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

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The concept for the Oak Ridge Multiple Attribute System (ORMAS) 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 \((1 \times 10^8 \text{ n/s})\), 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. 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, chemical agents, 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.
## Matrix of ORMAS Attribute Measurements

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Attribute</th>
<th>Method (Option, Implementation, Basis)</th>
<th>Active or Passive</th>
<th>Measurement Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>high explosive</td>
<td>presence</td>
<td>gamma spectrometry</td>
<td>active</td>
<td>neutron source, HPGe^a or BGO^b</td>
</tr>
<tr>
<td>chemical weapon</td>
<td>presence</td>
<td>gamma spectrometry</td>
<td>active</td>
<td>neutron source, HPGe^a or BGO^b</td>
</tr>
<tr>
<td>drugs</td>
<td>presence</td>
<td>gamma spectrometry</td>
<td>active</td>
<td>neutron source, HPGe^a or BGO^b</td>
</tr>
</tbody>
</table>

^aPINS system of A. J. Caffrey; see Reference 4.
APPENDIX A
Previous Paper On A Multipurpose Processor
Y-12
OAK RIDGE
Y-12
PLANT

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

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Nuclear Materials Management and
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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\textsuperscript{239} or
U\textsuperscript{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\textsuperscript{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 SIGNATURES

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 FISSION MASS

Both passive and active neutron interrogations with a $^{252}$Cf source can be 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 to obtain 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\textsuperscript{10} and Monte Carlo calculations are presented in another paper\textsuperscript{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\textsuperscript{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-\textalpha~measurements\textsuperscript{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-\textalpha~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\textsuperscript{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 isotopes$^{16}$.

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.
REFERENCES


Fig. 1. NMIS Processor with Gamma Ray Spectrum Analyzer.
Fig. 2. Simultaneous NMIS-Gamma Ray Spectrometry Measurements For Fissile Material in a Container.