FIELDABLE NUCLEAR MATERIAL IDENTIFICATION SYSTEM

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ABSTRACT

The Fieldable Nuclear Material Identification System (FNMIS), funded by the NA-241 Office of Dismantlement and Transparency, provides information to determine the material attributes and identity of heavily shielded nuclear objects. This information will provide future treaty participants with verifiable information required by the treaty regime. The neutron interrogation technology uses a combination of information from induced fission neutron radiation and transmitted neutron imaging information to provide high confidence that the shielded item is consistent with the host's declaration. The combination of material identification information and the shape and configuration of the item are very difficult to spoof. When used at various points in the warhead dismantlement sequence, the information complimented by tags and seals can be used to track subassembly and piece part information as the disassembly occurs. The neutron transmission imaging has been developed during the last seven years and the signature analysis over the last several decades. The FNMIS is the culmination of the effort to put the technology in a usable configuration for potential treaty verification purposes.

INTRODUCTION

The Nuclear Material Identification System (NMIS) is an active and passive interrogation system developed and refined at the Oak Ridge National Laboratory (ORNL) over the past 20 years.[1,2] The purpose of the system is to characterize both the fissile and nonfissile material in a containerized target that may have some of the materials of interest shielded from typical radiological measurements. The system can be used in the passive mode to analyze radiological emissions from nuclear materials, or with the addition of neutron and/or gamma interrogation, it can be used in the active mode to analyze radiological emissions caused by the interaction of the source neutrons or gamma rays with the target material. Both provide a nuclear reaction signature of the target that can be used for attribute determination and template matching to similar targets. The interrogation source is an associated particle D-T (deuterium-tritium) neutron generator. In addition to the NMIS signature capabilities, imaging capabilities have also been developed and added to NMIS over the past seven years.[3,4] The use of imaging with attribute determination capabilities can provide a high confidence level that the special nuclear materials (SNM) and other materials in the target are consistent with what has been declared by the host country.

Radiographic and tomographic imaging is accomplished through the detection of time and direction stamped neutron emissions passing through the interrogated target in conjunction with an array of 1 x 1 x 4-inch plastic detectors on the opposite side of the target. During the image scanning process, the attenuation of the neutrons is measured versus the anticipated path of the neutron through the target for any elevation desired. For axial symmetric targets, this information can be obtained from a single scan of the target. For nonsymmetrical targets, multiple scans must be completed from various angles relative to the target to provide the data necessary for the tomographic image reconstruction. Upon completion of the scan and determination of the attenuation through the various parts of the target, software can analyze the data and provide a 3D image reconstruction of the target.

A D-T neutron generator is the interrogation source most often used for imaging. The high energy, time and direction tagged neutrons provide high penetration of the target, even through dense materials. However, there are occasions for low attenuating objects where a ^{252}Cf source is desirable.[5] Its neutrons and gamma rays are time tagged but not directionally stamped. The gamma ray attenuation can provide more detailed images, and the fission spectrum neutrons can provide more image contrast for the low-density materials in the target.

While NMIS has been developed and refined over the past 20 years, it should be noted that it has also been used in several practical applications such as accountability applications in a production mode. This was accomplished by utilizing the NMIS signature capabilities to inspect the shipment and receipt of containers to determine if the declared material was actually present in the container or within the target.[6] It was also used to determine an estimated quantity of material in special situations due to the discovery of unknown quantities or material types discovered in containers or processing equipment (Fig. 1.).[7]

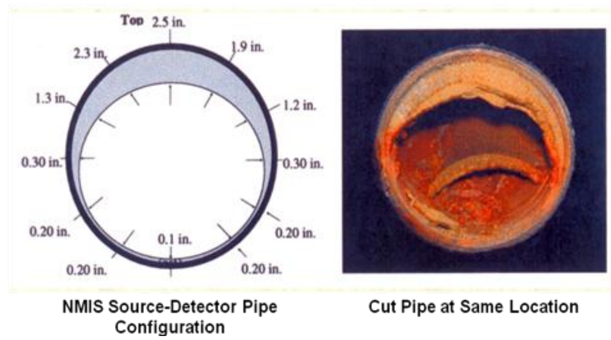

Figure 1. Image of material in processing pipe.

The usefulness of the NMIS signature and imaging system for arms control and nonproliferation purposes has been recognized by NA-241. Other organizations have also expressed interest for the NMIS system to provide a higher level of assurance that items in containers are consistent with the declaration. NA-241's primary interest is the use of NMIS imaging and signature capabilities for possible treaty verification regimes. In addition, there are other organizations that have a strong interest in NMIS capabilities for other applications. The user criteria for each of these applications are different. An example of the image capability for highly shielded uranium is shown in Figures 2 and 3 below. In this case, an approximately six-inch diameter cylinder of depleted uranium (DU) is shielded by four inches of lead on each side.

Figure 2. DU shielded by lead.

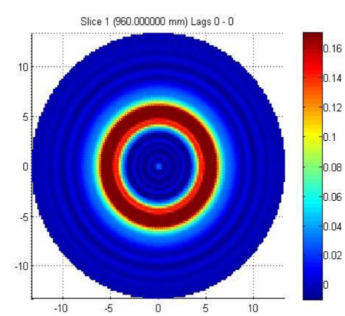

Figure 3. Image from shielded DU cylinder scan.

Based on the interest in the use of NMIS for treaty regimes, funding was provided to move the NMIS system in a direction from a fairly complicated, well-tested laboratory piece of equipment to a more automated user friendly Fieldable NMIS (FNMIS) system that could be used in a treaty regime application.

FIELDABLE NUCLEAR MATERIAL IDENTIFICATION SYSTEM (FNMIS)

FNMIS REQUIREMENTS FOR TREATY VERIFICATION PURPOSES

The first step in the design and fabrication process was obtaining a clear understanding of potential treaty regime requirements. NA-241 and ORNL technologists and managers developed a design criteria document over several months to ensure the equipment would be usable in a potential treaty regime scenario. There are over 100 specific design criteria to ensure that these needs are met, along with the needs of the technologists and designers. The following are some of the key criteria addressed in the requirements document:

- Imaging and signature capabilities
- Assembly or disassembly within an hour
- Assembly using two people
- Modular design
- Trained technicians with prior experience in nuclear field as operators
- Imaging scans within specific time limits
- Target rotation for multiangle tomographic images
- Transportable by standard shipping and handling practices
- Specified environmental and lighting conditions
- Items measured within a specified volume
- Target analyzed without moving the target (target rotation would not be allowed in this mode)
- Specific power use requirements
- Authentication and information barrier needs considered during design

The entire list is too lengthy to be included in this paper in totality. This list is only intended to give the reader an example of requirements criteria agreed to between the ORNL designers and the users. It should also be noted that the requirements document is a living document that can be altered when knowledge gained from the detailed design process and fabrication steps is implemented. These changes require documented agreement between the designers and users. The system will allow for future incorporation of a gamma ray spectrometry module.[8]

PRESENT FNMIS CONCEPT

The concept for the system is a FNMIS time-dependent coincidence system[9,10] that incorporates transmission tomographic imaging and utilizes a small, lightweight (30 lbs), portable D-T neutron (14.1 MeV) generator (1×10^8 neutrons/second), proton recoil scintillation detectors, and a fast (1GHz) time correlation processor. The system is being designed to allow for the eventual incorporation of gamma ray spectrometry. The proton recoil scintillators are 32 small 2.5 x 2.5 x 10.2-cm thick plastic scintillators for imaging and two arrays of four 25 x 25 x 8-cm thick liquid scintillators with online digital pulse shape discrimination to distinguish neutrons from gamma rays or plastic scintillators. A computer-controlled scanner moves the small detectors and the source appropriately for scanning a target object for imaging. The system is based on detection of transmitted 14.1 MeV neutrons, fission neutrons, and gamma rays from spontaneous inherent source fission of the target, fission neutrons, and gamma rays induced by the external D-T source, gamma ray from natural emissions of uranium and Pu, and induced gamma-ray emission by the interaction of the 14.1 MeV neutrons from the D-T source. This system is uniquely suited for detection of shielded highly enriched uranium (HEU), plutonium, and other SNM. It will be adapted to utilize a trusted processor that incorporates information barrier (IB) and authentication techniques using open software and then be useful in some international applications for materials whose characteristics may be classified. The proposed information barrier version of the FNMIS system would consist of detectors and cables, the red (classified side) system that processes the data, and the black (unclassified side) computer that handles the computer interface. The system could use the "IB wrapper" concept proposed by Los Alamos National Laboratory (LANL) and the software integrity (digital signatures) system proposed by Sandia National Laboratory (SNL). Since it is based entirely on commercially available components, the entire system, including the FNMIS data acquisition boards, can be built with commercial off-the-shelf components.

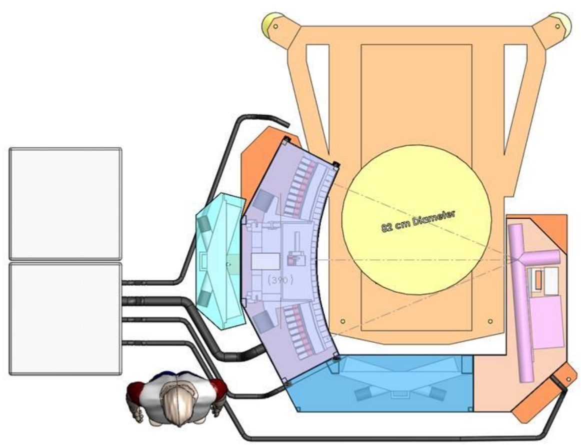

Figure 4. Top View Schematic of the FNMIS Equipment.

FNMIS CAPABILITIES

The system hardware and software can be configured to obtain the following: Pu presence, Pu mass, Pu 240/239 ratio, Pu geometry, Pu metal vs. nonmetallic compound (absence of metal), U presence, U mass, U enrichment, U geometry, and U metal vs. nonmetallic compound (absence of metal). A matrix of the quantities determined (without the incorporation of gamma ray spectrometry), the method of determination, whether active (external neutron source) or passive, and the measurement equipment involved are given in Table 1. Some of these attributes can be obtained by multiple data analysis methods. In addition, the imaging capability allows warhead authentication and traceability of weapons parts and weapons components through dismantlement and can be used to verify the destruction or change in form of SNM and other essential nonfissile components. In addition, the data imaging measurements and MCNP-PoliMi (a Monte Carlo code for correlation measurements) calculations of the FNMIS time correlation signatures can be used to obtain fissile shape and mass without calibration. Very good initial estimates of the configuration of materials from imaging can be provided for further refined Monte Carlo analyses. The system will be modularly constructed with the RF (radio frequency) shielded modules connected to the processor by appropriate control and signal cables in metal conduit. The system hardware and software modules may also be configured to estimate a selected subset of these attributes. In addition, signatures for fissile material can be used for template matching for confirmation of inventories and receipts for weapons components. This was done in an operational mode at the Y-12 National Security Complex in Oak Ridge for several years after 1996 where over 10,000 items were measured.

This system has been designed to eventually incorporate gamma ray spectrometry. When included, it will have the advantage of combining multiple technologies into a single system for a variety of applications.

Table 1: Matrix of FNMIS Capabilities

Material	Attribute		Method (option, implementation, basis)		Active or passive	Measurement equipment
Plutonium	presence metal/ nonmetal	1	time-dependent coincidence	detect internal spontaneous fission	active/passive	D-T neutron source (if active) scintillation detectors multichannel nanosecond time correlator
		2	time-dependent coincidence	measure density from neutron transmission	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
		3	time-dependent coincidence	attenuation of gammas emitted and multiplication depending on density	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	geometry	1	time-dependent coincidence	imaging	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	relative ^{240}Pu-content	1	time-dependent coincidence	compare spontaneous and induced fission rates	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	fissile mass	1	time-dependent coincidence	measure induced fission rate enhanced by imaging	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
		2	time-dependent coincidence	measure spontaneous fission rate	Passive	scintillation detectors multichannel nanosecond time correlator
	disposition or conversion of	1	time-dependent coincidence	transmission imaging tomography	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator

Table 1: Matrix of FNMIS Capabilities (continued)

Material	Attribute		Method (option, implementation, basis)		Active or passive	Measurement equipment
Uranium	presence	1	time-dependent coincidence	detect induced fission and absence of internal spontaneous fission	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	metal/ nonmetal	1	time-dependent coincidence	measure density from neutron transmission	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
		2	time-dependent coincidence	attenuation of gamma emitted and multiplication depend on density	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	geometry	1	time-dependent coincidence	imaging	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	U^{235}-enrichment	1	time-dependent coincidence	compare induced fission rates and neutron transmission for simple parts	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator High Purity Germanium (HPGe)
	fissile mass	1	time-dependent coincidence	measure induced fission rate complemented by imaging	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	disposition or conversion of	1	time-dependent coincidence	transmission imaging tomography	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
Fissile	spatial distribution	1	time-dependent coincidence	imaging plus D-T source pixel correlated multiplicities	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
Dismantlement	warhead authentication	1	time dependent coincidence	transmission imaging tomography	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	traceability of weapons/parts	1	time dependent coincidence	transmission imaging tomography	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	destruction of nuclear warhead casings	1	time dependent coincidence	transmission imaging tomography	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	destruction of essential nonnuclear parts	1	time dependent coincidence	transmission imaging tomography	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
High explosive	geometry	1	time dependent coincidence	imaging	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator
	separation from fissile	1	time dependent coincidence	transmission imaging tomography	active	D-T neutron source scintillation detectors multichannel nanosecond time correlator

SUMMARY

ORNL and NA-241 have reviewed and agreed on the conceptual design and program planning documents for the FNMIS. Funds have been provided, and the detailed design work for the mechanical, software, and electrical portions of the FNMIS are well underway. The current schedule for the completed system is lengthy. However, the system capabilities have been shared with other organizations interested in supporting a fieldable system for their applications. It is anticipated that with sufficient interest from other organizations and the additional interest in establishing capabilities for potential treaty regimes, the length of time to complete the FNMIS will be significantly reduced.

Upon completion, a well-planned neutron interrogation and imaging system will be available for:

- treaty regime considerations;
- mock treaty regime implementation testing;
- experimental work to further advance NMIS capabilities;
- material control and accountability use; and
- SNM identification needs that arise around the nuclear complex.

In addition, a fully developed system can be evaluated by other organizations to determine their respective needs. The coupling of these needs with the FNMIS design can ultimately produce additional FNMIS systems at a lower cost and on a faster schedule due to the lessons learned during the FNMIS design and fabrication.

The FNMIS will prove to be a very useful tool and will provide a high level of assurance that declared items and materials are actually present.

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