Recent Advances and Upcoming Challenges in Nuclear Nonproliferation, Safeguards, and the Prevention of Nuclear Terrorism

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National Security, Nuclear Nonproliferation, and Safeguards

- Today, there is an urgent need to detect, secure, and dispose of nuclear and radiological materials.

- The possibility that terrorists might acquire and use nuclear weapons is an urgent and potentially catastrophic challenge to global security.

- The resurgence of nuclear power requires advanced materials control and accounting techniques for nuclear fuel reprocessing in order to prevent diversions, ensure safety, and reassure the international community.

- These are global issues that require cooperation among nations.
Challenges
Detection of Nuclear and Radioactive Material

- Nuclear material may be concealed in packages of varying shape and size, surrounded by material that makes the accurate detection difficult
- In other applications the signal from the material may be masked by other emissions
- Fast and robust systems are needed to accurately detect and characterize the nuclear material
Solutions under Investigation
Detection of Shielded Special Nuclear Material

- **Passive technology**: based on radiation emitted from any spontaneous decay process occurring in the nuclear material
- **Active technology**: based on radiation emitted following stimulation by an external source of neutrons, gamma rays, or high energy electrons
MCNP-PoliMi Code System
General Description

- MCNP-PoliMi was developed to simulate correlation measurements with neutrons and gamma rays
- Unique features:
  1. Physics of particle transport
     - Prompt neutrons and gamma rays associated with each event are modeled explicitly; neutron and photon-induced fission multiplicity distributions have been implemented
     - Improved simulation of correlation and multiplicity distributions
  2. Physics of detection
     - Each collision in the detector is treated individually
     - Improved simulation of detector response
MCNP-PoliMi Code System

Physics of Detection

MCNP-PoliMi collision output file excerpt:

<table>
<thead>
<tr>
<th>History number</th>
<th>Particle number</th>
<th>Projectile type*</th>
<th>Interaction type*</th>
<th>Target nucleus*</th>
<th>Cell number of collision event</th>
<th>Energy deposited in collision (MeV)</th>
<th>Time (shakes)</th>
<th>Collision position (X)</th>
<th>Collision position (Y)</th>
<th>Collision position (Z)</th>
<th>Particle weight</th>
<th>Generation number</th>
<th>Number scatterings</th>
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<tr>
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<td>-99</td>
<td>1001</td>
<td>2</td>
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</tr>
</tbody>
</table>

* 1 = neutron; 2 = photon
* -99 = elastic scattering; 1 = Compton scattering
* 1001 = hydrogen; 6 = carbon

Detector cells:

1

\[ n_8 \]

\[ \gamma_{43} \]

2

\[ n_{20} \]

Source
Cooperation with Moscow Engineering Physics Institute

- DNNG cooperated with Prof. Romodanov from the MEPhI
- Cross-correlation distributions were simulated for a setup with four 50 x 50 x 5 cm plastic scintillation detectors shielded by lead
- Simulations were performed with the MCNP-PoliMi code.
- Time delay (x-axis) is the time difference between the particle detected by STOP detector and the particle detected by START detector. Data is shown with 1-ns bins.
Cooperation with Moscow Engineering Physics Institute cont.

Total Cross-Correlation Functions
Detectors 1 and 3; 4-cm water

40mm 1.3 cm

Counts normalized beamaver of source particles:

Time Delay (ns)

Total Correlation Functions
Detectors 1 and 3

Correlations per spontaneous fission of Cf-252

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Fast Neutron Detection

**Organic scintillators** are an excellent choice for simultaneous detection of neutrons and gamma rays for applications in nuclear nonproliferation, international safeguards, and national security.

**Capture-gated detectors**, in addition, provide enhanced neutron spectroscopic information which improves the accuracy of detection.

**Capture-gated neutron spectroscopy** can be performed by adding material(s) with high $\sigma_a$ cross section for thermal neutrons (B-10, Li-6, $^{nat}$Gd etc.)

Digitized Pulses from Organic Scintillators

- Using optimized offline digital pulse shape discrimination method
- The PSD method based on standard charge integration technique
- Pulse timing $t_p$ determined by linear interpolation between points around 50% $p_{\text{max}}$

PSD discrimination ratio $R_C$:

$$R_C = \frac{A_2}{A_1}$$

$A_2$ – tail integral
$A_1$ – total integral
Passive Measurements in Ispra, Italy
Cross-Correlations of Plutonium Oxide

- Measurements of PuO$_2$ standards were performed in August, 2008 at the JRC in Ispra, Italy.
- Passive cross-correlation data was acquired using six cylindrical EJ-309 liquid scintillation detectors.
  - Offline pulse shape discrimination (PSD) was used to separate the neutron and gamma contributions.
Pulse Shape Discrimination
Sample 106, Detector 1

~ 200,000 pulses shown
Threshold = 0.11 V ~ 100 keVee
Passive Detection Results
Simulated and Measured

PuO₂ samples and containers: varying fill heights

Pb shielding

Measured results for different isotopes and burnups:
- Pu-238(a,n)
- Pu-240(a,n)
- Pu-241(a,n)
- Pu-242(a,n)
- Pu-241(SF)
- Pu-242(SF)
- Pu-238(SF)
- Pu-239(SF)

Chart showing measured (n, n) and (g, g) correlations for high and low burnup.

Effective ²⁴⁰Pu Mass (g)

Correlation measured:
- High burnup
- Low burnup

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Passive Measurements with LGB Detector

Heterogeneous, 90%wt PVT, 10%wt of LGB

- The detector contains microspheres of lithium(L), gadolinium (G) and boron (B)
- 88,000 n/s Cf-252 source placed 30 cm from the detector
- 250 MHz 12 bit ADC250 waveform digitizer
Passive Measurements with $^6\text{Li}$ Detector

Heterogeneous $^6\text{Li}$-glass/plastic scintillator (Photogenics)

- The detector consists of 7 slabs (4 BC-408 and 3 GS20 slabs)
- 1 Ci $^{239}\text{Pu}\text{-Be}$ source shielded by 2 in. of lead
- The source was placed 30 cm from the detector
- Ratio of neutron captures from all neutron collisions: 2.5%
Passive Measurements with $^{10}\text{B}$ Detector
Homogeneous Liquid (Saint Gobain)

- The detector consists of BC-501A loaded with B-10 (4.41\%w)
- 1 Ci $^{239}\text{Pu}$-Be source shielded by 2 in. of lead was placed 30 cm from the detector
- Ratio of neutron capture to scattering pulses is 2.3\%
Active Experiments at the IAC

General Description

- Two sets of experiments have been performed at the Idaho Accelerator Center (IAC):
  1. Time of flight (TOF) data were acquired using 15- and 21-MeV bremsstrahlung beams with depleted uranium (DU) targets and small plastic scintillation detectors
  2. TOF data were acquired using 6.5- to 20-MeV bremsstrahlung beams with large liquid scintillation detector arrays
     - DU and Pb targets were irradiated at various beam currents
     - A $^{252}$Cf source was used for calibration
- These data are the basis for validation of MCNP-PoliMi and physics and detection models as well as pulsed-source multiplicity calculations
IAC Active TOF Experimental Results*

*Experiment performed at IAC by A.W. Hunt
Future Challenges

- The resurgence of nuclear energy will require advanced monitoring techniques for nuclear material in the fuel cycle.

- Research and development efforts:
  - Neutron and gamma ray sources for active interrogation
  - Detectors with higher efficiency and resolution
  - Simulation tools to plan and analyze experiments
  - Analysis algorithms to obtain the most information from the acquired data

These are examples of potential areas of collaboration.
Summary and Conclusions

- Monte Carlo code development provides unique simulation capabilities necessary for simulation of passive and active detection systems

- Experiments on fissile materials to validate code results
  - Experiments in the laboratory using radioactive sources
  - Passive detection measurements have recently been made on PuO₂ standards
    - Preliminary analysis shows good agreement with MCNP-PoliMi predictions
  - Active interrogation measurements have been performed using high-energy bremsstrahlung beams
    - Ongoing analysis is yielding improved agreement between measured data and MCNP-PoliMi
Concluding Remarks

- Cooperation between leading Russian and U.S. institutions is necessary to fully address the urgent issues in nuclear nonproliferation, safeguards, and the prevention of nuclear terrorism.

- In fact, these are global issues that require a global outlook for their solution.

- Wide collaborations within academia, national laboratories, and industry are the ideal settings for the development of innovative solutions.
Detection for Nuclear Nonproliferation Group

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Group Members
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- Shaun Clarke, Postdoctoral researcher
- Eric Miller, Graduate student
- Jennifer Dolan, Graduate student
- Ben Maestas, Graduate student
- Mark Bourne, Undergraduate student
- Scott Ambers, Undergraduate student
- Bill Walsh, Undergraduate student
- Lu Huang, Undergraduate student
- Ben Dennis, Undergraduate student
- Paul Stanfield, Undergraduate student

Collaborations - National
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- Alan Hunt, Idaho Accelerator Center
- Donald Umstadter, Univesity of Nebraska
- Peter Vanier, Brookhaven National Laboratory
- John Mattingly, Sandia National Laboratories
- Brandon Blackburn, Raytheon
- Andrey Gueorgueiv, Icx Radiation

Collaborations - International
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- Enrico Padovani, Polytechnic of Milan, Italy
- Paul Scoullar, Southern Innovation, Australia
- Peter Schillebeeckx, JRC Geel, Belgium
- Senada Avdic, University of Tuzla, Bosnia

"... Today, the greatest danger in the war on terror, the greatest danger facing America and the world is outlaw regimes that seek and possess nuclear, chemical and biological weapons... "
---President George W. Bush, 2003 State of the Union Address

The primary goal of our research is the advancement of technologies to control the proliferation of nuclear weapons and associated materials. We are also interested in applications such as nuclear medicine, imaging, and reactor safety analysis.

Please contact us for additional information!
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