

# Short Pulse Active Interrogation System for Finding Fissile Materials

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## ABSTRACT

There are important reasons to find fissionable materials quickly, cheaply, and safely. Passive gamma and neutron systems work reasonably well for unshielded fissile and fissionable materials (special nuclear material [SNM]) that have a strong gamma or neutron signal. However, many SNMs do not emit a strong enough gamma or neutron signal for passive systems to be able to detect the material. The detection sensitivity of these traditional systems can be somewhat improved by using very long count times and large detectors, and/or large numbers of detectors. Active interrogation methods have been used to overcome the weaknesses of passive systems. However, the traditional active systems pose a number of other logistics problems. Many configurations use neutron generators that are too large, too powerful, too expensive, and/or create too much exposure for the personnel operating them to be practical for rapid, portable detection capability. These weaknesses of active systems can be overcome by using a neutron source that emits very short and intense neutron pulses. We present results with a safe, portable, nearly instantaneous system that works at nominal 1-meter distances. Using a short intense burst allows us to make use of prompt emissions. This means that less radiation (orders of magnitude) over other systems is needed, resulting in a safe, more compact system. The short period of time and the interrogating pulses still create very characteristic gamma lines but make the system safe to use at a minimal stand-off distance. As an active system, it can detect both uranium and plutonium in shielded and unshielded scenarios. In this paper, we present the status of a joint research and development project between Sandia National Laboratories, Los Alamos National Laboratory, and Aquila Technologies using a short pulse interrogation active interrogation system for SNM, and some of the results obtained to date.



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## ACKNOWLEDGMENTS

We would like to acknowledge the support of T. Zipperian, D. Walsh, S. Dirk, K. Ortiz, W. Hermina and C. Renschler who have supported aspects of this work since its inception after 9/11.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. This paper describes objective technical results and information analysis. Disclaimer: Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.



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# 1 INTRODUCTION

Systems that can search cargo for special nuclear materials (SNM) and improvised nuclear devices (IND) using low-hazard methods without delaying commerce are critical to detecting trafficking of illicit nuclear materials. Methods for detecting and/or quantifying SNM for declared and later undeclared purposes were first developed for safeguards purposes.

International safeguards organizations such as the International Atomic Energy Agency (IAEA) use a variety of gamma and neutron detectors to inspect declared activities known to involve SNM for verifying the correctness of the records for materials types and their quantities.<sup>1,2</sup> Since the advent of the Additional Protocol,<sup>3</sup> the IAEA also looks for undeclared or hidden SNM.

High- and medium-resolution gamma systems with the appropriate software are common in the safeguards to verify uranium enrichment and plutonium isotopics.<sup>4</sup> Such systems are often combined with neutron counters for quantification of the SNM materials. Similar systems are used in nuclear and radioactive waste assay measurements where the waste is known to contain SNM or is suspected of containing SNM.

In addition to the passive techniques, the technology for active interrogation systems is common for safeguards and waste assay when the passive signal is too weak to give a useful measurement result. The U.S. Department of Energy complex uses active systems such as active well counters, differential die-away systems,<sup>5</sup> Cf-252 shufflers,<sup>6</sup> and Add-a-Source systems<sup>7</sup> for waste assay and in international safeguards. The basic technology and physics of these types of active and passive systems is mature and well understood.<sup>8</sup>

These safeguards and waste systems are not well suited for searching and detecting SNM materials in baggage, cargo, or various other field situations. The systems are often large and expensive. Passive systems are designed to either measure the amount of plutonium accurately for safeguards accounting purposes, or to find a very small amount of plutonium in a large waste container. This can only be done with long count times and large detectors, and/or large numbers of detectors. A typical count time is about 1 hour per container. Currently there are no practical passive techniques to find uranium in the presence of other materials.

Passive radiation portal monitors (RPMs) were initially designed in the context of safeguards and nuclear security to prevent someone from walking away from a facility with SNM. The first reports describing the concept date back as far as 1973.<sup>9,10</sup> The initial RPM systems measured gamma radiation and did some signal processing to differentiate SNM from changes in the natural background. Extensive shielding of the SNM was not a concern. The ability to detect neutrons was soon added to the portal monitoring concept.<sup>11,12</sup> Portal monitor designs became commercially available through several companies in the 1990s. The need for such devices grew explosively after the events of September 11, 2001. However, the current devices used at border crossings and other checkpoints, both in the U.S. and elsewhere, still use the same basic principles and science developed in the 1970s and 1980s. The number of detectors, their size, the signal processing, and the analysis algorithms have been updated and modernized for the new mission that often involves being able to make the measurement in a very short period and finding heavily shielded SNM.

In this new environment, these portal monitors must be able to adapt to varying natural radiation backgrounds, which in field conditions are much more variable than inside facilities. They must also be able to discriminate against medical or industrial radioactive sources that may be present,

something that was rarely an issue in the 1970s. This is not a simple task given the short time allowed for the measurement, the limited resolution of the detectors for cost effectiveness, and the very weak spontaneous gamma and neutron emissions from SNM.<sup>13,14</sup>

Various active interrogation systems for cargo and baggage inspection for both explosives and fissile materials/SNM also exist. Many of these systems started with explosives detection systems where the object of interest was irradiated with neutrons, and the signal of interest was characteristic prompt gamma rays produced by the absorption of such neutrons in the elements present in explosives. This class of analysis, entitled prompt gamma neutron activation analysis (PGNAA), quickly developed into several sub-methods such as thermal neutron activation (TNA), pulsed thermal neutron activation (PTNA), fast neutron activation (FNA), pulsed fast neutron activation (PFNA), etc.<sup>15,16</sup> While the physics of the method worked, concerns arose about the effects of such powerful irradiation.<sup>17</sup>

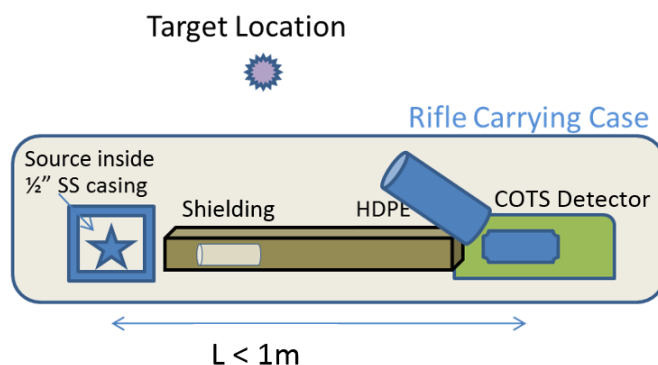
When the explosives detection systems were adapted for SNM detection, the measured signal was based on gamma rays characteristic of SNM.<sup>18</sup> Alternatively, the measured signal was based on induced neutrons emitted by the object of interest between the pulses of interrogating neutrons.<sup>19</sup> Some methods rely on interrogating the object of interest with high-energy photons and detecting the characteristic neutrons emitted by the SNM if such material is present.<sup>20</sup>

These active SNM detection systems generally need long count times; otherwise, they may not have the detection sensitivity for field operation and pose several other logistics problems as well. Many systems that use neutron generators or photon accelerators are too large, too powerful, too expensive, and/or they create too much exposure for the personnel running them to be practical for the rapid, man-portable detection capability needed. Even with sufficiently powerful neutron or photon generators, these designs may still need large detectors, often in large numbers, to achieve the desired detection sensitivity.

An analysis of the above neutron techniques shows that current efforts to detect SNM follow the paradigm of using long-pulsed systems, pulsed fast neutron analysis (PFNA), or associated particle methods. There is also detection work using just gamma sources in which the physics is different, but many of the goals and techniques are similar. Schumer et al. have used a short-pulse technique related to ours, but their method used gamma interrogation.<sup>21</sup> Eberhardt et al. are pursuing both gamma and neutron interrogation but use long-pulsed systems.<sup>22</sup> Neither group uses a single intense short neutron pulse for detection.

## 2 SUMMARY OF THE SHORT PULSE INTERROGATION METHOD

Our system's hardware and software employ an intense, short duration ( $\ll 1$  ms) neutron source in a stainless steel (SS) enclosure to generate an interrogation pulse. All mechanical components are contained in a standard hard-sided plastic rifle case. Figure 1 illustrates the geometry for the near-field active detection system. The bulk of the mass is the shielding (high density polyethylene, HPDE) between the source and the detector. Typically, a single trace from a commercial off-the-shelf (COTS) LaBr<sub>3</sub> scintillator is analyzed to determine gamma spectra, both while the source is on and again after the source is powered down. Traces from multiple consecutive shots can also be summed for better statistics, if needed.



**Figure 1. Experimental setup for near-field active detection system.**

The neutrons in the interrogation pulse interact with a target. The system is configured so that a gamma detector sees the target but does not see the neutron source. The interaction of the neutrons in the interrogation pulse with the target results in a detection pulse caused by the emission of gamma radiation characteristic of the material in the target. The timing and energy of the prompt gammas in the detection pulse are different from the timing and energy of gammas from the background. This prompt gamma portion of the detection pulse contains identifying features that are primarily observed while the neutron source is on or shortly after the interrogation pulse ends. Therefore, we use a gamma detector that has a high data rate. The current data was collected with a LaBr<sub>3</sub> detector connected to a photomultiplier and a fast digital oscilloscope. Other types of detectors and signal processing electronics are also possible, provided they can handle the fast data rate. The data stream from the gamma detector is analyzed using an algorithm that rapidly converts the data stream into gamma spectra. The algorithm bins both the time and the magnitude of the responses to create the spectra. The algorithm emphasizes the short-time, fissionable-material-prompt gamma response to maximize the signal-to-noise ratio of the binned signals.

This method is much faster than the other active systems for the same purpose and provides a much lower dose to the item being interrogated and the system operators. This is because only a single, short-duration neutron pulse is needed, and the greatest number of neutron-photon decays occur during a very short time after the interaction. Table 1 shows a summary comparison of our method with other active detection methods.<sup>23,24,25</sup> Safety and dose considerations are shown in column 3 of the table.

**Table 1. Parameter assessment for various methods of active detection.**

Method	Group	Estimated Normalized Neutron Source Dose <sup>†</sup>	Estimated Interrogation Time / Target	Effectiveness
Combined Neutron and Gamma (Long Pulse)	Eberhardt	5000	180 seconds (at 1 meter/minute scan rate for a 3-meter target)	Imaging 2D Z map
Delayed Neutrons Differential Die Away (14 MeV)	Runkle	100	500 seconds	Presence of SNM
Associated Particle (Prompt and Delayed)	Mihalcz	400	600 seconds	Presence of SNM
Short Prompt Intense Neutron (SPIN) Sensing	Our work	1	< 1 second	Presence of SNM, quantity of SNM

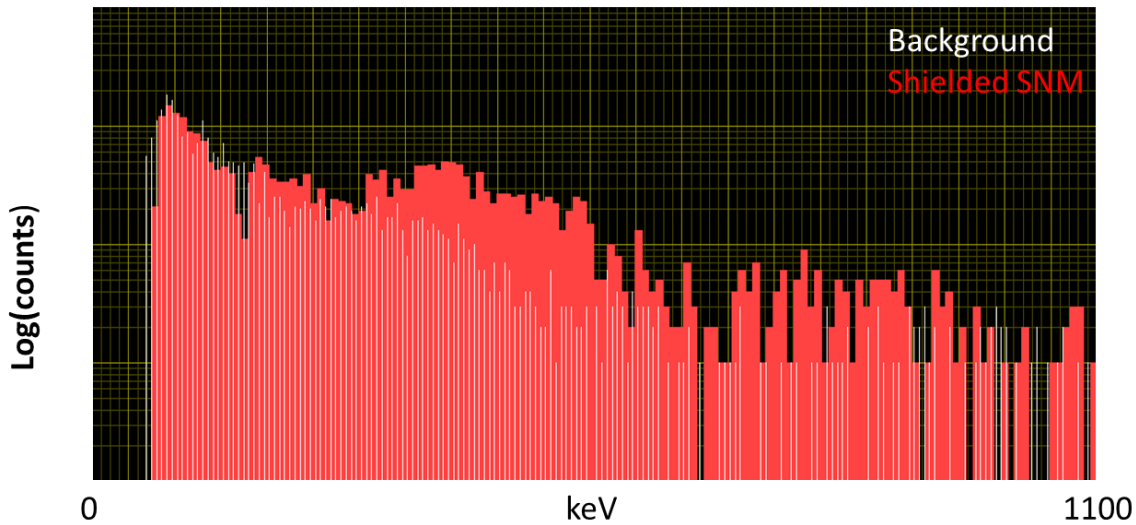
<sup>†</sup> Estimated Normalized Neutron Source Dose = (Group Src / SPIN Src)\*(SPIN Solid Angle / Group Solid Angle)\*(SPIN Estimated Detector Efficiency / Group Estimated Detector Efficiency)

### 3 RESULTS

We conducted a series of experiments with differing shielding materials combined with various SNM target materials. Identical statistical analyses were performed for the matrix of experiments, showing adequate statistical variation between configurations for us to have a high degree of confidence discriminating between target types and nulls (solid targets without actinides).

The spectra were obtained using custom software to correct for pulse pile-up and to identify the peak voltage for individual events. Analysis of the spectrum acquired during source operation was enough to identify the presence of actinides in the field of view. Analysis of the spectrum once the source is off offers additional information not discussed here. The spectra were summed from five source events and five summed background events (see Figure 2). Each histogram was weighted by the source output as measured on an independent neutron sensor (not shown in figure). The red histogram (more events) was obtained with a polymer-shielded small amount of SNM as a target. The white histogram was obtained with no target as background. The two histograms illustrate the difference between a clean background and fissionable material. The difference is clearest in the fission continuum between nominally 300 keV and 500 keV. They are both visually and statistically distinct.

During the experiments, operator dose was monitored, and no appreciable dose was measured. Extrapolating from prior use with the source, we believe reasonable concepts of operation for in-field use which do not exceed occupational limits for radiation workers can be developed.



**Figure 2. Clear distinction between shielded SNM and background spectra. Histogram created from summing multiple traces.**

#### **4 CONCLUSIONS AND FUTURE WORK**

The spectral distribution between 200 keV and 500 keV is consistent with a fission gamma spectrum. The rest of the background is consistent with expectations for the materials in the environment as modeled with Monte Carlo N-Particle (MCNP®) code.\* This, along with other results not shown, gives us statistical confidence in distinguishing between different backgrounds and SNM in multiple combinations.

With these results, the SNL/LANL/Aquila collaboration has now demonstrated the fundamental characteristics of a near-field, portable, and nearly instantaneous method for searching for SNM. There are statistically significant differences between actinide-bearing targets and a series of non-actinide targets and backgrounds. The use scenario(s) can allow a user to operate the system routinely and still be below the occupational dose limit of 0.05 Sv/yr (5 rem/yr).

Additional work needs to be done to develop false positive and negative rates under the array of conditions expected during practical scenarios for SNM/WMD detection. The foundation justifying further work has been documented. With additional effort and funding, we expect an operational configuration could be provided for special operations use in as little as 1 to 2 years.

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