Niowave Neutron Interrogation System

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INTRODUCTION

Special nuclear materials (SNM), primarily enriched uranium and plutonium, are easily shielded from the existing passive detection systems at the ports of entry to the United States. Recent technological advances in electron accelerators, neutron generators, and radiation detectors make X-ray and neutron based active interrogation systems technically and economically feasible. Therefore, Niowave is developing an active interrogation program based on X-rays and neutrons using its superconducting electron linacs and compact DD neutron generators.

In a neutron based active interrogation system, Niowave is uniquely capable of developing a modular and mobile interrogation system quickly and economically because we can leverage our current resources that include: a subcritical assembly with kilograms of SNM, a pulsed DD neutron generator (DD n-gen), various neutron and γ-ray detectors, and expertise in radiation safety and licensing of accelerators. Niowave will produce a system capable of detecting 1 kg ^{235}U at 1 meter in less than 10 seconds, with multiple corroborating signals leading to a confidence level greater than 95%. This initial determination can then trigger a longer secondary scan to measure: SNM with ~0.1 kg resolution, isotopic composition of object, γ-ray imaging with ~1 cm resolution, and the k-value of the SNM assembly. Because we will be looking for multiple signals using five concurrent detection methods, this system will distinguish between shielded or unshielded ^{235}U or plutonium and other contraband. This is a distinct improvement over interrogation techniques that would rely on one or two types of signals. The entire system will use less than 5 kW of electrical power and will fit inside a standard van for discrete interrogation with removable components for pin-point interrogation or conveyor belt operation.

TECHNICAL APPROACH

In Niowave's Neutron Interrogation System (NIS), multiple corroborating signals will be investigated during, in between, and after the pulses of a DD n-gen. Only an interrogation system capable of cross checking correlations between signals from a variety of detection methods can distinguish SNM or contraband, independent of shielding configuration or other disguising techniques. These methods are labeled A through E in Fig. 1 that illustrates the pulsed structure of the interrogating neutron beam and the respective detection methods the NIS system will utilize. Detection methods A through D are measured concurrently while the pulsed DD n-gen is running and used for the initial SNM-detection algorithm. Data for methods A and C are collected while the neutron beam is On whereas data for methods B and D is collected in between pulses (when the beam is Off). Detection method E occurs after the last beam pulse and measures the rate at which the γ-ray and *n* signals decay in a few seconds due to beta decay of shorted lived fission products (FP).

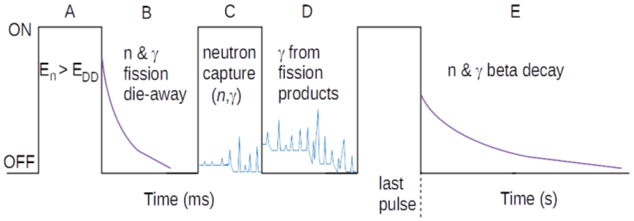

Fig. 1. Structure of 100 Hz pulsed neutron beam (not to scale) with five concurrent detection methods the NIS will utilize during beam On and beam Off periods to detect SNM and other contraband.

Table I. Chart of detectors and signals for different interrogation methods.

Method	Label	*n* Source	Signals	Detectors
E_n>E_{DD} (TENA)	A	On	*n* energy	Stilbene
Fission die-away	B	Off	γ rate, *n* rate	Stilbene, ^{6}Li-panel, HPGe
n-capture gamma's	C	On	γ spectra	HPGe
Short-lived FP	D	Off	γ spectra	HPGe
Beta decay of FP	E	Off	γ rate + γ spec, *n* rate	Stilbene, ^{6}Li-panel, HPGe

Method A is called Threshold Energy Neutron Analysis (TENA) and looks for neutrons from fission with energy above the DD n-gen (~2.5 MeV). Method B detects the die-away signals of prompt fission and is only looking at the rate of decay of the γ-ray and *n* intensity (not spectroscopy) on millisecond time-scales. Methods C & D are looking for characteristic γ-rays from neutron capture and very short-lived FP, respectively.

The NIS design begins with a portable Starfire DD n-gen running at 100 Hz with 10% duty cycle and a peak intensity of 2.5×10^8 *n*/s and a suite of detectors to mount inside a standard van. Three detector types are used to measure the signals from the five detection methods: ^{6}Li-based thermal-neutron detector from Silverside Detectors, γ/*n* discriminating organic stilbene scintillator [1], and high purity germanium (HPGe) γ-ray spectrometer and imager from PHDS Co. Table I lists the overlapping signals each detector type will measure. Fig. 2 shows a CAD drawing of the interrogator components. These detectors are connected to the digital data acquisition system (DAQ) and live-analysis system capable of cross checking the results from detection methods A-D to detect 1 kg of ^{235}U within 10 seconds. This determination could then trigger a secondary scan of up to 5 minutes, using all detection methods, to refine the results. This is a technique transcends previous proposed active interrogation methods that rely on single detection modalities, which can be compromised by specific shielding or disguising techniques. Appropriate collimation and shielding is included to: reduce background to detectors from the DD n-gen, reduce radiation exposure to the technicians and public, and increase neutron intensity at the object. The entire system power consumption is less than 5 kW, using an AC hookup if available or battery backup.

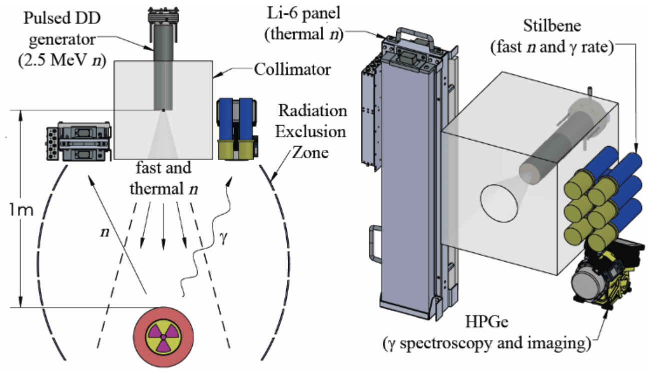

Fig. 2. CAD drawing of interrogation assembly with DD n-gen, collimator, and three types of detectors.

Niowave specializes in manufacturing superconducting electron linacs and their applications for *X*-ray-based active interrogation and fission-based radioisotope production. We have a license to operate our DD n-gen in Michigan public spaces for in-field testing. We also have extensive experience with necessary radiation-safety protocols to protect technicians and the public. Niowave has ~2 kg of SNM and attained preliminary results for most of the detection methods using Niowave's subcritical uranium target assembly (UTA) shown in Fig. 3. Based on preliminary data, and reviews of published results [2,3], the detection requirements for the final NIS using the Starfire DD n-gen are calculated to be: 2 Silverside ^{6}Li-panels, eight 2" Stilbene detectors, and 2 PHDS modules.

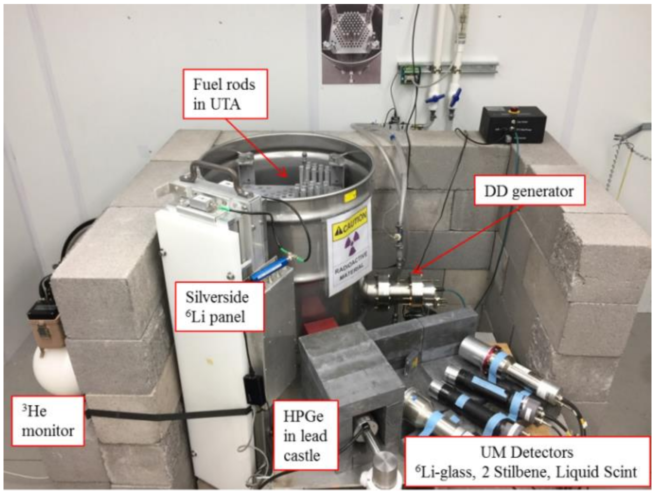

Fig. 3. UTA with detectors for which we already have data on neutron-interrogation of ^{235}U.

PRELIMINARY RESULTS

Preliminary results were obtained using different detectors shown in Fig. 3. The stilbene and liquid scintillator detectors were used for the threshold energy neutron analysis. The difference between On and Off settings was clear in all fast neutron detectors (stilbene, liquid scintillator). Fig. 4 and 5 shows the response for the liquid scintillator detector for both DD generator Off and On, respectively. With the DD generator Off there were only a few signals above the 0.56 MeVee (which corresponds to the light output threshold for 2.51 MeV neutrons) threshold in 20 minutes of running. The count rate for neutrons (blue data) increases one to two orders of magnitude above 2.51 MeV neutrons when the DD generator is On. This method showed the potential to provide rapid verification of fissionable material.

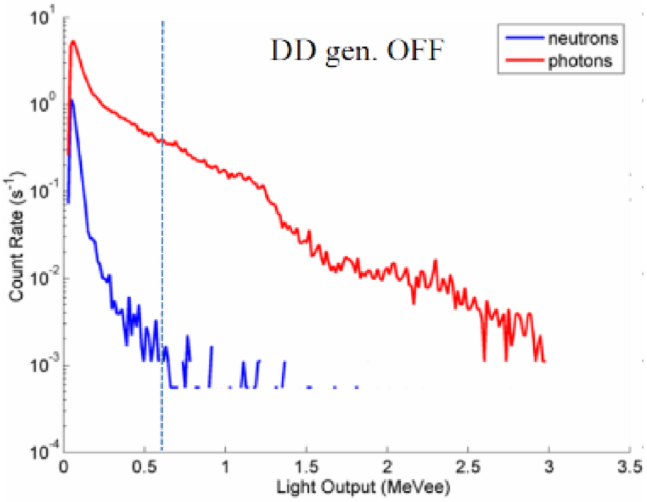

Fig. 4. Response of UM Liquid detector to UTA interrogation (with water) for DD generator Off.

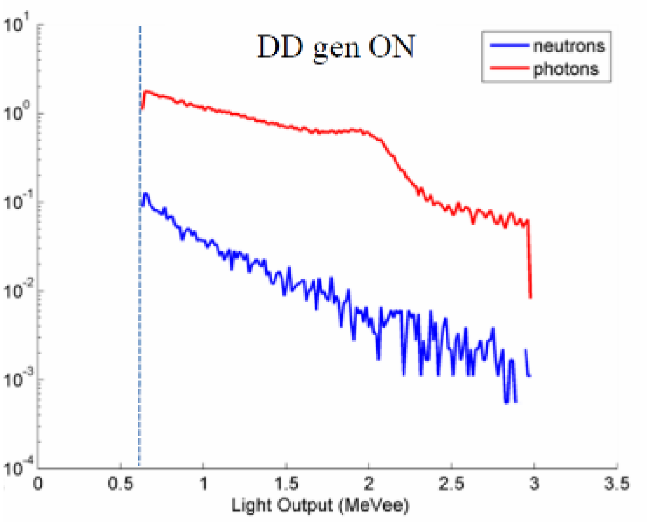

Fig. 5. Response of UM Liquid detector to UTA interrogation (with water) for DD generator On.

Beta-delayed neutrons are neutrons emitted from neutron-rich beta-decay of fission products. A select few fission products, called delayed neutron precursors, undergo beta decay but a small fraction of the daughter product, called delayed neutron emitter, are excited enough to undergo neutron emission. This process of neutron emission happens much later from the fission event standpoint (hence called delayed neutrons) and is determined by the half-life of the delayed neutron precursor.

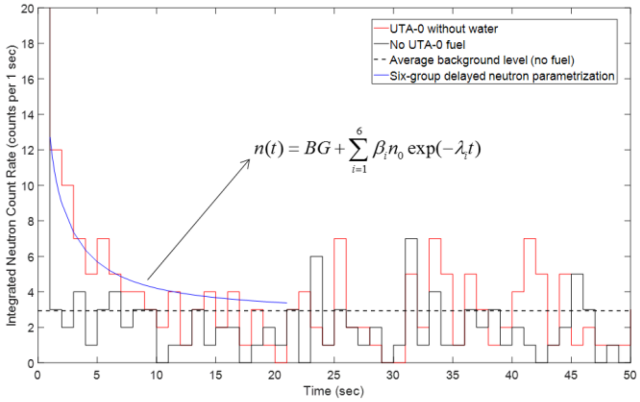

Fig. 6. Beta-delayed neutron temporal profile in Silverside Li-6 panel after DD neutron source was turned off at t = 1 s, with and without UTA fuel.

The Li-6 panel was used to observe the temporal profile of the beta-delayed neutron signal. Fig. 6 shows the data recorded from an empty barrel and UTA target (without water). The measured data are shown after 1 second from turning the DD generator Off, since it takes about 0.3 seconds to completely ramp down. Without UTA fuel rods and no water in the barrel (black curve), the neutron count rate drops to background level at around 3 counts per second. The dashed line indicates the long-term average background per second. With UTA as the interrogating target and no water in the barrel (red curve), the delayed neutron emission was observed for 10 seconds after DD neutron source was Off. The expected signal level was calculated using the well-established six-group delayed neutron parametrization (blue curve). A good agreement between the expected and measured beta-delayed neutron signal confirms the presence of fissionable material. When the UTA barrel was filed with a significant amount of hydrogenous medium (light water), the signal on the detector were undistinguishable from background. This is due to the significant attenuation of the neutrons in water combined with the fact that beta-delayed neutrons are relatively low energy (~0.5 MeV average energy).

The induced fission on the SNM results in some strongly populated and intense gamma rays from the decay of short-lived fission products. Additionally, neutron activation of surrounding material (i.e. (n,γ) reaction) emits characteristic capture-gamma rays. Both signals can be used to identify the presence of SNM and the makeup of the surrounding material. Table II lists a sample of the two types of steady state gamma ray signals that were observed and recorded during UTA test.

Table II. Source of characteristic gamma rays.

Source of Gamma Ray	**Isotope**	**Gamma Energy, keV [%]**
Neutron capture (n,γ)	^{1}H	2223.25 [100%]
	^{12}C	4945 [100%]
	^{27}Al	7724 [96%], 7693 [12%], 4133 [25%] from ^{28}Al decay $T_{½}$ =2.2m, 1779 [100%]
	^{56}Fe	7631 [100%] 7645 [86%]
	^{238}U	4060 [23%]
	^{207}Pb	7368 [100%]
Intense short-lived fission fragments	^{134}I	847 [96%], 884 [65%]
	^{90}Kr	1119 [39%], 539 [31%]

In collaboration with University of Michigan and Silverside Detectors, feasibility of the multiple corroborating signal detection method was successfully demonstrated. Niowave will continue to acquire more SNM and data with various detectors and will optimize the efficiency and cost of all the components. The program will culminate in commissioning tests of the compact NIS which can address the needs of detecting shielded SNM and other contraband.

CONCLUSIONS

An intense source of neutrons from a DD neutron generator was used to interrogate a uranium assembly by inducing fission for confirmation and identification of special nuclear material. Neutrons in the system were detected using different detectors including a ^{6}Li panel, stilbene scintillator, and liquid scintillator. The neutron detector was able to detect beta-delayed neutrons and confirm the existence of fissionable material. In addition, the fast neutron detectors were able to detect prompt-fission neutrons with energies above DD neutron energy to confirm the existence of fissionable material. Gamma rays were detected with a HPGe detector that offers high energy resolution to identify characteristic fingerprints. The HPGe was able to identify surrounding material from neutron activation as well as detect delayed gamma signals from beta decay of fission products to confirm the presence of fissionable material.

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