Fission Product Yield Measurements
Supporting Nuclear Forensics

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Update for WANDA 2021
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Why is nuclear physics / nuclear data important to the mission

The defining signature of a nuclear detonation is the presence of nuclear reaction products in the debris. These can be from
- Fission products (FP) from the fuel.
- Activation products (AP) from the fuel or nearby materials.
- Production/Destruction depends on fuel type and neutron spectrum.

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ENDF Fission Chain Yields

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Fission Product Yield (atoms/fission)

Fission Product Mass Number

The Chain Reaction

Activity (Bq)

Time (hours)

ENDF Fission Chain Yields

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U-235 Thermal
U-235 Fission
U-235 14 MeV
Pu-239 Thermal
Pu-239 Fission
Pu-239 14 MeV
U-238 Fission
U-238 14 MeV

ENDF Fission Chain Yields

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Neutron Sources

**Flattop (NCERC)**
- Fast/fission Spectrum
- U(93) (17.7 Kg) & WG Pu (6 kg) cores / NatU Reflector (~1000 kg)
- Horizontal ("traverse") glory hole
- $10^{13}$ fissions/g on samples

**Godiva IV (NCERC)**
- Fast/fission neutron spectrum
- U(93) (65.5 kg, 1.5% Mo by weight)
- Super-Prompt Critical Operations
- Vertical glory hole for samples
- $1\times10^{16}$ Total Fissions / burst

**D-T Generator (PNNL)**
- Thermo D711 neutron generator
- Low scatter facility at PNNL
- Max neutron flux of $1\times10^9$ n/cm$^2$/s
Short-Lived Fission Product Yields (FASTER)

Fabricate High Quality Targets
Pulse Irradiate at NCERC
Acquire γ spectral data
Symmetric Temporal Spectral Analysis (LLNL)
Asymmetric Temporal Spectral Analysis (PNNL)
Evaluate Neutron Fluence & Fissions
Publish Fission Yields in Nuclear Data Sheets for NNDC

Very rich high-resolution spectroscopy allows us to unfold the time dependent behavior of FPs.
Cumulative Fission Product Yields (BETTER)

Fabricate Fission Chambers to Determine Absolute FPYs
Prepare High Quality Reference and Macro-foils
Irradiate Samples at NCERC and PNNL
Post-Irradiation Whole Foil $\gamma$-Counting
Radiochemical Dissolution and Analysis
R-values ($R_{i/k}^j$) and Absolute FP Yields ($Y_{i/k}^j$)
Publish Results and Post in XFOR

Reference foil
Brass anode
Macor® insulator

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Relative to Absolute Fission Yields

\[ Y_{i,j,k} = \frac{(1 + \alpha_i)A_{i,j,k}}{\lambda_i \epsilon_i f_i N_f} \]

\[ R_{l,j,k} = \left( \frac{A_{i,j,k}}{A_{25,th}^{i,j,k}} \right) = \left( \frac{Y_{i,j,k}}{Y_{25,th}^{i,j,k}} \right) \]
Relative to Absolute Fission Yields

\[
Y_{i,k}^{j,k} = \frac{1 + \alpha_i A_i^{j,k}}{\lambda_i \epsilon_i f_i N_f^{j,k}} \frac{A_i^{j,k}}{A_{99}^{j,k}} \frac{Y_i^{j,k}}{Y_{99}^{j,k}} \frac{Y_i^{25,th}}{Y_{99}^{25,th}}
\]

Gammas
Fission Products
Pulser

Radiochemistry
Fission Chamber Performance

Pulse height spectra from the Mark II fission chamber
• Benchtop testing with $^{252}\text{Cf}$
• Testing at MIT with $^{235}\text{U}$

Data taken with an Amp-Tek MCA8000D Pocket MCA

Data taken with a CAEN DT5781 Desktop MCA
The Ultraweld L20 is set up to weld two pieces of aluminum into a disc with a pocket diameter of 0.455”, and will effectively weld two pieces of 0.003” to 0.006” aluminum shim.
Plans for FY21

Cumulative FPYs at NCERC/Flattop:
- FC testing at the MIT Nuclear Reactor Laboratory
  Oct 27 - 29, 2020 – COMPLETED
- FC testing on Flattop at NCERC
  Nov 17 - 19, 2020 – CANCELED
- FC testing at the MIT Nuclear Reactor Laboratory
  Scheduled Mar 2 - 4, 2021
- FC testing on Flattop at NCERC
  Scheduled Mar 30 – Apr 1, 2021
- $^{235}$U foil irradiations on the Flattop critical assembly
  Scheduled April 17 - 14, 2021
  Parallel radiochemical analyses at LANL and PNNL
  Direct foil counting and radiochemical analyses to determine relative CFPYs.
  Collocated fission chambers to determine absolute CFPYs.

Short-Lived FPYs at NCERC/Godiva:
- $^{233}$U foil irradiations on the Godiva critical assembly
  Yet to be Scheduled
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