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OAK RIDGE
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OAK RIDGE MULTIPLE ATTRIBUTE SYSTEM (ORMAS) FOR PU, HEU, HE, CHEMICAL AGENTS, AND DRUGS

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OAK RIDGE MULTIPLE ATTRIBUTE SYSTEM (ORMAS) FOR PU, HEU, HE, CHEMICAL AGENTS, AND DRUGS

The concept for the Oak Ridge Multiple Attribute System (ORMAS)[1] is a Nuclear Materials Identification System (NMIS) time-dependent coincidence processor that incorporates gamma ray spectrometry and utilizes a small, lightweight, portable DT neutron (14.1 MeV) generator (1×10^8 n/s)[2], proton recoil scintillation detectors, and a gamma ray detector (HPGe). ORMAS is based on detecting fission neutrons and gamma rays from inherent source fission, fission induced by the external DT source, gamma ray detection of natural emissions of uranium and Pu, and induced gamma ray emission by the interaction of the 14.1 MeV neutrons from the DT source. This system is uniquely suited for detection of shielded highly enriched uranium (HEU), plutonium and other special nuclear materials, and detection of high explosives (HE), chemical agents, and in some cases, drugs.[3] It could easily be adjusted to utilize a trusted processor that incorporates information barrier and authentication techniques using open software and then be useful in some international applications for materials whose characteristics may be classified. Since it is based entirely on commercially available components, the entire system, including the NMIS data acquisition boards, can be built with commercial off the shelf components (COTS). ORMAS incorporates the PINS technology of A. J. Caffrey of the Idaho National Engineering and Environmental Laboratory for HE,[4] chemical agents,[4] and drugs detection.

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. non metal (absence of metal), time (age) since processing for Pu, U presence, U mass, U enrichment, U geometry, U metal vs. non metal (absence of metal), high explosives, chemical weapons, and in some cases, drugs. A matrix of the quantities determined, the method of determination, whether active (external neutron source) or passive and the measurement equipment involved is given in the following table. Some of these attributes can be obtained by multiple data analysis methods. The gamma ray spectrometry methods for Pu, HE, and drugs are well known and have been developed by other laboratories. The system hardware and software may also be configured to estimate a selected subset of these attributes. In addition, signatures from ORMAS for fissile material can be used for template matching such as has been implemented for confirmation of inventories and receipts for weapons components at the Y-12 National Security Complex in Oak Ridge since 1996. Recently, Y-12 personnel were trained and have been operating three NMIS systems at the Y-12 complex.

ORMAS has the advantage of combining multiple technologies into a single system for a variety of applications and thus is cost effective.

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[1] A variant of this system was described in the following reference which is included as Appendix A: J. A. Mullens, J. E. Breeding, R. B. Perez, J. T. Mihalczo, T. E. Valentine, and J. A. McEvers, "A Multipurpose Processor for Arms Control and Nonproliferation and NMC&A," Institute of Nuclear Materials Management Annual Conference, July 1999.

[2] While the active source is operational at 10^7 n/sec, the radiation dose is ~5 mrem/hr at 1 meter with the source unshielded; the source is turned off when not in use.

[3] Personnel communication, INEEL, July 2001.

[4] A. J. Caffrey, J. D. Cole, R. J. Gehrke, and R. C. Greenwood, "Chemical Warfare Agent and High Explosive Identification by Spectroscopy of Neutron-Induced Gamma Rays," IEEE Transactions of Nuclear Science, **39**, p. 1422-1426 (1992).

Matrix of ORMAS Attribute Measurements

Material	Attribute	Method (Option, Implementation, Basis)			Active or Passive	Measurement Equipment
plutonium	**presence**	1	time-dependent coincidence	detect internal spontaneous fission	active	neutron source, scintillation detectors, time-correlator
		2	gamma spectrometry	detect Pu spectral lines	passive	high-resolution gamma detector, multi-channel analyzer
	age	1	gamma spectrometry	measure in- and out-growth of impurities	passive	high-resolution gamma detector, multi-channel analyzer
	metal / non-metal	1	neutron-initiated gamma spectrometry	detect 6129 KeV gamma from 14.1 MeV neutron interactions with O & F	active	neutron source, high-resolution gamma detector, multi-channel analyzer
		2	time-dependent coincidence	measure density from neutron transmission	active	neutron source, scintillation detector, time-correlator
		3	time-dependent coincidence	attenuation of gammas emitted and multiplication depending on density	passive	scintillation detectors, time-correlator
	geometry	1	time-dependent coincidence	measure axial density gradient from neutron transmission	active	neutron source, scintillation detector, time-correlator
	relative ^{240}Pu-content	1	time-dependent coincidence	compare spontaneous and induced fission rates	active	neutron source, scintillation detectors, time-correlators
		2	gamma spectrometry	compare ^{240}Pu and ^{239}Pu spectral lines	passive	high-resolution gamma detector, multi-channel analyzer
	fissile mass	1	time-dependent coincidence	measure induced fission rate	active	neutron source, scintillation detectors, time-correlators
		2	time-dependent coincidence	measure spontaneous fission rate	passive	scintillation detectors, time-correlator
uranium	**presence**	1	time-dependent coincidence	detect induced fission and absence of internal spontaneous fission	active	neutron source, scintillation detectors, time-correlators
	metal / non-metal	1	neutron-initiated gamma spectrometry	detect 6129 KeV gamma from 14.1 MeV neutron interactions with O & F	active	neutron source, high-resolution gamma detector, multi-channel analyzer
		2	time-dependent coincidence	measure density from neutron transmission	active	neutron source, scintillation detector, time-correlator
		3	time-dependent coincidence	attenuation of gamma emitted and multiplication depend on density	active	neutron source, scintillation detector, time-correlator
	geometry	1	time-dependent coincidence	measure axial density gradient	active	neutron source, scintillation detectors, time correlation
	^{235}U-enrichment	1	time-dependent coincidence	compare induced fission rates and neutron transmission	active	neutron source, scintillation detectors, time-correlators
	fissile mass	1	time-dependent coincidence	measure induced fission rate	active	neutron source, scintillation detectors, time-correlators

Matrix of ORMAS Attribute Measurements (Cont'd.)

Material	Attribute	Method (Option, Implementation, Basis)			Active or Passive	Measurement Equipment
high explosive	**presence**	1	gamma spectrometry	N presence and ratios of N/C, H/C, and O/C	active	neutron source, HPGe[a] or BGO[b]
chemical weapon	**presence**	1	gamma spectrometry	ratios of N/C, H/C, and O/C	active	neutron source,HPGe[a] or BGO[b]
drugs	**presence**	1	gamma spectrometry	ratios of N/C, H/C, and O/C	active	neutron source, HPGe[a] or BGO[b]

[a]PINS system of A. J. Caffrey; see Reference 4.
[b]G. Vourvopolos and P. C. Womble, "Pulsed Fast/Thermal Neutron Analysis: A Technique for Explosive Detection," Applied Physics Institute, Western Kentucky University, Bowling Green, KY 42101 (2001).

APPENDIX A
Previous Paper On A Multipurpose Processor

Y-12

OAK RIDGE
Y-12
PLANT

Report No.: **Y/LB-15,993**

A MULTIPURPOSE PROCESSOR FOR ARMS CONTROL AND NONPROLIFERATION AND NMC&A

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ABSTRACT

A processor for active and passive measurements with both nuclear materials identification system and gamma-ray spectrometry capabilities is useful for a variety of nuclear material control and accountability applications such as multiplicity counting, 2nd, 3rd, and 4th order correlation measurements as well as gamma-ray spectrometry. It may be useful for fissile mass (e.g., Pu^{-239} or U^{-235}) determination; fissile configuration, presence of Pu and in some cases HEU, Pu isotopics, time since reprocessing for Pu, HEU enrichment in some cases, and high explosive detection.

1. INTRODUCTION

A variety of radiation detection technologies are being evaluated and developed by a number of National Laboratories for arms control and non-proliferation applications. Both active (externally stimulated) and passive technologies are under investigation. Some of these passive methodologies are: passive gamma-ray spectrometry for U and Pu, passive correlation (multiplicity) counting for Pu, passive nuclear materials identification system (NMIS) for Pu, and neutron counting for Pu. Some of the active methodologies are: active NMIS for U and Pu, active well multiplicity counting for U, gamma-ray spectrometry for activation analysis including PINS for high explosive (HE) detection and pulsed neutron methods. A sensible, cost-effective approach is to incorporate data acquisition for all these technologies into a single processor. A recent application of NMIS at the Oak Ridge Y-12 Plant incorporated a multichannel analyzer (MCA) card into the computer with the NMIS processor cards the NMIS processor for use with high resolution HPGe gamma-ray spectrometry. The resulting processor performs the gamma-ray spectrometry independently of the NMIS data acquisition[1] since it is not CPU intensive and requires only a start and stop instructions and transfer of the data from the MCA card to the computer storage.

This processor employing the NMIS technology and gamma-ray spectrometry simultaneously was recently (February 1999) tested at the Oak Ridge Y-12 Plant in measurements. This paper briefly described this combined processor and the measurements for which it can be used.

2. INCORPORATION OF A MCA IN NMIS

The computational platform using Intel Pentium technology for NMIS has capability for addition of a multichannel analyzer (MCA) thus providing gamma-ray spectrometry. NMIS is an up to 1 GHz synchronously sampling system with five-detection channel inputs. The inputs (up to five) are conventional NIM logic signals and for the MCA are the conventional amplifier outputs of spectroscopy amplifiers. Other platforms as well could be utilized for the combined processor. A photograph of a Pentium based processor with NMIS and MCA cards installed is shown in Fig. 1, and a configuration of source and detectors for a measurement using this processor with fissile material in a container is shown in Fig. 2.

3. MEASUREMENT CAPABILITY

This combined processor has capability for a wide variety of measurements related to arms control and non-proliferation and conventional nuclear material control and accountability.

3.1 GAMMA-RAY SPECTROMETRY SIGNATUES

The addition of gamma ray spectrometry adds the following capabilities (not described here but referenced) to such a combined processor.

1. Pu Presence	(Ref. 2)
2. Pu Isotopics	(Refs. 3 and 4)
3. Time Since Reprocessing For Pu	(Ref. 5)
4. High Explosive Detection (PINS)	(Ref. 6)
5. Highly Enriched Uranium (HEU) Presence in Some Cases	(Ref. 2)
6. HEU Enrichment in Some Cases	(Ref. 2)

3.2 FISSILE MASS

Both passive and active neutron interrogations with a ^{252}Cf source can been used to quantify the fissile mass of Pu components from dismantled nuclear weapons. NMIS provides a wide variety of data that can be used for Pu and U mass quantification.

3.2.1 NMIS Multiplicity Measurements

NMIS measures the number of times m pulses occur in a time interval, P(m), whose initiation is triggered by a Cf source fission, a detection event, and also randomly. For passive measurements with fissile material with inherent sources like Pu only, the latter two triggering modes are used. NMIS processes such data for each detection channel and the sum of all detector channels where a total of five detection channels can be used. These data are then processed further using methods described by Hage, Boehnel, and others[7, 8, 9] to obtain the multiplicities. When the trigger is Cf source fission, the start of the time interval after Cf fission can be delayed and the end of the time interval is specified as input. For fissile mass determination, the sum of all detectors can be

utilized. For many unmoderated uranium and plutonium metal systems of interest, the time decay of the fission chains lasts not much longer than 200 nsec. In the use of source trigger for the P(m), the time intervals for detection event and randomly triggered are also the same length. Multiplicity measurements have a long history of uranium and plutonium mass quantification. The theory of this multiplicity which includes gamma-rays are presented in a paper at this meeting[10] and Monte Carlo calculations are presented in another paper[11]. For plutonium systems, passive (no Cf source) measurements are adequate although active (with Cf source) measurements are also adequate. For active measurements with Pu, triggering on Cf source fission and measuring for a short time interval thereafter may make it possible to separate the effects of source induced fission and inherent fission.

3.2.2 Second Order Cross Correlations With the Cf Source

The correlation function between the detectors and the source in active measurements is characterized mainly by gamma-ray transmission, neutron transmission, and fission production induced by neutrons from the ^{252}Cf source. The temporal distribution of counts is measured. The induced fission component of this signature is related to the fissile mass and in one sense corresponds to a pulsed neutron measurement[12] (differential die away). This NMIS signature has recently (1999) been used to determine the fissile mass and enrichment of uranium parts from nuclear weapons components to within ± 1.7% RMS relative uncertainty on the declared mass in a measurement time of four minutes for NMC&A at the Oak Ridge Y-12 Plant. In this particular case, enrichment was determined to ± 1.9% RMS relative error.

3.2.3 Second Order Cross Correlations Between Detectors

The production of gamma-gamma coincident pairs, gamma-neutron pairs, and neutron-neutron pairs contribute to the cross correlation functions between detectors. For passive measurements with Pu, many of these pairs result from inherent ^{240}Pu by the inherent source fission. For active measurements there are additional induced fissions from neutrons from the ^{252}Cf source. These measurements are similar to two detector Rossi-α measurements[13] for both U and Pu.

3.2.4. Auto Correlation of Detector Signals

Correlated pairs of events from fission contributes to the amplitude and time decay of the auto correlation function and are related to the fissile mass. This correlation function is similar to a single detector Rossi-α measurement.

3.2.5 Higher Order Correlations

Third and limited fourth correlation functions have been implemented in this processor and provide additional signatures which have higher sensitivity to fissile mass[14, 15]. Third order correlation functions require three correlated events in different detectors from fission or fission chains to make a contribution to the correlation function and thus require three detection channels.

Whereas, second order correlations between detector pairs contained correlation from all fission sources, third order correlations between the ^{252}Cf source and a pair of detectors containing only correlations from Cf fission and induced fission by Cf neutrons. Thus, the third order correlation function including the Cf source channel may be used to separate the effects of Cf neutrons and inherent source neutrons. This may allow the separation of the effects of ^{240}Pu and ^{239}Pu and thus provide a estimate of the Pu isotopics[16].

Third order correlations between three fixed detectors can be used passively to determine the shape of plutonium[17]. This is based on the detection of coincident gamma rays from fission in two different detectors. These coincidences indicate the time of fission, and a correlated neutron detection in the third detector at a measured time later can indicate how far the fission site was from the detector since the energy distribution of neutrons from fission is known.

4. CONCLUSIONS

This combined processor processing NIM signals from detection systems for NMIS input and spectroscopy amplifier signals from a gamma-ray detector provides a wide variety of information useful for NMC&A: multiplicity counting, 2, 3, and 4th order correlation functions with the second order related to pulsed neutron and Rossi-α measurements, and gamma-ray spectrometry.

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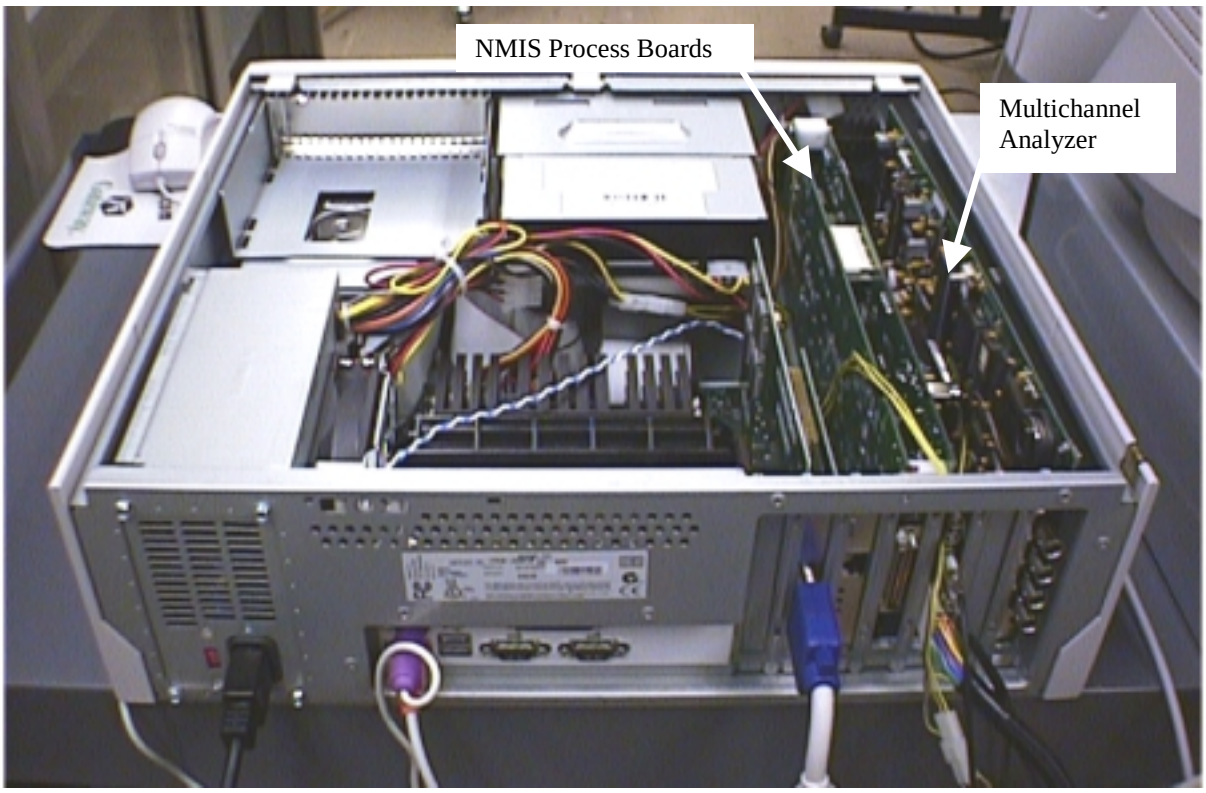

Fig. 1. NMIS Processor with Gamma Ray Spectrum Analyzer.

Fig. 2. Simultaneous NMIS-Gamma Ray Spectrometry Measurements For Fissile Material in a Container.