LLNL-CONF-642561

Comparison of Hand-Held and Pager Radionuclide Identification Systems for Inspections

J. Koglin, S. Sangiorgio, L. Murphy

August 19, 2013

American Nuclear Society
Washington, DC, DC, United States
November 10, 2013 through November 14, 2013

Disclaimer

Comparisons of Hand-Held and Pager Radionuclide Identification Systems for Inspections

J. Koglin[1,2], S. Sangiorgio[1], L. Murphy[3], and the ITRAP+10 Collaboration

[1]*Lawrence Livermore National Laboratory, Livermore, CA 94550*
[2]*Pennsylvania State University, University Park, PA 16802*
[3]*Department of Homeland Security Domestic Nuclear Detection Office, Washington, DC 20528*

INTRODUCTION

Under the Non-Proliferation Treaty (NPT) non-nuclear weapons states with nuclear facilities are subject to onsite inspections. The International Atomic Energy Agency (IAEA) provides facility assessments to ensure peaceful operations are undertaken. Inspections cover a range of nuclear technologies: fresh fuel fabrication plants, research and commercial reactors, wet and dry spent fuel storage sites, and fuel reprocessing facilities.

As a part of the safeguards inspection, evaluators use radiation detection systems to verify the presence of nuclear material and, in some cases, the relative isotopic quantities. Detection instruments are an important component of the non-destructive assay (NDA) techniques employed by inspectors. Such systems are used to perform a number of verifications including:

- Detection of declared nuclear activity
- Detection of declared nuclear material
- Detection of undeclared nuclear activity
- Detection of undeclared nuclear material
- Partial defect detection (spent fuel)

Small, lightweight systems are necessary for these operations. First, the detection system(s) are often needed to be transported quickly in an airplane or automobile for no-notice inspections. Second, the inspector will carry the instrument during the visit and should be encumbered as little as possible.

Currently, inspectors carry a hand-held identification system classified as a Radionuclide Identification Device (RID). However, technological improvements to radiation detectors have produced smaller and lighter systems. Spectroscopic Personal Radiation Detectors (SPRDs) are small enough to be worn on the body and constantly monitor the environment during the inspection.

Commercial SPRDs and RIDs are compared to determine if the smaller system is a viable replacement. Data collected under the Illicit Trafficking Radiation Assessment Program (ITRAP+10) and by the IAEA is used in this comparison. ITRAP+10 was developed to evaluate and compare the performance of available commercial radiation detection equipment against accepted standards. A wide range of RID and SPRD systems have been tested under ITRAP+10. This data is used to recommend additional testing to determine if SPRDs are a viable replacement to current RIDs for some inspection activities.

DATA COMPARISONS

RID data was taken from ITRAP+10 testing at Pacific Northwest National Laboratory (PNNL) in Richland, WA. For the sake of simplicity, a single RID from these tests was considered as a representative of typical RID performance.

SPRD data was obtained from ITRAP+10 testing at the European Commission's Joint Research Centre (JRC) in Ispra, Italy and from the results of a workshop performed at the IAEA Research Laboratories in Seibersdorf, Austria. The SPRDs included in this report are a sample from these tests that show the most promise for use in an inspection environment.Tests were not performed using the same procedures and test conditions between each testing site; differences are noted when relevant.

SPRDs are pocket-sized and worn on the body for the purpose of rapid detection and identification of radioactive materials. These devices are not designed to provide radionuclide identification at the same level as RIDs. The results of these tests should be viewed in the context of acceptable performance in an inspection situation.

General Characteristics

General characteristics of the tested instruments are listed in Table 1. SPRDs are by definition smaller and lighter than RIDs, a characteristic favorable for portable detectors that are carried with a variety of other equipment on inspections. The compact size is primarily achievable by reducing the sizes of the gamma and neutron sensors. This results in lower detection efficiencies, especially at high gamma energies as they can more easily pass through the small detector volume without interacting. This leads to longer count times necessary for accurate radionuclide identifications.

The absolute gamma ray detection efficiency is included

Table 1: ***General Characterisitics***

	SPRD 1	SPRD 2	SPRD 3	SPRD 4	RID 1
Gamma sensor	NaI	CZT	CsI(Tl)	CsI(Tl)	NaI
Neutron sensor	N/A	^{3}He	Li$_6$I(Eu)	Li$_6$I(Eu)	^{3}He
Mass	500 g	370 g	310 g	260 g	1200 g

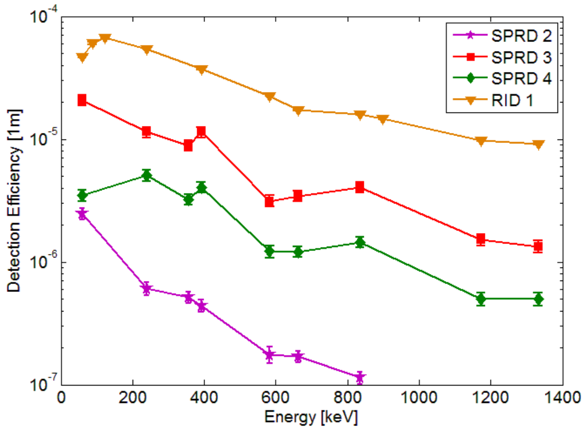

Figure 1: ***Detector Efficiency at 1 m***

in Figure 1 at a distance of one meter as a function of energy for each device included in this test. The RID has the highest efficiency as it is the largest detector with the largest gamma crystal, however, all devices exhibit decreasing efficiency at with increasing energy. This effect is exacerbated by the small crystal size of SPRDs. The efficiency of SPRD 2 is the lowest overall and quickly decreases with energy; typical of CZT crystals.

Dose Accuracy

Accurate response of the systems over their operational dose range is important for identifying declared and undeclared nuclear activities. Neither SPRDs nor RIDs are designed primarily to measure dose-equivalent rate. However, their indication can provide an approximate value of ambient dose-equivalent rate that should be reasonably accurate. Dose rate measurements were compared for ^{137}Cs and ^{241}Am to understand the response of a range of energies. Within a factor of two, the measured dose-equivalent rate agreed with the true value at low doses. At fields in excess of 50 μSv/h, the reported dose-equivalent rate significantly differed from the true value. However, at field strengths below this, such as would be encountered in typical inspection activities, the RID only marginally outperforms the SPRDs.

The dose rate measurement feature is only available while operating the "search" mode of the RID. SPRDs are continuously scanning the dose-equivalent rate. Instead of physically carrying a detector to identify increased radiation levels, as is necessary when using the RID, an SPRD can be worn on a belt clip and continuously monitor.

Radionuclide Categorization

Both the ANSI and IEC standards characterize the radionuclides that are most likely to be encountered by hand-held instruments. The overarching and familiar categories are Special Nuclear Material (SNM), Naturally Occurring Radioactive Material (NORM), Industrial Isotopes, and Medical Isotopes.

All of the instruments have the ability to identify important SNM isotopes and isotopes from the other categories. However, the RID has library entries that distinguish between Highly Enriched Uranium (HEU) and Low Enriched Uranium (LEU) and between Reactor Grade Plutonium (RGPu) and Weapons Grade Plutonium (WGPu). These are both important distinctions for item verification and identifying unknown radiation sources during inspections.The inclusion of a radionuclide in the identification library does not reflect the ability of a device to properly and consistently identify these isotopes.

Single Radionuclide Identification

An important use for hand-held detectors in inspection activities is to verify SNM inventories by identifying Uranium and Plutonium in storage. Single radionuclide identification test results from ITRAP+10 and the IAEA workshop included here are compiled based on testing conditions. Table 2 refers to data collected by the JRC and PNNL as part of the ITRAP+10 effort. These tests were conducted in accordance to ANSI standards; the dose rate and collection times of which differ for RIDs and SPRDs. SPRDs were exposed to a field of 1 μSv/h above background and allowed an identification time up to 5 minutes. The RID was exposed to a field of 0.5 μSv/h above background and allowed a count time of 1 minute for unshielded cases and 2 minutes for shielded cases.

Identifications are considered complete if the tested isotope is the primary identification reported by the instrument, regardless of any secondary identifications. An identification is considered correct if only the tested isotope is identified. Identifications of ^{241}Am for of WGPu and RGPu tests is considered correct since the aged samples contain considerable amounts of ^{241}Am.

In the case of shielded HEU, 24 out of 25 of the incorrect identifications by the RID were of LEU. The steel shielding attenuates the 186 keV gamma of ^{235}U more than the 1001 keV gamma of ^{238}U which results in an overrepresentation of ^{238}U, and hence an identification of LEU. Of the 7 incorrect identifications by the RID of WGPu, 6 were of RGPu. This is most likely a symptom of the more detailed SNM library the RID employs. These distinctions the RID makes tends to inflate its rate of incorrect identifications.

Results included in Table 3 are taken from the IAEA workshop. The data was collected as follows: two tests at a dose rate of 0.5 μSv/h, two at 0.25 μSv/h, and two at 0.05 μSv/h above background. As well as two tests at 0.5 μSv/h behind 6 mm of steel. Two models of SPRD 1 and SPRD 2 were tested and the results combined. In the case of WGPu, one test at 0.05 μSv/h was omitted. Identification time up to 5 minutes was allowed; the actual identification time was not recorded.

In these tests, the SPRDs perform remarkably well, with the exception of SPRD 4, especially considering 2/3 of the tests were conducted at dose rates those of the RID tests. Most of the incorrect identifications came at the 0.05 μSv/h, the same dose rate allowable for background during the testing. Although more direct comparisons between RIDs and SPRDs are necessary, these tests suggests that SPRDs are capable of reliably and consistently identifying SNM, given appropriate count times.

Multiple Radionuclide Identification

The instruments were tested in their ability to identify multiple isotopes simultaneously. There were few cases in which the detectors were tested with the same isotopes under the same conditions, but it was observed that the RID more often correctly identifies SNM and the secondary isotope even when the SNM is heavily masked. SPRD 4 performed poorly, rarely identifying the SNM. SPRD 3 had difficulty identifying Plutonium samples, often identifying ^{241}Am. SPRD 1 and 2 performed near the level of the RID but often missed the SNM when it was heavily masked.

CONCLUSIONS AND RECOMMENDATIONS

It is difficult to directly compare RID and SPRD performance for use in IAEA inspections using the available ITRAP+10 data due to dissimilar testing conditions. In the tests included here, SPRDs are not heavily outperformed by the RID, however more testing is necessary for a definitive and quantifiable comparison.

The tests compiled here have been taken from a variety of sources with a variety of test configurations. These tests should be performed under the same test conditions to directly compare the performance of SPRDs to RIDs. Dose rate and count times for identification are the most obvious differences in these tests. However, it is also necessary to test Uranium and Plutonium samples of the same composition and to test with the same shielding configuration and number of trials. The Plutonium samples used in these tests have a significant ^{241}Am contamination due to their age which many detectors identified. Using a more pure Plutonium sample would better showcase a detector's ability to identify this material.

Performing a spectral comparison of SNM samples between RIDs and SPRDs to test the ability to infer the enrichment of Uranium samples would be informative and pertinent to an inspection situation. The ability of each system to resolve the ^{235}U 186 keV line from background radiation should be investigated; the ability to discern this peak is important for "infinitely thick" verifications of stored fresh fuel pellets. The 186 keV peak and the 1001 keV peak, from the decay of ^{238}U, is used for thinner samples. The resolution and efficiency of the 1001 keV peak and the ratio of integrated net counts in both peaks should be compared. The resolution of peak areas of lines from ^{241}Pu and ^{241}Am should be examined, which may be used to estimate the age of Plutonium samples.

An important aspect not addressed by the tests used above is the time to identify SNM. Many of the tests above allow a 5 minute identification time for the SPRDs; often the identification is completed sooner. The length of time required to accurately identify SNM samples for SPRDs and RIDs should be compared and lower limits established.

ACKNOWLEDGMENTS

This work was performed under the auspices of the U.S. Department of Energy under contract number DE-AC52-07NA27344.

Table 2: ***Single Radionuclide Identification - ITRAP+10***

	SPRD 1	SPRD 3	SPRD 4	RID 1
HEU				
Number of Tests	30	32	33	30
Complete	28	32	33	29
Correct	28	32	26	29
Percent Correct	93%	100%	79%	97%
HEU + 5mm Steel				
Number of Tests	32	30	32	30
Complete	32	14	30	5
Correct	32	14	19	5
Percent Correct	100%	47%	60%	17%
RGPu				
Number of Tests	30	30	35	
Complete	30	27	32	
Correct	30	27	32	
Percent Correct	100%	90%	91%	
WGPu				
Number of Tests				30
Complete				23
Correct				23
Percent Correct				77%

Table 3: ***Single Radinuclide Identification - IAEA***

	SPRD 1	SPRD 2	SPRD 4
HEU			
Number of Tests	12	12	6
Complete	12	12	6
Correct	12	12	6
Percent Correct	100%	100%	100%
HEU + 6mm Steel			
Number of Tests	4	4	2
Complete	4	4	2
Correct	4	4	2
Percent Correct	100%	100%	100%
RGPu			
Number of Tests	12	12	6
Complete	9	10	0
Correct	7	10	0
Percent Correct	58%	83%	0%
RGPu + 6mm Steel			
Number of Tests	4	4	2
Complete	1	4	0
Correct	1	4	0
Percent Correct	25%	100%	0%
WGPu			
Number of Tests	10	10	5
Complete	8	9	0
Correct	8	9	0
Percent Correct	80%	90%	0%