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# Evaluation of Repurposing Archetypal Preventive Radiological/Nuclear Detectors to the Consequence Management Mission

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**ABSTRACT**

In the first hours or days after an unplanned release of radioactive material to the environment, the radiation detection instruments most widely available to local first responders may be those currently fielded for interdiction missions. This study investigated how such preventative radiological / nuclear detection instruments could perform if repurposed to consequence management missions. A representative sample of three archetypes (body-worn, human carried, and other/large detection volume) encompassed six categories: personal radiation detector, extended range personal radiation detector, personal emergency radiation detector, radio-isotope identification device, human portable detector/backpack, and vehicle mounted large detection volume. Overall 19 models of equipment were included in the study. Laboratory evaluations were designed to assess the capabilities of the instruments in four consequence management missions: exposure rate, integrated exposure, radiation survey, and contamination screening. As applicable, the evaluations included measurement of exposure rate, integrated exposure, over-range response, and angular response. The results were compared to benchmarks from the American National Standards Institute ANSI N42.49A. The performance of the instruments for initial screening for contamination was assessed by an automated radioactive source moving past the detectors at various speeds and distances. The results demonstrate that if the equipment is used in accordance with the mission analysis and categories, and within the original equipment manufacturer specifications, it is possible to achieve sufficient accuracy to estimate and document doses to responders, plan entries into contaminated areas, detect contamination, and protect the public, until such time as outside resources arrive with sufficient numbers of standard health physics instruments and personnel dosimetry to replace the preventative radiological / nuclear detection instruments. This evaluation campaign was conducted to complement the National Council on Radiation Protection and Measurements Report-179 on Guidance for Emergency Response Dosimetry.

# INTRODUCTION

In the event of a radiological or nuclear emergency involving a large-scale release of radioactive material, local first responders would perform initial radiation measurements to assess impacts and issue protective action recommendations for the responders and the public. Over the first 24-36 hours, Federal responders and resources will deploy to augment the local efforts, and if necessary, provide extensive radiation monitoring and assessment capabilities coordinated by the Department of Energy-led Federal Radiological Monitoring and Assessment Center and the Federal Emergency Management Agency. Unless Federal resources are already on scene (e.g., a preventative radiological/nuclear detection mission for a scheduled special event), the local response to an incident will commence and persist for many hours with no on-scene Federal support. For a catastrophic incident, such as a nuclear detonation or severe reactor accident, the local jurisdictions may not have a full range of adequate supplies of health physics instruments and personnel dosimetry. Therefore early in a crisis, the local responders will inevitably conduct their operations with available radiation detection and dosimetry capabilities until additional resources and support are requested and arrive. Most of the radiation detection instruments currently fielded at the local level are carried by law enforcement officers and are designed for interdiction missions - referred to here as preventative radiological/nuclear detection (PRND) instruments. This study investigated how PRND equipment can be repurposed in consequence management (CM), i.e. response and recovery, missions.

To help fill the monitoring and assessment shortfalls in this period of austerity, the Department of Homeland Security's Science and Technology Directorate commissioned three complementary and coordinated projects. The first project is a Report and Commentary by the National Council on Radiation Protection and Measurements (NCRP). The Report provides

guidance for the actual accrual and control of dose when dosimetry resources are austere. It answered three questions (NCRP 2017):

- *"With minimal dosimetry resources, how do responders make decisions to control the total dose and associated risk?*
- *How are doses assigned to responders when not every responder is issued a dosimeter before exposure occurs?*
- *What is the regulatory framework for responders who are not trained as radiation workers?"*

The Commentary by the NCRP to assist users in implementing the Report- 179 is currently under development. The second of these efforts, discussed herein, was a project to evaluate and describe the data quality afforded by using PRND equipment to make measurements for the CM mission. The scope included three components, mission analysis, equipment categorization, and evaluation of equipment archetypes in the laboratory to the various CM missions. The third project incorporated the results of the evaluations into the development of concise job aids[*] to repurpose the instruments within their manufacture limitations to the CM missions described below.

## MATERIALS AND METHODS

### Equipment categorization and instrument selection for evaluation

There are three archetypes of PRND equipment currently in use:

1. Body-worn
2. Human carried
3. Other (mobile system with a large detection volume)

[*] https://www.dhs.gov/publication/st-frg-using-preventative-radiological-nuclear-detection-equipment-consequence, accessed May 19, 2018.

The archetypes span over 100 different makes and models of PRND equipment with significantly different capabilities. The archetypes were broken down to six categories and the associated characteristics and alignment to CM missions, Table 1 (Buddemeier et al. 2017).

For the purpose of this study, a primary assumption was the instruments perform to their respective original equipment manufacturer specifications, because it was not practical or necessary to test every make and model, a representative sample from each category was tested. In accordance with a previous survey of the most common makes and models of currently fielded PRND equipment (Buddemeier 2017), a representative set of nine body-worn radiation detectors, nine human portable detectors, and one mobile system with a large detection volume were evaluated for the various missions that they would be repurposed to support. The equipment evaluated is shown in Fig. 1 and listed in Table 4, which also serves as a key to the legends in Figs. 3, 4a, 4b, 5, 6, 7. The assortment of body-worn instruments in Table 4 includes devices having various sensitivities, capabilities, and display units.

The categories of body-worn instruments evaluated included six Personal Radiation Detectors (PRD) and two Extended Range Personal Radiation Detector (ER-PRD). The one additional model, instrument B, is a Personal Emergency Radiation Detector (PERD) type unit, which was designed to ensure responder safety in high radiation fields and not intended to perform with the low end sensitivity of an ER-PRD. While this instrument is designed and built as a PERD, it has a dynamic range of 2 Gy $hr^{-1}$ which does not meet the ANSI N42.49A value of 9.99 Gy $hr^{-1}$ (ANSI 2011). Notwithstanding this instrument was treated as a PERD with respect to the evaluation. Spectroscopic Personal Radiation Detectors were not evaluated.

**Mission analysis**

The archetypes were aligned to the equipment categories, which were then mapped to the CM missions (Buddemeier 2017). Although there are no universally accepted definitions of radiation hazard zones in an emergency response, the three zones defined in NCRP Report-165 were used for the alignment of the equipment categories to the missions:

- Hot Zone – The NCRP identifies the Hot Zone boundary by exposure rate or surface contamination levels, > 0.1 mGy $h^{-1}$, 1,000 Bq $cm^{-2}$ beta/gamma surface contamination, or 100 Bq $cm^{-2}$ for alpha surface contamination (NCRP 2010).
- Cold Zone – This is the area outside of the Hot Zone. There may be some contamination and elevated radiation in this area, but it is below the levels indicated for controlled access. e.g. a Hot Line. For a large incident, the Cold Zone may include areas where protective actions are in place, such as an agricultural embargo. There may also be a response agency defined Warm Zone as a transition area between Hot and Cold Zones.
- Dangerous Radiation Zone – The NCRP defines a Dangerous Radiation Zone where the exposure rate exceeds 0.1 Gy $h^{-1}$, within which actions taken should be restricted to time-sensitive, mission-critical activities, such as lifesaving (NCRP 2010).

**Mission area requirements**

Subsequently the CM mission areas were mapped to four radiological detection and measurement equipment requirements, Table 2 (Buddemeier 2017):[†]

- Exposure rate – warn the user who is approaching or has entered the Hot Zone or the Dangerous Radiation Zone.

[†] The four mission definitions are the same as the terms Emergency Worker Exposure Control, Emergency Worker Dose Monitoring, Radiation Survey, and Person/Object Contamination Detection (β,γ) as defined in NCRP Report-179 (NCRP 2017).

- Integrated exposure – measure accumulated exposure or dose and alarm when predetermined levels are exceeded.
- Radiation survey – to or establish the boundary of a radiation hazard zone, map areal exposure rates, or estimate integrated exposure.
- Contamination screening – to determine if the radioactivity on a person or object exceeds predetermined criteria. For this initial screening mission, the device must be able to detect a minimum of 37 kBq on a person or object (NCRP 2010).

**Equipment repurposing**

Most of the equipment evaluated in this effort have been specifically designed by technology manufacturers and purchased by responders for preventative detection and source interdiction operations, the equipment can serve an important technical role in a CM response, as it is currently the most widely available and fielded type of radiological instrumentation by state and local agencies.

The evaluation campaign provided functional evaluations in surrogate operational radiation fields on how best to deploy and use this PRND equipment in an actual response, with respect to the CM missions, Table 1. Gaining a better understanding of how PRND equipment can operate and perform in a radiological environment will provide important information on how responders can and should tactically approach CM operations. The results of this evaluation are intended to form the technical basis for the envelope of operations, tactical operational procedures, and demonstrate the data quality is sufficient to meet the CM mission requirements. There were four assumptions for the evaluations:

1. Instruments function to original equipment manufacturer specifications.
2. Energy response was not a subject of the evaluation of data quality.

3. Original equipment manufacturer specifications are the basis to preplan assignment of mission requirements (Buddemeier 2017).
4. In the context of the CM mission, neutron radiation is not a primary exposure risk. It is unlikely to be encountered, a negligible radiation hazard, and PRND archetypes without a neutron detector will detect the concurrent gamma radiation.

Standard radiation protection equipment, such as handheld survey instruments, were not in the scope of the testing.

**Methodology for characterization**

Laboratory characterization studies consisted of two parts. Part 1 covered exposure rate, integrated exposure, orientation, and over-range evaluations. Part 2 covered simulation of contamination screening. All irradiations used $^{137}$Cs as the radioactive source: the former used stationary irradiators and the latter used small check sources on a moving track for contamination detection simulations.

**Radiation units**

The quantity exposure in units of roentgen (R) is used here because the users of PRND equipment in the United States typically do not use the instruments in International System (SI) units. Results are reported in units of roentgen (R), which is the value reported by PRND equipment typically used in the United States. The roentgen (R) is defined as the exposure that results one electrostatic unit of charge in one $cm^3$ of dry air, this would be equivalent to 2.58 x $10^{-4}$ C $kg^{-1}$ of air in SI units. Because $^{137}$Cs was used as the source of radiation to conduct the evaluations, all the values reported herein can be converted to the quantity Personal Dose Equivalent in Sieverts (Sv) by the conversion factor 1.06 x $10^{-2}$ Sv $R^{-1}$ (ANSI 2011).

**Part 1 Methods – exposure rate, integrated exposure, orientation, over-range evaluations**

The exposure rate, integrated exposure, orientation, and over-range evaluations were adapted from ANSI N42.49A, "American National Standard for Performance Criteria for Alarming Electronic Personal Emergency Radiation Detectors (PERDs) for Exposure Control" (ANSI 2011). While N42.49A is not designed to address all of the CM missions, it provides an adaptable framework and benchmarks for comparison that are suitable for this characterization study. Because PRND instruments are not designed to meet N42.49A requirements, the evaluations were not intended to serve as a pass/fail performance test. Instead, the N42.49A performance measures are used as a comparison benchmark to characterize the level of accuracy to expect if PRND equipment is repurposed to CM missions. Table 3 shows the N42.49A performance requirements for reference; the standard requires two out of three replicates to be within the criteria in each category.

Following the N42.49A paradigm, three replicates of each instrument were evaluated and 10 exposure rate readings were recorded for each irradiation level.[‡] For integrated exposures, only one reading was recorded at each level. The delivered exposures (evaluation levels) for this study were chosen to span the potential range of radiation levels that could be encountered during CM missions in Cold, Hot, and Dangerous Radiation Zone, and are in Table 3. Instrument-specific exposure levels were selected from this Table corresponding to the manufacturer-stated operational range and capabilities of each device evaluated.

The irradiation geometry used was instrument and mission appropriate. To simulate the body-worn instrument exposure rate or integrated dose conditions, the instruments were placed on a standard polymethyl methacrylate (PMMA) slab phantom having dimensions 15 cm thick, 30 cm wide and 30 cm high with the instrument face towards the source. For integrated exposure, the body-worn instruments were placed on the phantom and then the three consecutive

[‡] In the case of the RIIDs only one unit of one product, Instrument M, was available.

integrated exposures were delivered. To get a measure of the angular sensitivity and to simulate the hand-held use of instruments (such as for exposure rate or contamination surveys), other irradiations were performed free-in-air in two orientations: with the back oriented toward the source and in the horizontal position such that the top of the instrument faced toward the source.

All irradiations were performed at the Building 348 calibration facility at Brookhaven National Laboratory (BNL), using $^{137}$Cs sources traceable to the National Institute of Standards and Technology. These sources were in two geometries, a low scatter irradiator and a gamma beam irradiator. With respect to referenced measurements, the estimated statistical error for the delivered exposures is ≤ 4% and ≤ 2%, respectively.[§]

**Part 2 Methods – contamination simulations**

Simulations of the instruments' response to contaminated persons and objects were performed with small check sources BNL in laboratory E1 in Building 815. The evaluations were done with $^{137}$Cs point sources equivalent to 37, 185, 370, and 740 kBq. The benchmark activities 37, 185, and 370 were selected to correspond to the Federal Emergency Management Agency minimum detectable levels for health effects for loose contamination in a small spot (FEMA 2002). The value of 740 kBq was based on recent analysis[**] indicating that a spot of $^{137}$Cs contamination of this amount or more may cause mis-attributed alarms on nearby portal monitors; for this reason, there was interest in identifying a rapid contamination detection

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[§] The two $^{137}$Cs sources used in the BNL low scatter irradiator were 133.2 MBq and 7263.1 MBq with estimated statistical errors at the 95% confidence level of 3.85% ± 1.97% and 3.16% ± 2.78%, respectively. A larger 68.5 GBq (± 2%) was used in the BNL gamma beam irradiator for the 10 R h$^{-1}$ and 100 R h$^{-1}$ fields and for the integrated exposure tests. Condemi, G. Private communication, Calibration Facility Supervisor, Upton, NY, 2017.
The radiation fields from the two irradiation facilities are comparable, because NIST-calibrated, secondary standard ion chambers are used for exposure rate measurements, while the overall room geometries are slightly different, scattered photons off of walls are not significant, the data from exposure rate measurements for exposure rate calibration are mathematically analyzed to develop characteristic equations of exposure rate as a function of distance, and vice versa, for both rooms. This accounts for room effects and allows direct comparison. Welty, T. Private communication, Radiological Control Division, Upton, NY, 2018.

[**] Laboratory tests of a pedestrian radiation portal monitor and handheld personal radiation detectors for use at community reception centers, National Urban Security Technology Laboratory – *in progress*

technique for this level of contamination to reduce disruption of screening capabilities and help prioritize candidates for early decontamination. The speeds and distances used were considered to span those that could potentially be practical during CM operations.

Placing these sources at the correct distance achieved a virtual source that corresponded to the four desired activities. The correct distance was calculated from the $^{137}Cs$ specific gamma ray constant, and then the source-to-detector distance adjusted accordingly, Fig.2 (right). The activities of the actual sources ranged from 12 to 450 kBq.

To simulate moving an instrument past a person or object to detect surface contamination, a source transporter with a conveyor belt was constructed to move the source past a stationary detector at fixed distances, Fig. 2 (left). The system included a high precision stepping motor to achieve and iterate various speeds of 15, 36, 60, and 120 cm $s^{-1}$. The sources to detector distances were varied, 5, 15, and 30 cm.

One set of evaluations simulated a person with a detector walking past a line of people or object, or a choke point or an improvised portal monitor with people or objects moving past the detector so as to screen for a contamination level that should be given priority for decontamination and possibly medical evaluation.

Subsequently, lower levels of contamination were simulated to evaluate how the instruments performed in a hand-held manner to scan for localized a spot of contamination on a person or object.

For the contamination measurement tests, three replicates of each instrument were positioned at a fixed distance from the track. As the source moved past, the instruments' display reading and alarm condition were noted. For the instruments that were capable of user defined alarm settings, the manufacturer defaults were the configurations for the evaluations.

Notwithstanding that some reconfiguration might assist the user, it was not pursued or recommended because typically the controls to change settings are locked out to the user. Thus the as-is evaluation would be representative of a repurposed the instrument at the moment a crisis unfolded. While not discussed in this paper the Job Aids, which were a complimentary project, requires a complete of the evaluation dynamic range and limitations for each make/model against the mission requirements.[††]

## RESULTS

### Exposure rate accuracy

The results of the evaluation for exposure rate accuracy are in Fig. 3. The data points are the percent difference of the average of ten readings compared to the laboratory delivered exposure rate at the reference levels.[‡‡] This shows that some of the instrument responses varied between replicates. For example, for instrument C at the delivered exposure rate of 2 m $hr^{-1}$, one of the replicates under-responded by 15-20%, while the other two over-responded up to 40% over the range of exposure rates. In contrast, all three instrument D replicates were in agreement with one another.

For exposure rates less than 10 mR $h^{-1}$, corresponding to the Cold Zone, 27 out of 30 instruments' measurements were within the ANSI N42.49A performance benchmark of ± 50%. The exceptions over-responded at 2 mR $hr^{-1}$ and showed variation among replicates. One replicate of instrument A over-responded 53.6% at 2 mR $hr^{-1}$, while all three were within ± 50% at the four higher exposure rates. Two of the three detector F replicates responded with > 50%

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[††] https://www.dhs.gov/publication/st-frg-using-preventative-radiological-nuclear-detection-equipment-consequence, accessed May 11, 2018.

[‡‡] The ANSI N42.49A test paradigm calls for calculating the mean of ten independent readings having a coefficient of variation (COV) ≤ 10%. The COV for the exposure rate readings of all the body-worn and RIID instruments evaluated were < 10% and generally <5%.

error, 72.2 and 62.4% respectively, while the third was 28.7% and within the benchmark. While the results from one instrument F detector appeared questionable, when it was irradiated without the phantom in air for angular response the result was different. Without the phantom, all three were within the ANSI 2 mR $hr^{-1}$ benchmark. Possibly there was some effect from low energy backscatter off the phantom. Instrument I appeared to be inconsistent between 2 and 10 mR $h^{-1}$. This is an artifact because the system switched to the secondary Geiger-Müller detector at the higher exposure rate. With the instrument in the horizontal position, the secondary detector is located approximately 10 cm behind the primary one. When the unit was positioned vertically the response improved at 10 mR $hr^{-1}$ to 21%, 11% and 36%, which are within the ANSI benchmark. At 10 mR $hr^{-1}$, six out of the ten instruments evaluated were within the ANSI benchmark of ± 15%, and all were within ± 40%.

Only three of the body-worn instruments evaluated have sufficient range for use in the Hot Zone. Two were ER-PRD type that over-ranged at 0.1 and 6 Gy $hr^{-1}$ (although the latter model is ruggedized as a PERD), and the third was a PERD[§§] that over-ranged at 2 Gy $hr^{-1}$. For the evaluations at 1 R $hr^{-1}$, instruments A and C over responded outside the benchmark, but within +50%. Instrument B under-responded, one within the benchmark and the other two outside the benchmark but within +25%. At 10 R $hr^{-1}$, instrument A over-responded outside the benchmark but within +45%, instrument B responded accurately within the benchmark within 7%. At 100 R $hr^{-1}$, instrument A over-responded outside the benchmark but within +45% and instrument B was within the benchmark within ±10%.

**Integrated exposure accuracy**

[§§] This instrument is referred to as a PERD but it over-ranges at 2 Gy hr-1 and does not provide the full dynamic range in the ANSI N42.49A standard.

The three models of body-worn instruments with high range capability were evaluated on the phantom for integrated exposure. The results are Figs. 4a and 4b. Instrument A was outside the benchmark and consistently showed a significant over-response, as it did for exposure rate. One of the three over-responded by ~250% and it was assumed to be a malfunction. That particular instrument was also the spare unit that replaced another detector that failed. Instrument B was within the benchmark and C was outside the benchmark, but two replicates were within +25% and one was within –25%.

Conducting irradiations to evaluate integrated dose on low range PRD instruments was not practical. Depending on the instrument, it could take many hours to deliver 5 R. Therefore due to the time and cost constraints to access the calibration facility, the low range instruments were not evaluated for integrated exposure and it was assumed the exposure rate accuracy is indicative of integrated exposure accuracy. Conversely the high range doses could be delivered in minutes with the 68.5 GBq source.

**Over-range accuracy**

For responder safety in CM missions, it is important that an instrument provide a warning if it is exposed to a radiation field higher than its operational range stated by the manufacturer.[***] When exposed to a field 125% of the maximum range, instruments A, B, C, D, E and F indicated an over-range condition with visible, audible, and vibration alarms.

While the RIIDs have over-range capability, they were not included in the over-range. Since this instrument is not deemed appropriate to use in the Hot Zone, over-range evaluations were not considered critical.

[***] In addition, for instruments that measure integrated exposure, the warning should be retained with the integrated dose reading so that the wearer will be aware that the measured value may not be trustworthy; that capability was not verified here.

The instruments that measured integrated exposure at high exposure rates, A, B, and C, promptly recovered from an over-range state and continued to function.

**Angular response**

Because the instruments may be used to conduct wide area radiation surveys, the five body-worn models that display exposure rate were evaluated in air for angular response as a hand-held survey instrument. To simulate this operation, the instruments were evaluated in the vertical and horizontal positions. In the vertical orientation, the instrument was positioned such that radiation was incident on the back (i.e. a rotation of 180° from the front face) and in the horizontal position it was positioned such that radiation was incident on the top (90° rotation). Two exposure rates were delivered with the $^{137}$Cs source, 2 mR h$^{-1}$ and 10 R h$^{-1}$. Instrument C was evaluated at 8 R h$^{-1}$ rather than 10 R h$^{-1}$ corresponding to its operational range. The results are Fig. 5. Of the 15 instruments, 14 were within the ± 30% benchmark, one unit was –34%.[†††] A negative percent difference indicates that an instrument is more sensitive in the vertical orientation. In most cases this is consistent with the manufacturers' indication of the detector position with the case. While Instrument B was within the benchmark it was unclear why it responded with less sensitivity in the vertical orientation.

**Contamination control simulation**

Figures 6 and 7 are the results of the evaluations with the automated moving source with various source strengths, source-to-detector distances, and speeds for all of the instruments, but not including the data for the RIIDs. With the exception of Instrument B, all of the instruments including the RIIDs reliably detect a 37 kBq source at a distance of 5 cm and speed of 15 cm s$^{-1}$.

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[†††] The ANSI N42.49A angular response test requirement is ±30% for angles up to ±45 degrees from the front face, and "In addition, the instrument shall not under-respond by more than 40% when rotated ±45 to 90 degrees from the reference orientation (0 degrees)." The standard does not include a performance requirement for response at 180 degrees (back).

Similarly, all of the instruments except B reliably detected the 740 Bq source at a distance of 30 cm and speed of 30 cm $s^{-1}$. For the 370 Bq source, the backpacks alarmed in 100% of the evaluations, whereas the body-worn instruments results varied. Instruments C, D and two of F alarmed in 100% of the evaluations. For the 185 kBq source, the backpacks alarmed in 100% of the evaluations, and all but Instrument F did not respond to the source. It was inconsistent; two alarmed in 100% and one in 10% of the evaluations, respectively.

**Systems with large detector volumes**

A large detector volume was found to be too sensitive for any type of initial screening mission. Contamination levels of interest would be detected too far away from the source.

## DISCUSSION

Consideration of the results yielded recommendations for procedures to use in repurposing PRND instruments to the specific CM missions and the aforementioned job aids for the operators.

**Exposure rate monitoring and radiation survey**

The results indicate that the body-worn instruments evaluated for exposure rate and angular response provide sufficient accuracy for responder safety or wide area radiation surveys for dose planning and control.

Inside the Hot Zone, monitoring personnel safety requires use of body-worn archetypes with a dynamic range ≥ 10 mR $hr^{-1}$ and overload indication (NCRP 165). Only three out of eight body-worn instruments evaluated had the appropriate operational range and over range indication for use in the Hot Zone. Instruments A, B, and C did not meet the N42.49A benchmark for ±15% accuracy in this zone but were within –25% to +50% accuracy, which is considered acceptable in an emergency. Although the instruments that do not display exposure

rate are best suited for contamination detection, because exposure rates in a contaminated area of a Cold Zone are low, it is acceptable to use instruments that do not read out in exposure rate to monitor for small changes in radiation levels.

**Integrated exposure**

Because it is assumed that only instruments with an over-range capability are appropriate for use in the Hot or Dangerous Radiation Zones and within their respective dynamic range, the exposure rate data are indicative of the accuracy that will be achieved for integrated exposure. Because instruments A and B have extended ranges above 0.1 Gy $hr^{-1}$ but not the full dynamic range in the ANSI N42.49A standard, these instruments would be conditionally useful in the Dangerous Radiation Zone.

Because it is assumed that changing of the parameters set for the instruments is not under operator control, the preset integrated exposure alarm(s) may or may not be appropriate for CM missions. The value(s) should be noted in an associated job aid. In addition to the operator periodically checking the value of integrated dose, the over-range annunciation will provide a second layer of protection to prevent an unplanned integrated exposure.

**Contamination Screening**

<u>Contamination detection</u>

For contamination screening with a body-worn instrument, observations indicated that the audible/visual alarm function should be used, rather than looking for a numerical value in the display for decisions, in conjunction with the prescribed source to detector distance. For example, instruments C and D both alarmed the same for 37 kBq of $^{137}Cs$, but instrument C did not update the exposure rate display. In general the numeric value is not relevant to decision-making and could complicate operation by the user for contamination screening.

Holding the instrument in a horizontal orientation may confound the measurement. It should be oriented in the vertical orientation with the back toward the person or object.

All the body-worn archetype models evaluated except instrument B were found suitable for the initial screening missions. This instrument, a PERD, is designed for personnel safety in high radiation fields and not designed for low levels such as a PRD. As such, the lack of sensitivity was expected.

In general, instruments assigned to initial screening missions should be verified with a 37 kBq source of $^{137}$Cs.

- To reliably detect 740 kBq of $^{137}$Cs on personnel or objects, position the detector at a distance of 30 cm or less and move it a speed no faster than 30 cm $s^{-1}$.
- To reliably detect 37 kBq of $^{137}$Cs, position the detector at a distance of 5 cm from the surface of clothing, skin, or object and move it at a speed of 15 cm $s^{-1}$ but no faster than 30 cm $s^{-1}$.

**Human carried**

<u>Human-Portable Detector (Backpack)</u>

Backpacks performed comparable to the body-worn archetype for both initial screening detection and low-level contamination screening. The backpacks should be oriented in the vertical orientation with the back toward the person or object being screened

<u>RIID - no clear repurposing missions</u>

RIID-type instruments can provide accurate exposure rate and contamination detection but require a knowledgeable user to interpret the readout. They generally do not have manufacturer default settings that align to CM missions, such as body-worn archetypes. For example, while a RIID has a much larger detector volume than the body-worn archetype, for use

to screen for contamination, the operator must look for an exposure rate that would exceed a pre-established value that corresponds to the 37 or 740 kBq of the $^{137}$Cs reference value. Similarly, alarms could be configured, but it is not considered practical in the field and also not likely to be an operator accessible setting.

While the RIID archetypes evaluated each have a secondary high range detector that would enable exposure rate monitoring in the Hot Zone, the high range tests were not performed above 10 mR hr$^{-1}$. Except for advanced users, the RIIDs are generally not a practical instrument to use in the Hot Zone and would require some technical support to use for contamination screening. If technical support is available they could be used to resolve false alarms such as nuclear medical patients. Without a minimal amount of support from an advanced operator or health physics professional, this type of instrument, as-is, generally does not readily fit any particular repurposing mission.

**Other**

Systems with large detections volumes

Because radiation from a contaminated person or object would be detected too far away from the source and this category of equipment is generally not practical to correlate the response or perform localization measurements. These detectors are suitable to be used at a choke point in an uncontaminated area to ensure it remains clean.

## CONCLUSIONS

This study characterized a representative sample of instruments currently deployed for PRND missions to gauge their potential applicability for repurposing to CM missions. Table 5 is a concise summary of the implications of results to repurpose instrumentation. Nine body-worn devices, nine human-carried detectors, six RIIDs and three backpacks, and one mobile system

(large detection volume) were evaluated in laboratory settings for response to various $^{137}Cs$ sources to simulate CM missions. The evaluations demonstrated that the body-worn archetype would have acceptable performance if repurposed appropriately for CM missions. For measuring exposure rate, many of these instruments are appropriate only for use in the Cold Zone, where radiation fields are less than 0.1 mGy $h^{-1}$. The evaluation showed most models performed within or close to the ANSI N42.49A benchmarks, or if not, tended to over respond and err on the side of caution. The instruments deemed appropriate for use in the Hot Zone displayed a warning when exposed to a radiation field higher than the inherent operational range, a crucial requirement for responder safety in CM missions. For the three body-worn instruments with higher ranges appropriate to the Dangerous Radiation Zone, > 0.1 Gy $h^{-1}$, performance was within –30% to +50%. This range of error does not meet the expectations for standard health physics instruments, but in the case of an emergency, first responders must choose between conducting or not conducting missions to save lives, alleviate human suffering or protect critical infrastructure. In lieu of not conducting those missions and the impacts it would entail, this range of uncertainty is acceptable, especially in conjunction with a reasonable predetermined decision dose to remove a responder form an area to control the integrated dose.

Eight of the nine body-worn instruments reliably detected gamma radiation from simulated surface contamination via the audible alarm function if used as a handheld device with appropriate orientation, distance, and survey speed. Therefore this archetype may be used as an emergency alternate for traditional population monitoring equipment, such as a portal monitor or contamination survey probe.

In contrast to the body-worn instruments, RIIDs and mobile systems with large detector volumes were not found to be useful for repurposing. The RIIDs are relatively small in number

and require expert users to interpret their outputs, and a large detection volume is too sensitive for contamination screening. Notwithstanding, users with training a RIID them could make use of them in CM missions compared to all the other equipment categories that would require essentially no user training.

Therefore in the early period of a radiological or nuclear incident when monitoring and dosimetry instrumentation resources are austere, PRND equipment can be effectively repurposed to the CM mission. If used in accordance with the mission analysis and categories, and within the original equipment manufacturer specifications, these instruments can be used to estimate and document doses to responders, plan entries into contaminated areas, contamination screening, and protection of the public, until such time as outside resources arrive with sufficient numbers of standard health physics instruments and personnel dosimetry to replace the PRND equipment.

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List of Figures

1. Photographs of the four PRND archetypes evaluated for consequence management mission. The body-worn archetype includes three categories, personal radiation detector, extended range personal radiation detector, and personal emergency radiation detectors & monitors. The human carried archetype includes two categories, Radio-Isotope Identification Device, Personal Emergency Radiation Detectors and Monitors. The Other archetype includes one category, vehicle mounted large detection volume.

2. The conveyor system is shown with two backpack detectors under test (left) and setting the source to detector distance for the instruments to achieve the virtual source (right). The source is visible on the conveyor system at end of the red holder.

3. Exposure rate accuracy expressed as percent difference with the delivered exposure rate. Points within the shaded areas correspond to the ANSI N42.49A benchmark performance measures of ±50% for less than 10 mR $hr^{-1}$, and ±15% from 10 mR $hr^{-1}$ to 100 R $hr^{-1}$. Note that some of the data points outside the benchmarks are artifacts and are fully explained in the text.

4a. Integrated exposure accuracy of Instrument A expressed as percent difference with the delivered exposure.

4b. Integrated exposure accuracy of Instruments B and C expressed as percent difference with the delivered exposure. The shaded area corresponds to the ANSI N42.49A benchmark performance measure of ±15%.

5. Percent difference between horizontal and vertical orientation to simulate repurposing of a body-worn instrument as a hand-held exposure rate survey instrument. A negative percent difference indicates that an instrument is more sensitive in the vertical orientation. Only one of the 15 instruments tested was outside the benchmark. While Instrument B was within the benchmark it was unclear why it responded with less sensitivity in the vertical orientation.

6. Percent of alarms to a 185, 370 and 740 kBq source of $^{137}Cs$ at a fixed speed 30 cm from the detector that is moving at a speed 30 cm per second. The three rows of bars correspond to source activities of 185, 370 and 740 kBq.

7. The percent of alarms to a source of 37 kBq source of $^{137}Cs$ at distance of 5 cm from the detector. The rows of bars are the source speeds of 15, 30, 60, and 120 cm per second.

Figure 1.

## BODY-WORN RADIATION DETECTOR

RAE Systems – GammaRAE II R PRM-3040

Canberra – UltraRadiac™

Thermo Scientific – RadEye-ER™

Thermo RadEye™ – PRD

Sensor Technology Engineering – Pager S®

Polimaster – 1703M

Sensor Technology Engineering – Pager®

D-Tech – Minirad-D™

## HUMAN-CARRIED RADIATION DETECTOR

Canberra – Inspector™ 1000

Exporanium® – GR-135

FLIR – IdentiFinder™ II

FLIR – IdentiFinder™ I

Thermo Scientific – IdentiFinder™ I

Smith Detection – Radseeker™

Sensor Technology Engineering – RADPACK

Bubble Tech Industries – FlexSpec

Thermo Scientific – PackEye™ FHT-1377

## OTHER

Radiation Solutions Inc. – RSI 700

Figure 2.

Figure 3.

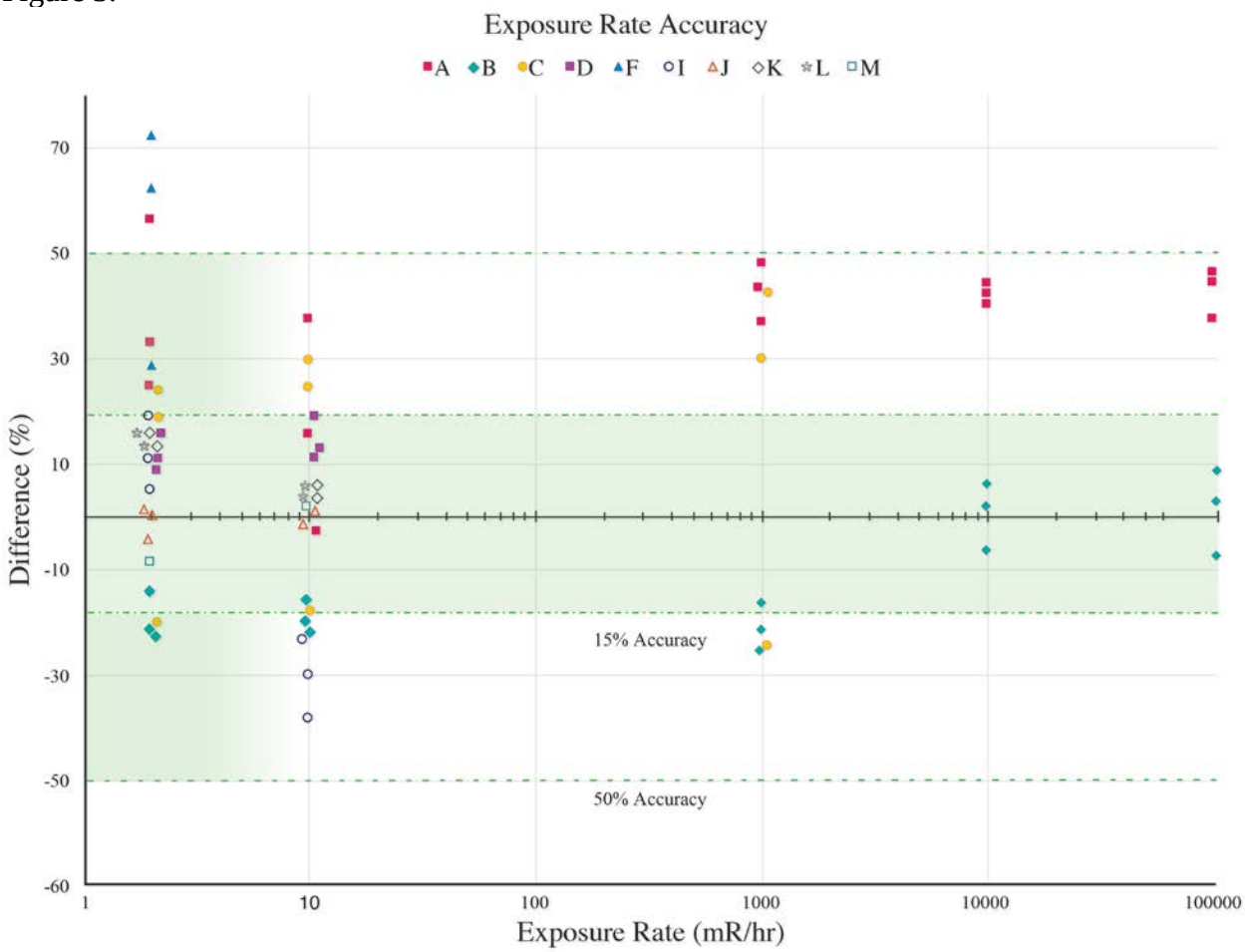
Exposure Rate Accuracy
A B C D F I J K L M
70
50
30
10
-10
-30
-50
-60
Difference (%)
15% Accuracy
50% Accuracy
1
10
100
1000
10000
100000
Exposure Rate (mR/hr)

Figure 4a.

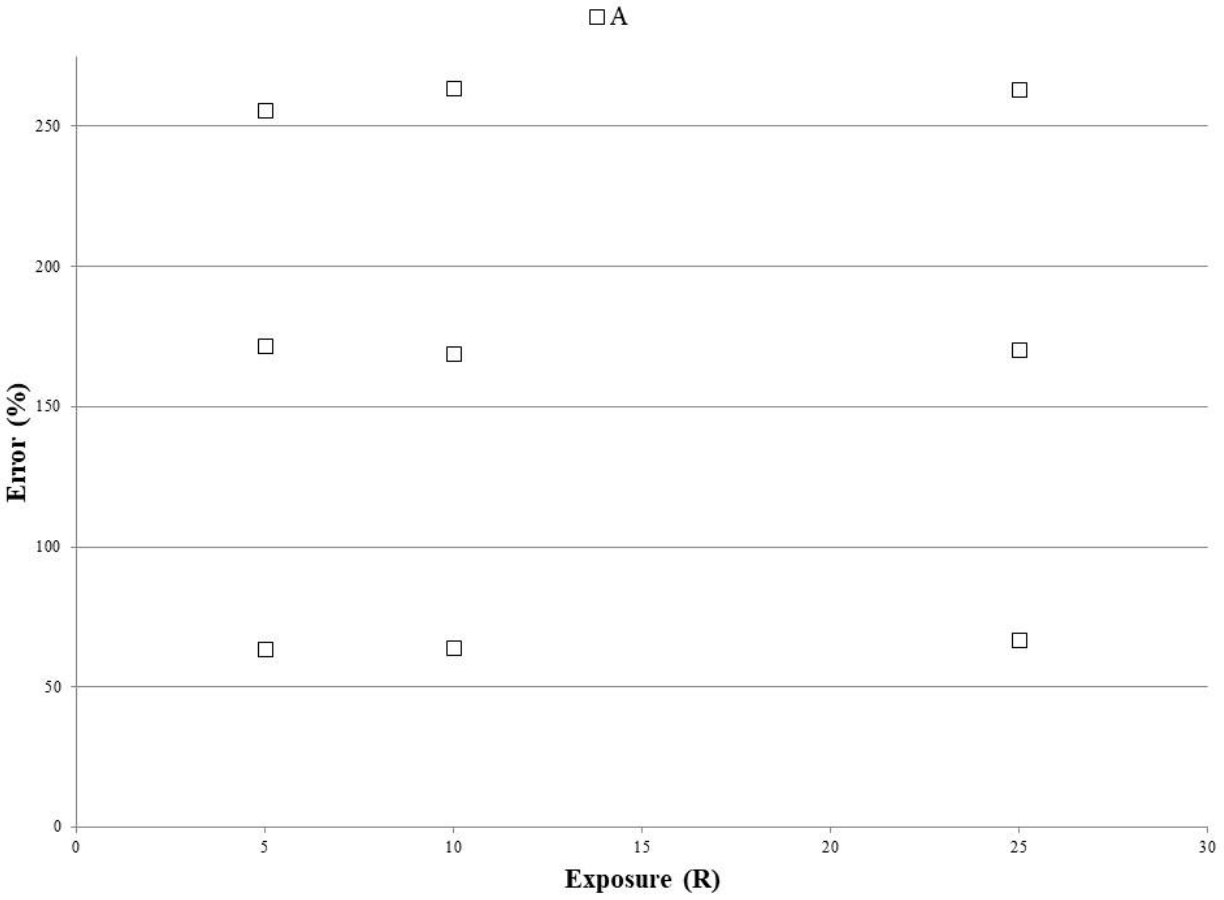

Figure 4b.

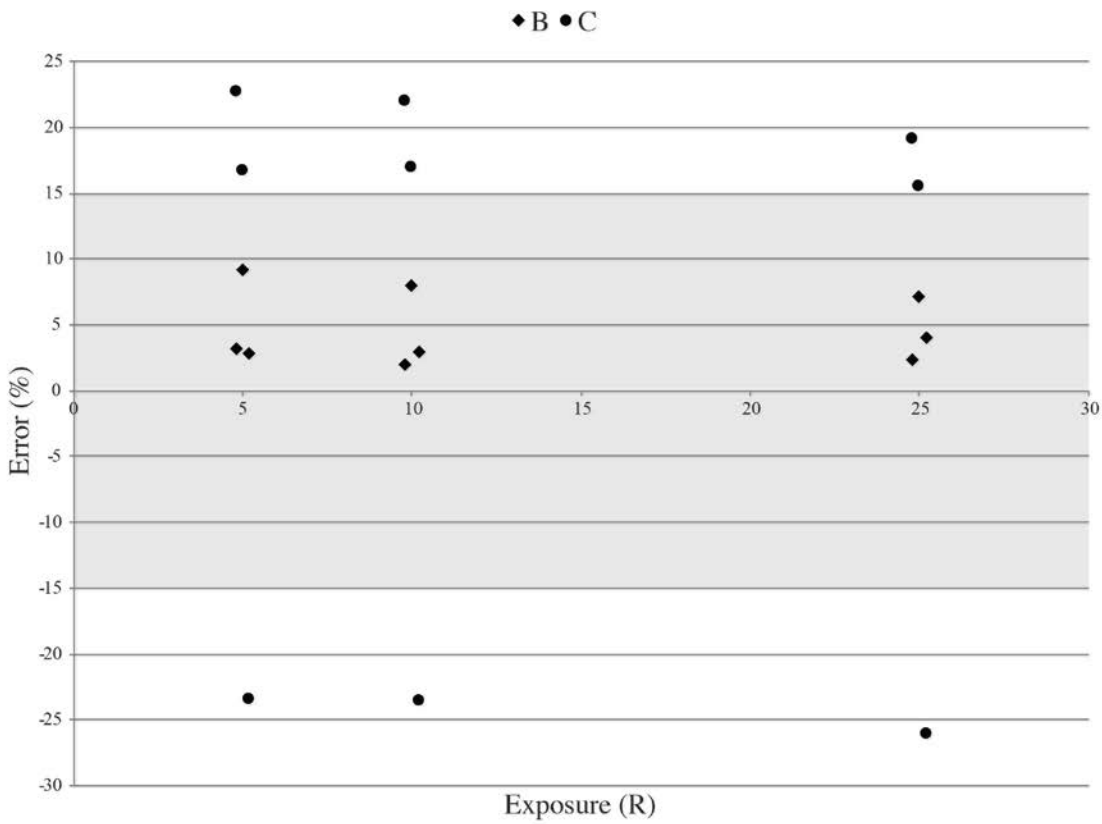

Figure 5.

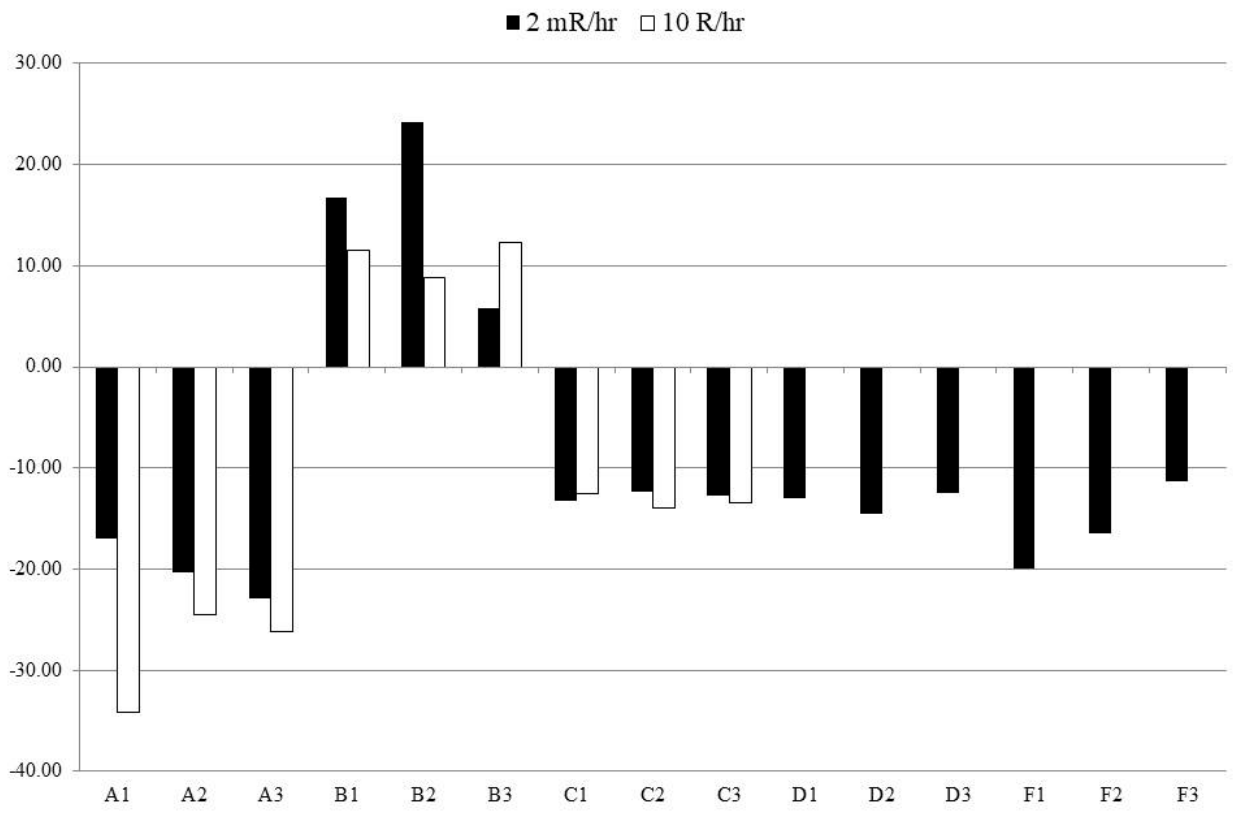
2 mR/hr
10 R/hr
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
A1
A2
A3
B1
B2
B3
C1
C2
C3
D1
D2
D3
F1
F2
F3

Figure 6.

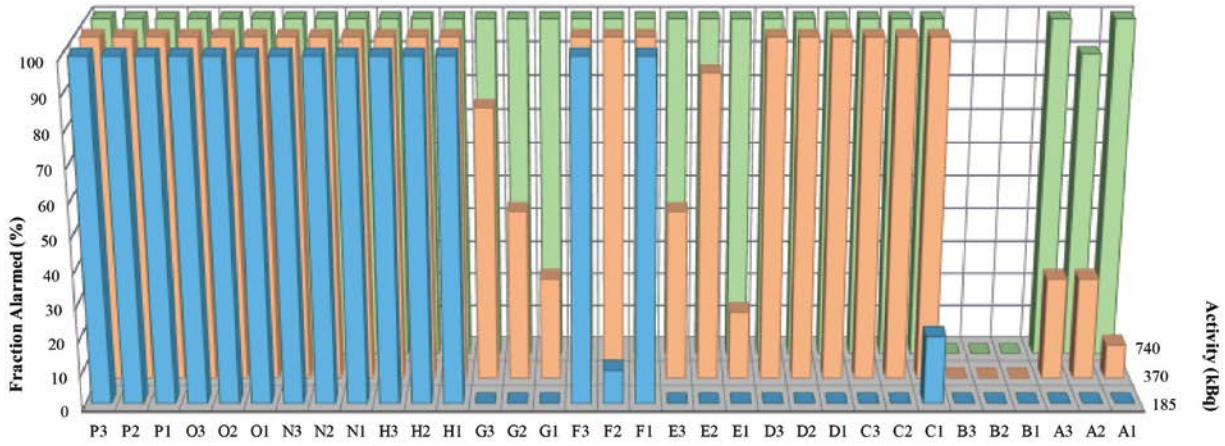


Figure 7.

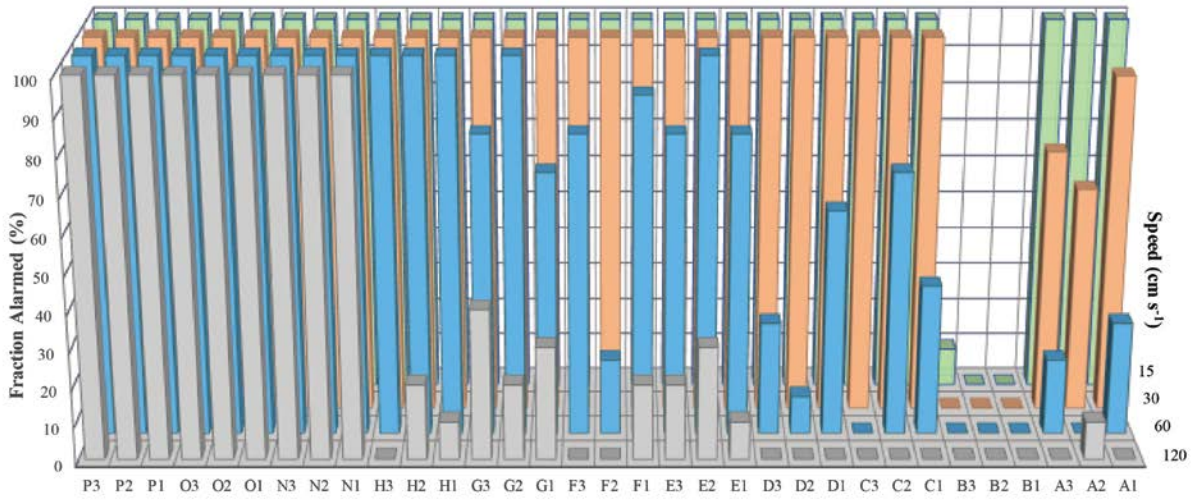

Table 1. Summary of equipment categorization broken down by three archetypes, six categories, and the associated mission applicability (Buddemeier 2017).

| | Category | Characteristics | Mission Applicability for PRND | Mission Applicability for CM |
|---|---|---|---|---|
| **Body-worn** | Personal Radiation Detector | Highly sensitive, can detect small changes from background, alarming, body-worn device capable of passing low exposure rate tests of ANSI N42.32, typically uses scintillation detectors. | Detection of low level radiation for contraband investigation. | Environmental and personnel contamination surveys in Cold Zone |
| | Extended Range Personal Radiation Detector | Extended range, alarming, body-worn device capable of passing low exposure rate tests of ANSI N42.32, but has an extended capability to measure up to 10 R/h or more. | Detection of low level radiation for contraband investigation. | Cold and Hot Zone survey and responder exposure control. |
| | Personal Emergency Radiation Detectors & Monitors | High range, alarming, body-worn device capable of operating in harsh environments and capable of operating above 10 R/h, potentially up to 1,000 R/h (ANSI N42.49A) | N/A | Detection and entry into Hot Zone, exposure control and possibly dose monitoring tool. |
| **Human Carried** | Radio-Isotope Identification Device | Low range, hand-held radiation detector with gamma spectroscopic capabilities. The device should be capable of passing the radiological performance tests indicated in ANSI N42.34. | Identification of the type of radioactive material to support a law enforcement investigation. | Exposure rate or personnel or object contamination surveys in Cold Zone |
| | Human-Portable Detector | Larger (backpack or suitcase sized) detectors capable of passing | Detection of low level radiation for contraband | Environmental and personal contamination |

| | | | | |
|---|---|---|---|---|
| | (Backpack) | radiological performance tests indicated in ANSI N42.43 | investigation. | surveys in Cold Zone |
| **Other** | Vehicle Mounted (Large Detection Volume) | Large detector systems that can be mounted on a car, boat, or aircraft capable of passing radiological performance tests indicated in ANSI N42.43 | Detection of low level radiation for contraband investigation. | Environmental and personal contamination surveys in Cold Zone |

Table 2: Six equipment categories evaluated against the mission analysis (Buddemeier 2017).

| **Mission** | Personal Radiation Detector (PRD and SPRD) | Extended Range Personal Radiation Detector (ER-PRD) | Personal Emergency Radiation Detectors (PERD) & Monitors | Radio-Isotope Identification Device (RIID) | Human-Portable Detector (Backpack) | Mobile System with Large Volume Detector |
|---|---|---|---|---|---|---|
| **Cold Zone (< 10 mR/h)** | | | | | | |
| Exposure Rate | ■ | ■ | ■ | ○ | ○ | ⦸ |
| Integrated Exposure | ⦸ ■[1] | ⦸ ■[1] | ■ | ⦸ ○[1] | ⦸ | ⦸ |
| Contamination Screening | ■ | ■ | ○ ■[2] | ■ | ■ | ○ |
| Radiation Survey | ○ ■[3] | ■ | ○ ■[2] | ■ | ■ | ○ |
| **Hot Zone (> 10 mR/h)** | | | | | | |
| Exposure Rate | ⦸ | ○ ■[4] | ■ | ⦸ | ⦸ | ⦸ |
| Integrated Exposure | ⦸ | ⦸ ■[1,4] | ■ | ⦸ | ⦸ | ⦸ |
| Radiation Survey | ⦸ | ■ | ■ | ⦸ | ⦸ ■[5] | ⦸ |
| **Dangerous Radiation Zone (> 10 R/h)** | | | | | | |
| Exposure Rate | ⦸ | ⦸ ■[5,6] | ■ | ⦸ | ⦸ | ⦸ |
| Integrated Exposure | ⦸ | ⦸ ■[1,5] | ■ | ⦸ | ⦸ | ⦸ |

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

1: Instrument can display integrated exposure or dose.
2: Instrument lower dynamic range 0.1 mR/h.
3: Instrument can display exposure or dose rate, and does not automatically adjust for changes in background.
4: Instrument can alarm with both loud audible and vibration.
5: Instrument dynamic range up to 10 R/h.
6: Instrument dynamic range up to 999 R/h.

Table 3. Laboratory test parameters and benchmarks.

| Test Category | Unit | Irradiation Levels | N42.49A Benchmark |
|---|---|---|---|
| Exposure Rate | R $h^{-1}$ | 0.002 | ±50% |
| | | 0.01<br>1<br>10<br>100 | ±15% |
| Integrated Exposure | R | 5<br>10<br>25 | ±15% |
| Angular Response | R $h^{-1}$ | 0.002<br>10 | ≥ ± 40% |
| Over-range | % | 125 | Display over-range rate warning and retain warning on integrated dose. |

Table 4. Key to graphics and instrument specifications.

| Key | Instrument | Detector Type | Maximum Range (R $hr^{-1}$) | Integrate Exposure | Display Units |
|---|---|---|---|---|---|
| **Body-worn** | | | | | |
| A | RAE Systems GammaRAE II R PRM-3040 | CsI | 600 | Yes | R $hr^{-1}$ |
| B | Canberra UltraRadiac™ | GM | 200 | Yes | R $hr^{-1}$ |
| C | Thermo RadEye - ER™ | NaI | 10 | Yes | R $hr^{-1}$ |
| D | Thermo Radeye ™ - PRD | NaI | 0.025 | Yes | R $hr^{-1}$ |
| E | Sensor Technology Engineering Pager S® | CsI | 0.012 | No | Integer 1-9 |
| F | Polimaster PM 1703-M | CsI | 0.0099 | Yes | R $hr^{-1}$ |
| G | Sensor Technology Engineering Pager® | CsI | 0.0038 | No | Integer 1-9 |
| H | D-Tech Minirad-D™ | CsI | 0.0011 | No | Integer 1-9 |
| **Human Carried** | | | | | |
| I | Canberra Inspector™ 1000 | NaI | 10 | Yes | mR $hr^{-1}$ |
| J | Exporanium® GR-135 | NaI | 10 | Yes | mR $hr^{-1}$ |
| K | Thermo Scientific/FLIR IdentiFinder™ II | NaI | 1 | Yes | mR $hr^{-1}$ |
| L | Thermo Scientific IdentiFinder™ I | NaI | 1 | Yes | mR $hr^{-1}$ |
| M | Smiths Detection RadSeeker™ | NaI | 0.015 | No | µSv $hr^{-1}$ |
| N | Sensor Technology Engineering RADPACK | CsI | N/A | No | N/A |
| O | Bubble Tech Industries FlexSpec | NaI | N/A | No | N/A |
| P | Thermo Scientific PackEye™ FHT-1377 | NaI | N/A | No | N/A |
| **Other (large volume detector)** | | | | | |
| Q | Radiation Solutions Inc. RSI 700 | NaI | N/A | No | N/A |

Table 5. Recommendations to repurpose PRND instrumentation.

| Instrument | Consequence Management Mission* | | |
|---|---|---|---|
| | Exposure Rate and Integrated Dose | Contamination Screening | Radiation Survey |
| PRD | Cold Zone Only | • Use audible/visual alarm rather than looking for a numerical value<br>• To detect 37 kBq of $^{137}Cs$, position the detector at a distance of 5 cm from surface and scan at a speed of 15 cm $s^{-1}$ (no faster than 30 cm $s^{-1}$<br>• To detect 740 kBq of $^{137}Cs$ position the detector at a distance of 30 cm or less and move it a speed no faster than 30 cm $s^{-1}$.<br>• Hold the instrument in the vertical orientation with the back toward the person or object. | Cold Zone |
| ER-PRD | Hot and Cold Zones<br><br>Conditionally in Dangerous Radiation Zone | Same as PRD | Hot and Cold Zones<br><br>Not recommended in the Dangerous Radiation Zone |
| PERD | Hot, Cold, and Dangerous Radiation Zones | Not suitable | Hot and Cold, Zones<br><br>Not recommended in the Dangerous Radiation Zone |
| Backpack | Not recommended | • Same as PRD<br>• Backpacks should be oriented in the vertical orientation with the back toward the person or object | Not recommended |
| RIID | Not recommended | Not recommended | Not recommended |

*All the recommendations are subject to the limiting conditions stated in Table 2.