in a user-supplied standard SUV or other vehicle. Formerly known as the ARIS Mobile, and available since 2010, the ARIS (Advanced Radioisotope Identification System) includes pairs of PVT and NaI gamma detectors and a neutron detector. Alarms from gamma rates above background in the 7-liter PVT detectors can trigger accumulation of spectra and radionuclide identification using the NaI detectors. The total weight of the system is 350 lb. The system is designed to withstand and be operational after a high-speed crash per ANSI N42.43-2006. Extended warranty and various service plans available.

Gamma Detectors
NaI(Tl): one or two 2.1-liter, one per side, with shielding on the inboard side to improve directionality
Photon energy: 20 keV–3 MeV
Directionality: left–right
Calibration at system startup using an internal ^{40}K source (relies on vehicle cabin's conditioned air to keep detector temperature constant, not automatically, continuously stabilized)
Module weight: 50 lb

PVT: two 7-liter, one per side, with NBR (natural background rejection) technology[17]

Neutron Detector
He-3: 1.65 liter (2” diameter x 32” long cylindrical) 2.7 atm pressure

Detection Capability Standards
(ANSI)/IEEE N42.43

Connectivity
Detectors to control module: wired
Control module to user interface: wired
Data to remote server: cellular (included)
Data export: ANSI N42.42-compliant
Reachback capable
RadResponder not included (available upon request)

User Interface
Hardware: laptop (user-supplied or optional)
Software: proprietary ViewPoint™ Enterprise Management Software

Data Display and Analysis
Dose rate and count rate units configurable to any user selection
Real-time display of gamma and neutron readings, alarms and events, spectrum, and nuclide ID
Real-time user control and mapping
Mapping: GPS position and color-coded radiation overlays, playback review mode

GPS
Integrated into controller module

Other Sensors
Internal temperature sensors warn if component temperatures outside functional range

Power Options
12 V secondary vehicle battery charged by (but isolated from) vehicle
120 VAC shore power interface (included)
Integrated battery, up to 2 hrs. runtime

Environmental
IP rating: *not provided*
Operating temperature: 65°F–75°F in vehicle

Price
$60,000–$70,000
includes hardware, software, and integration into a user-supplied vehicle

[17] NBR (natural background rejection) uses the gamma-ray energy distribution to distinguish between naturally occurring and man-made radioactive material.

3.17 Thermo Fisher Scientific Matrix Maritime RADspec

PLATFORM: WATER

The Matrix Maritime RADspec is a radiation detection and interdiction system housed in a rugged, low-atomic number plastic shell designed for constant exposure to elements. Separate detector and controller modules allow for flexible mounting arrangements on maritime vessels. The system consists of one or more gamma and neutron detectors.

Figure 3-25 Matrix Maritime RADspec
Image credit: Thermo Scientific

Gamma Detectors
NaI(Tl): 2-liter
Photon energy: 20 keV–3 MeV
Automatic stabilization to internal ^{40}K
Continuous stabilization for temperature and background changes
Directionality: Left–right with two or more modules
Upper range: 10 mrem/h
Module weight: 50 lb

Neutron Detector
^{3}He: 0.75” x 3”, 8 atm pressure, with 10 mm-thick PE moderator

Connectivity
Detectors to controller: RJ-45 Ethernet
Controller to user interface: wired
Data to remote server: internet
Data export: ANSI N42.42-compliant
RadResponder: not included (available upon request)

User Interface
Hardware: laptop computer (included)
Software: proprietary ViewPoint Enterprise Management Software

Data Display and Analysis
Exposure rate in mR/hr
Real-time detection in boat, can be transmitted to command post or reachback
Visible and audible alarms
Displays nuclide ID
Mapping: real-time color-coded

GPS
Receiver (included)

Power
Vehicle battery (DC)
POE

Environmental
IP68
Operating temperature: -5 °F–122 °F

Price
$150,000–$250,000 depending on system configuration

4.0 MANUFACTURER AND VENDOR CONTACT INFORMATION

Additional information on the products in this market survey report can be obtained from their manufacturers and vendors 4.

Table 4-1 Manufacturer and Vendor Contact Information

Manufacturer/ Vendor	Website	Address	Phone Number	Email Address or Web Form
Arktis Detection Systems, Inc.	www.arktis-detectors.com	4047 Wilson Blvd. 8th Floor Arlington, VA 22203	(571) 478-0575	info@arktis-detectors.com
Berkeley Nucleonics Corp.	www.berkeleynucleonics.com	2955 Kerner Blvd. San Rafael, CA 94901	(415) 453-9955	info@berkeleynucleonics.com
Bubble Technology Industries (BTI)	www.bubbletech.ca	3128 Highway 17 Chalk River, ON Canada K0J1J0	(613) 589-2456	info@bubbletech.ca
CAEN Technologies Inc.	www.caentechnologies.com	1 Edgewater St. Suite 101 Staten Island, NY 10305	(718) 981-0401	info@caentechnologies.com
Gamma Reality Inc. (GRI)	www.gammareality.com	1301 S. 46th St. B478-102 Richmond, CA 94804	(510) 542-9025	www.gammareality.com/contact-us
JGW International (distributor for Nuvia Dynamics, Inc.)	www.jgwgroup.com	1801 Robert Fulton Dr. Suite 400 Reston, VA 20191	(703) 547-6270	info@JGWgroup.com
Mirion Technologies, Inc.	www.mirion.com	1218 Menlo Dr. Suite A Atlanta, GA 30318	(404) 384-1048	www.mirion.com/#contact-modal
Nuvia Dynamics (distributed by JGW International)	www.nuviatech-instruments.com	5448 Timberlea Blvd. Unit No. 1 Mississauga, ON Canada L4W 2T7	(905) 760-2210	instruments@nuviatech.com

Manufacturer/ Vendor	Website	Address	Phone Number	Email Address or Web Form
ORTEC (Advanced Measurement Technology)	www.ortec-online.com	801 South Illinois Ave. Oak Ridge, TN 37831	(216) 225-7808	ortec.info@ametek.com
Physical Sciences Inc. (PSI)	www.psicorp.com	20 New England Business Center Andover MA, 01810	(978) 689-0003	contact@psicorp.com
Radiation Solutions Inc. (RSI)	www.radiationsolutions.ca	5875 Whittle Rd. Mississauga, ON Canada L4Z 2H4	(905) 890-1111	info@radiationsolutions.ca sales@radiationsolutions.ca
Rapiscan Systems	www.rapiscansystems.com	2805 Columbia St. Torrance, CA 90503	(310) 978-1457	www.rapiscansystems.com/en/contact
Scienta Envinet	www.envinet.com	Hans-Pinsel-Str.4 85540 Haar, Bavaria, Germany	+49 (89) 456657-0	info@envinet.com
Symetrica Inc.	www.symetrica.com	4 Lyberty Way Suite 1 Westford, MA 01886	(978) 440-0731	sales@symetrica.com
Technical Associates	https://tech-associates.com	7051 Eton Ave. Canoga Park, CA 91303	(818) 883-7043	sales@tech-associates.com
TerraTracker, Inc.	www.terratracker.com	1911 Second St. Livermore, CA 94550	(925) 447-6275	info@terratracker.com
ThermoFisher Scientific	www.thermofisher.com	168 Third Ave. Waltham, MA 02451	(781)-622-1000	customercare@thermofisher.com

5.0 CONCLUSIONS

This report described 24 mobile radiation detection products from 16 manufacturers. Some products are designed for use in a single platform environment (land-based, maritime, or airborne) while others can be configured for two or more environments. Most vendors offer flexible options for customization based on the user's needs. While prices are highly dependent on the user's selected options, they range from approximately $33,000 to $414,800. Most systems consist of modular components, with some configurations designed to be integrated semi-permanently in a vehicle and others intended to be easily removed from or transferred between vehicles. Vendors may offer vehicle integration included or at an additional charge; one of the products includes the vehicle in the cost.

For gamma detection, all the products use sodium iodide scintillators with volume of at least one liter and are capable of radionuclide identification. Three products also offer large volume organic plastic scintillators to enhance the low range of detection sensitivity. Eleven systems offer Geiger-Mueller detectors to increase the upper range capability for measurement of high exposure rates. Twenty-one mobile radiation systems are capable of measuring exposure rates up to 1 Roentgen per hour (R/h) or higher, with nine of those having an upper range of 100 R/h or greater. All offer options for neutron detection capability, with neutron detector types and sizes varying greatly. Most land-based systems can display real-time maps of exposure rate and offer options for left/right directionality. Additional features available in some systems include 360-degree geometry, video cameras, source localization, isotope-specific alarms, and data output compatibility with RadResponder.

Information included in this report has not been independently verified by the SAVER program. Emergency responder agencies should carefully research the overall capabilities and limitations of mobile radiation detection systems in relation to their agency's operational needs when making equipment selections

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Appendix A. STANDARD ENCLOSURE DESIGNATIONS

This section provides information on the levels of protection as specified by enclosure designations in two standards. The American National Standards Institute (ANSI)/International Electrotechnical Commission (ANSI/IEC) 60529 standard uses a numeric two-digit ingress protection (IP) code. [8]. The first digit designates the level of solid ingress protection, and the second digit designates the level of protection for liquid ingress, as described in Tables A-1 and A-2.

The National Electrical Manufacturers Association (NEMA) standard uses a different, alpha-numeric designation to define types of enclosure ratings. NEMA enclosure ratings address additional requirements including corrosion resistance and the effects of icing. Table A-3 summarizes NEMA enclosure type ratings. The NEMA enclosure ratings are defined and compared to ANSI/IEC IP designation in the publication NEMA EN P1-2021 [8].

Appendix Table 1 Levels of Solid Ingress Protection per First Digit of IP Code

Digit	Object Size Effective Against	General Description
0	No Protection	No protection against contact and ingress of solids
1	> 50 mm	Large surfaces, e.g., back of hand, but no protection against deliberate contact with body part
2	> 12.5 mm	Prevents entry of fingers and similarly sized objects
3	> 2.5 mm	Prevents entry of tools, thick wires, etc.
4	> 1 mm	Prevents entry of most wires, screws, large ants, etc.
5	Dust Protected	Dust ingress not entirely prevented but does not enter in sufficient quantity to interfere with satisfactory operation of equipment
6	Dust Tight	No ingress of dust

Appendix Table 2 Levels of Liquid Ingress Protection per Second Digit of IP Code

Digit	Water Exposure Protection	General Description
0	No Protection	No protection
1	Vertically dripping water	Vertically dripping water has no harmful effects
2	Dripping water, enclosure tilted up to 15 degrees	Vertically dripping water has no harmful effects when enclosure is tilted at an angle up to 15 degrees of normal vertical position
3	Spraying water	Water sprayed at angles up to sixty degrees from the vertical position has no harmful effects
4	Splashing water	Water splashed against the enclosure from any direction has no harmful effect

Digit	Water Exposure Protection	General Description
5	Water jets	Water projected by a nozzle (6.3 mm) against enclosure from any direction has no harmful effects
6	Powerful water jets	Water projected in powerful jets against the enclosure from any direction has no harmful effects
7	Temporary immersion in water	Ingress of water in harmful quantity is not possible when the enclosure is temporarily immersed in water under standard conditions or pressure and time
8	Continuous immersion in water	The equipment is suitable for continuous immersion in water under conditions more severe than for numeral 7

Appendix Table 3 National Electrical Manufacturers Association Standards for Enclosures

Provides a Degree of Protection Against the Following Conditions	NEMA Type of Enclosure
Access to hazardous parts	3, 3X, 3R, 3RX, 3S, 3SX, 4, 4X, 6, 6P
Ingress of solid objects	
Ingress of water dripping and light splashing	
Ingress of rain, snow, and sleet	
Sleet	3S, 3SX
Ingress of windblown dust, lint, fibers	3, 3X, 3S, 3SX,4, 4X, 6, 6P
Ingress of hose-down and splashing water	4, 4X, 6, 6P
Corrosive agents	3X, 3RX, 3SX, 4X, 6P
Occasional temporary submersion in water	6, 6P
Occasional prolonged submersion	6P