INNOVATE. COLLABORATE. DELIVER.

Nuclear Data for Nonproliferation Applications

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NNSA Office of Defense Nuclear Nonproliferation R&D (NA-22)

Workshop for Applied Nuclear Data Activities (WANDA)
26 February 2024

National Nuclear Security Administration

Defense Nuclear Nonproliferation Research & Development Program

DNN R&D At a Glance

Our Purpose

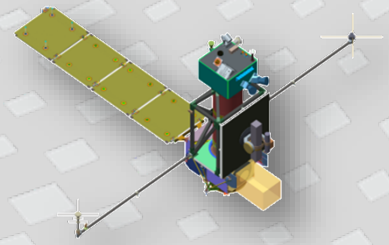
DNN R&D is the leading U.S. Government (USG) organization for the development of advanced technology in support of the USG's nuclear nonproliferation and nuclear security goals

Applications in cooperative and non-cooperative environments that address horizontal and vertical proliferation

Our Environment

Our Mission

Develop technical capability resident at the DOE National Labs, to be leveraged by mission partners for specific applications



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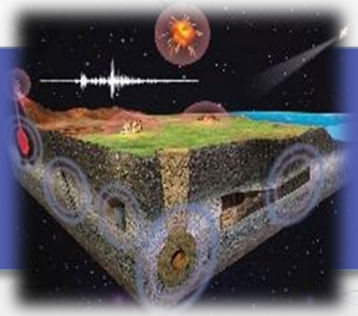
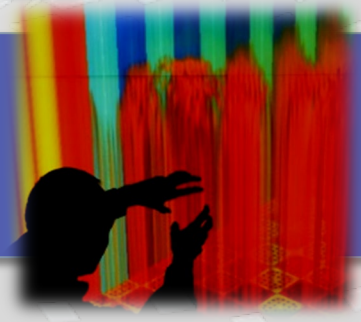
DNN R&D Goals

1. Detect Foreign Weapons Activities
Detect, locate & characterize foreign nuclear weapons development activities

2. Increase Nuclear Security
Detect presence, movement & diversion of SNM, including for interdiction, emergency response, safeguard; nuclear forensics; monitor and verify nuclear arms control treaties



3. Detect Nuclear Explosions
Detect and characterize underground, atmospheric, and space-based nuclear detonations



4. Sustain Nonproliferation Capabilities
Enabling infrastructure, S&T, and expert workforce to meet future nonproliferation challenges

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DNN R&D Office of Nuclear Detonation Detection (NDD)

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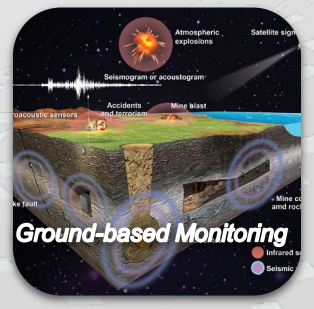
Advance U.S. technical capabilities by delivering nuclear detonation detection sensors to the USSF for global monitoring and by improving the means to detect, identify, locate, and characterize any nuclear test or explosion

Space-based Nuclear Detonation Detection

Nuclear Forensics



Ground-based Nuclear Detonation Detection

Nuclear Test Detection Testbeds

Collaboration with United Kingdom

Collaboration with Interagency

Collaboration with Small Business

Collaboration with University Program for Nuclear Forensics

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DNN R&D Office of Proliferation Detection (PD)

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Develop U.S. technical capabilities to detect, prevent, counter, and respond to nuclear security threats by investing in research and development at the DOE National Laboratories

- *Uranium Production Detection*
- *Plutonium Production Detection*
- *Weapons Development Detection*
- *Other Nuclear Processes*

- *Near-field Detection*
- *Emergency Response*
- *International Safeguards*
- *Radiological Source Replacement*
- *Arms Control Monitoring and Verification*

- *Laboratory Enhancement*
- *Innovation*
- *Remote Detection*
- *Data Science/Artificial Intelligence*
- ***Nuclear Data***

New portfolio began 2023
Supports both PD and NDD

Collaboration with Interagency

Collaboration with Small Business

Collaboration with Integrated University Program

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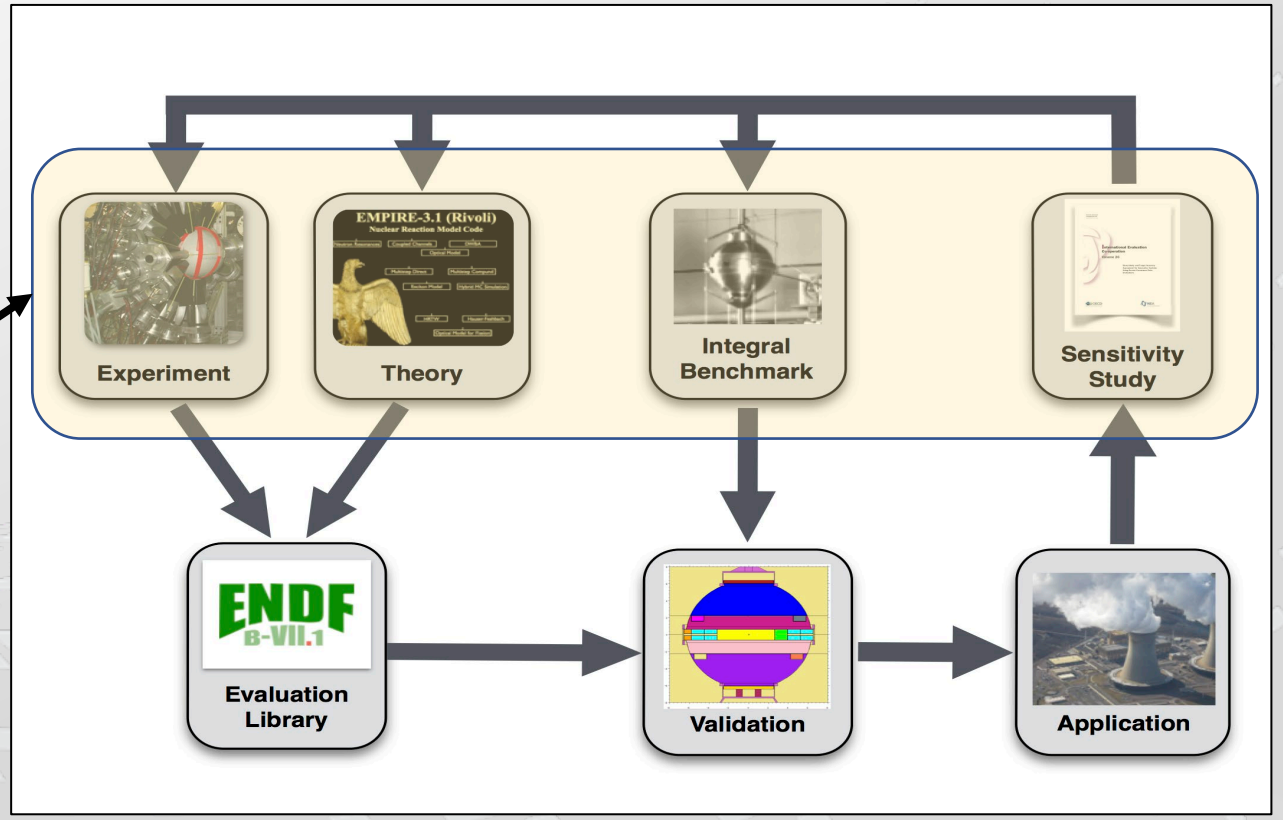
Nuclear Data within DNN R&D

Vision: DNN R&D is the primary U.S. Government sponsor of nuclear physics research for nonproliferation applications. The projects this office funds produce data that are used in numerous technologies, and they have considerable impact on a broad range of missions. DNN R&D is committed to working with the nuclear physics community to continue to advance this important area of research.

DNN R&D nuclear data investments address key components of the nuclear data pipeline, enabling work by the National Nuclear Data Center and other stakeholders to advance the state of nuclear data relevant to nonproliferation applications



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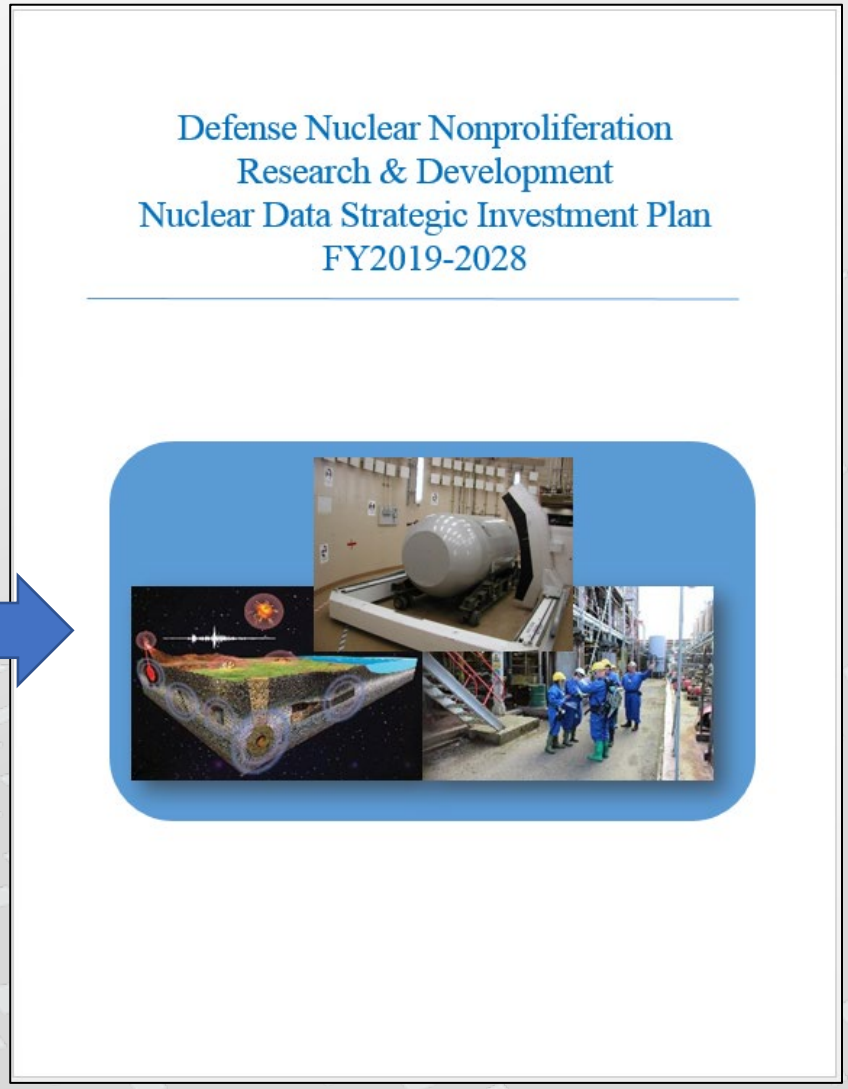
DNN R&D Efforts to Improve Nuclear Data

- Between FY09-FY24, **DNN R&D's investments to improve nuclear data through experiment and theory total ~$90M**
- Investments made by:
  - NA-221 – Emergency Response, Safeguards, Arms Control Monitoring & Verification, Data Science, and Near-field Detection (FY09-FY22), and the **Nuclear Data portfolio (FY23-present; differential data)**
  - NA-222 – **Forensics (integral benchmark data)**
- NDREW (2018) provided input for DNN R&D collectively organize nuclear data efforts
- WANDA (2019-present), CSWEG (2019-present), and NDIAWG (2020-present) engagements help keep DNN R&D connected with researchers and end users
- Participation in the **Nuclear Data Interagency Working Group (NDIAWG) FOA in FY18 through FY24**



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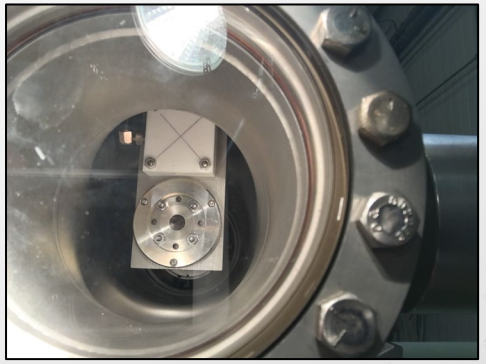
Ongoing Nuclear Data Projects in DNN R&D (began FY23 or earlier)

- 2018-2024, ANL: Improving Antineutrino Spectra Predictions for Nonproliferation Applications
- 2021-2024, BNL: Accurate Decay Data for Nuclear Forensics
- **2022-2024, BNL/LLNL/LBNL: Gamma Rays Induced by Neutrons (GRIN)**
- **2023-2025, LBNL: Gamma Production Cross Sections for Active Neutron Interrogation with GENESIS**
- 2018-2024, LLNL/TAMU: Improving the Nuclear Data on Fission Products at CARIBU
- **2019-2026, LANL/BNL/LBNL/PNNL/LLNL: Evaluation of Energy Dependent Fission Product Yields**
- **2022-2024, LANL/LLNL: Evaluation of Gamma-ray Production Data**
- **2022-2024, LANL/UND/NCSU: White-Source n-γ Coincidence Measurements of γ-Production Cross Sections at LANSCE**



Sample harvested at CARIBU

Target chamber for installation in the Gammasphere array

The GENESIS detector array at the LBNL 88" cyclotron

Indicates presentation at WANDA 24

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Current DNN R&D Priorities (led to projects funded in FY24)

- **(α,n) reaction data relevant to safeguards and arms control verification**
  - Neutrons from (α,n) reactions are an important component of nondestructive assay (NDA) techniques to determine enriched uranium and other actinide inventories in a variety of critical points in the nuclear fuel cycle. However, uncertainties in the **cross section, total neutron yield and neutron spectrum, and gamma emissions from these reactions** introduce large uncertainties in the determination of mass of actinides of interest and can represent several significant quantities in unaccounted material in certain facility processes. Improved measurements of these data are needed, according to the priority isotopes listed below.
- **Fission data for safeguards and forensics applications**
  - Improved measurements of fission-related quantities involving even-A isotopes of Pu are needed to enable physics-based NDA of nuclear materials. These **quantities include the ^{238}Pu, ^{240}Pu, and ^{242}Pu spontaneous fission half-lives, prompt fission neutron spectra, nu-bar, and multiplicity distributions**. Proposals are sought to perform measurements of these data to a high degree of accuracy (targeting <0.25% uncertainty, if possible).
- **Cross sections for reactions involving short-lived fission products (Scoping Study)**
  - Isotopes far from stability can play an important role in a variety of nonproliferation applications, including modeling and understanding post-detonation nuclear forensics scenarios. Recent advancements in experimental facilities and techniques (e.g., radioactive beams and inverse kinematics) and improved nuclear reaction models can help quantify formerly inaccessible cross-section data for these short-lived isotopes. Proposals are sought to complete a scoping study to determine how to leverage new capabilities to measure and model cross sections for reactions involving isotopes far from stability that are relevant to nonproliferation.

List of priority isotopes for improved (α,n) reaction data (2023 NDIAWG FOA)

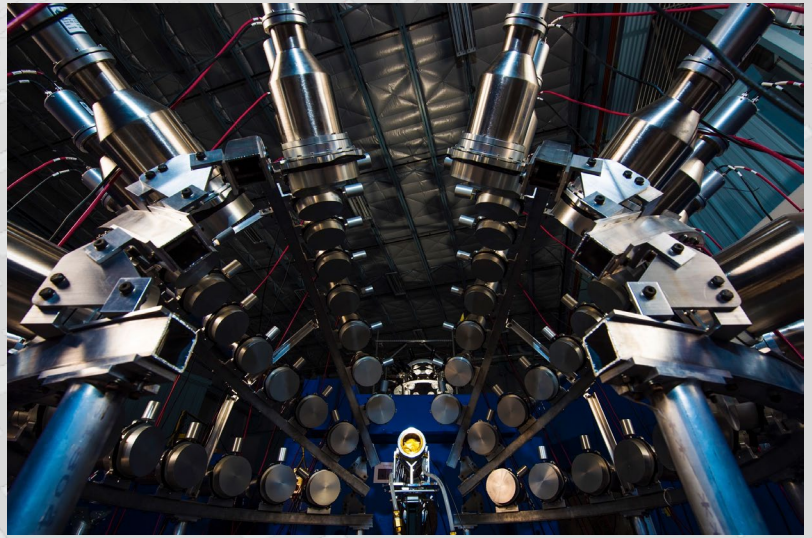
First Priority	
^{19}F	Additional measurement data and evaluation, including secondary gamma rays and neutron spectrum to reduce uncertainties as low as possible. Energy range 2-8 MeV.
^{13}C	New measurement data and evaluation required, including secondary gamma rays and neutron spectrum. Differential partial cross sections from 5 to 9 MeV are of particular interest. Integration with international efforts is encouraged.
^{17}O	Integral measurements specific to NDA applications, including coincidence gamma rays.
^{18}O	Integral measurements specific to NDA applications, including coincidence gamma rays.

Second Priority	
^{10}B	Measurement data and evaluation, including secondary gamma rays and neutron spectrum. Energy range 2- 8 MeV.
^{11}B	Measurement data and evaluation, including secondary gamma rays and neutron spectrum. Energy range 2- 8 MeV.
^{7}Li	Measurement data and evaluation, including secondary gamma rays and neutron spectrum. Energy range 2- 8 MeV.
^{27}Al	Measurement data and evaluation, including secondary gamma rays and neutron spectrum. Energy range 2-8 MeV.

New DNN R&D Nuclear Data Projects for FY24

- **2024-2025, LLNL: Scoping Study for Nuclear Reaction Cross Sections on Short-Lived Fission Products**
  - One-year scoping study to identify approaches for modeling and measuring nuclear reaction cross sections on fission products relevant to nonproliferation applications
- **2024-2027, LANL/LLNL/Umich/UNM: New measurements of spontaneous fission properties of Pu isotopes**
  - Perform new measurements of the prompt fission neutron spectra, neutron number distributions, some lifetime data, and fission modeling for the spontaneous fission of ^{238,240,242}Pu
- **2024-2028, ORNL/LANL/AFIT/NDU : Reaction Cross Sections, Secondary Gamma-Ray Yields, and Measured Neutron Spectra for Alpha-Induced Reactions on Light Nuclei**
  - Measure alpha-induced cross sections, secondary gamma-ray yields, and neutron spectra on ^{19}F, ^{13}C, ^{10}B, ^{11}B, and ^{7}Li nuclei

Short-lived Fission Products Workshop at LLNL



The Chi-Nu Liquid Scintillator Detector Array at LANL, used in the Spontaneous Fission of Pu Isotopes project

Indicates presentation at WANDA 24

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Future DNN R&D Priorities (current NDIAWG FOA Topics → FY25)

- **(α,n) reaction data relevant to safeguards and arms control verification**
  - Neutrons from (α,n) reactions are an important component of nondestructive assay (NDA) techniques to determine enriched uranium and other actinide inventories in a variety of critical points in the nuclear fuel cycle. However, uncertainties in the **cross section, total neutron yield and neutron spectrum, and gamma emissions from these reactions** introduce large uncertainties in the determination of mass of actinides of interest and can represent several significant quantities in unaccounted material in certain facility processes. Improved measurements of these data are needed, according to the priority isotopes listed below.

- **Cross sections for reactions involving short-lived fission products (Exploratory Projects)**
  - Isotopes far from stability can play an important role in a variety of nonproliferation applications, including modeling and understanding post-detonation nuclear forensics scenarios. Recent advancements in experimental facilities and techniques (e.g., radioactive beams and inverse kinematics) and improved nuclear reaction models can help quantify formerly inaccessible cross-section data for these short-lived isotopes. **Exploratory projects are sought to measure cross sections for reactions involving isotopes far from stability that are relevant to nonproliferation**. Also of interest are projects to **develop theoretical models that can be used to validate measured data from these reactions**, which are needed to enable the evaluation of new data for adoption in NNDC libraries.

Priority isotopes for improved (α,n) reaction data

^{27}Al	Measurement data and evaluation, including secondary gamma rays and neutron spectrum. Energy range 2-8 MeV.
^{17}O	Integral measurements specific to NDA applications, including coincidence gamma rays.
^{18}O	Integral measurements specific to NDA applications, including coincidence gamma rays.

Nuclear Data Needs by DNN R&D Portfolio

Nuclear Data Needs for Plutonium Production Detection (PM: Dr. Novella Bridges, novella.bridges@nnsa.doe.gov)

- Detection, location, and characterization of plutonium production activities often relies on inferences made from key fission product ratios.
  - Therefore, improved **independent and cumulative fission product yields** are needed.
- Plutonium production reactors differ from commercial LWRs
  - Typical reactor types include:
    - Graphite Moderated
    - Heavy-Water Moderated
    - Fast Breeder Reactors
  - Therefore, **improved capture cross sections (for actinides, fission products, and activation of structural materials)** relevant to these neutron spectra are needed.
- Key **fission product gamma emission energies and intensities** may also useful.

Nuclear Data Needs for Near-Field Detection & Emergency Response (PM: Dr. Hank Zhu, hank.zhu@nnsa.doe.gov)

- **Radiative capture (n,γ) and inelastic scattering (n,n'γ) production data**
  - Application: neutron associated particle imaging (API) for identification of nuclear materials
  - Gap: gamma-ray production data and reaction modelling for active interrogation using thermal to fast neutrons on ^{235}U, ^{238}U, and ^{239}Pu, as well as a variety of elements that comprise structure and shielding materials, controlled substances, and detector materials.

- **Correlated fission data evaluation**
  - Application: neutron/gamma multiplicity analysis for characterization of nuclear devices
  - Gap: prompt fission gamma modeling and measurements, such as time-correlated neutron/gamma multiplicity and gamma-ray spectra, for $^{235}U/^{239}Pu$ as a function of incident neutrons from thermal to fast.

- **Stopping powers**
  - Application: neutron detector development
  - Gap: stopping powers of neutrons in scintillator materials revealing how recoil protons and ions deposit their energy, which directly relates to how they generate scintillation photons.

Nuclear Data Needs for Arms Control Monitoring & Verification (PM: LTC David Matters, david.matters@nnsa.doe.gov)

NNSA has needs for improved data on a variety of elements that comprise structural and shielding materials, controlled or dangerous substances, and detector materials

- Modeling of secondary γ-ray emission from active neutron interrogation would benefit from quality assurance checks with benchmark datasets
- **Improved γ-production cross sections are needed on priority elements**, as are correlated neutron-gamma emission probabilities for isotope identification
- Benchmark data are primarily required for from **radiative capture (n,γ) and inelastic neutron scattering (n,n'γ)**, depending on which cross sections dominate γ-ray production

First Priority	Second Priority	Third Priority	
H	He	F	Gd
C	Li	Mg	Bi
N	Be	P	Np
O	B	S	Am
Na	Cl	Ar	
Al	Cr	K	
Si	Mn	Ca	
Fe	Ni	Ti	
Cu	Ge	As	
Pb	Br	Kr	
W	Cd	Mo	
U	I	Sn	
Pu	Cs	Sb	
	La	Xe	

Being addressed in a current DNN R&D-sponsored project

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Nuclear Data Needs for Safeguards (PM: Dr. Julie Gostic, julie.gostic@nnsa.doe.gov)

- **Spontaneous fission yields for ^{239}Pu, ^{240}Pu**
- **Spontaneous neutron multiplicity factorial moments and distributions**
- **Fission-neutron induced neutron multiplicity moments and distributions**
- **Neutron energy distributions**, characterized by mean energies

Isotope	Parameter	Uncertainty	Goal	Comment
^{240}Pu	g, fis/s/g	0.82%	<0.25%	SF half-life
^{240}Pu	υ_{s1}, n/fis	0.20%	<0.25%	nu-bar
^{240}Pu	υ_{s2}, n^2/fis	0.30%	<0.25%	2nd factorial moment
^{240}Pu	υ_{s3}, n^3/fis	1.30%	<0.25%	3rd factorial moment
^{239}Pu	υ_{i1}	0.20%	<0.20%	Averaged over a PFNS
^{239}Pu	υ_{i2}	0.50%	<0.20%	
^{239}Pu	υ_{i3}	0.80%	<0.20%	
^{240}Pu : ^{252}C	$\langle E_{Pu} \rangle / \langle E_{Cf} \rangle$	~2%	<0.1%	Mean emission energy

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Nuclear Data for Ground-based Nuclear Detonation Detection (PM: Dr. John Lazarz, john.lazarz@nnsa.doe.gov)

- **Nuclear physics data that would improve ground-based measurements:**
  - X-ray and conversion electron branching ratios for:
    - Current interest: Xe-135, Xe-133m, Xe-131m, Xe-133
    - Future NEM interest:
      - Xe-127 (used in seepage experiments)
      - Xe-122, Xe-125 (seen in samples and suspected to be from spallation neutron sources)
      - Ar-37, Ar-39 (possible NEM signature)
  - Half-life experiments to confirm accuracy

Nuclear Data Needs for Forensics (PM: Dr. Rich Gostic, richard.gostic@nnsa.doe.gov)

General Nuclear Data Goals:

- Uncertainty reduction to support measurements, modeling and simulation
- Signature discovery and exploitation

Areas of interest:

- Short-lived fission products.
- Activation products
- Cumulative fission yields of major and minor actinides

Questions?

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