# Measurements of the Fission Neutron Spectrum Using Threshold Activation Detectors Final Design

**November 2016**

**ANS Winter Meeting, Las Vegas, NV**

**Theresa Cutler, John Bounds, Travis Grove, Dave Hayes, Jesson Hutchinson, Bill Myers, Rene Sanchez, Jessie Walker, Morgan White**

**Los Alamos National Laboratory**

# Overview of the Experiment

- **Purpose: Determine the prompt fission neutron spectrum (PFNS) of U-235**
  - The fidelity PFNS above 10 MeV is known to be questionable
- **Rocky Flats shells, with a hollow internal cavity**
  - ~93 wt. % $^{235}U$
  - Shells 33-64
- **Use threshold activation detectors in a critical HEU system**
- **Designed on Planet critical assembly machine**

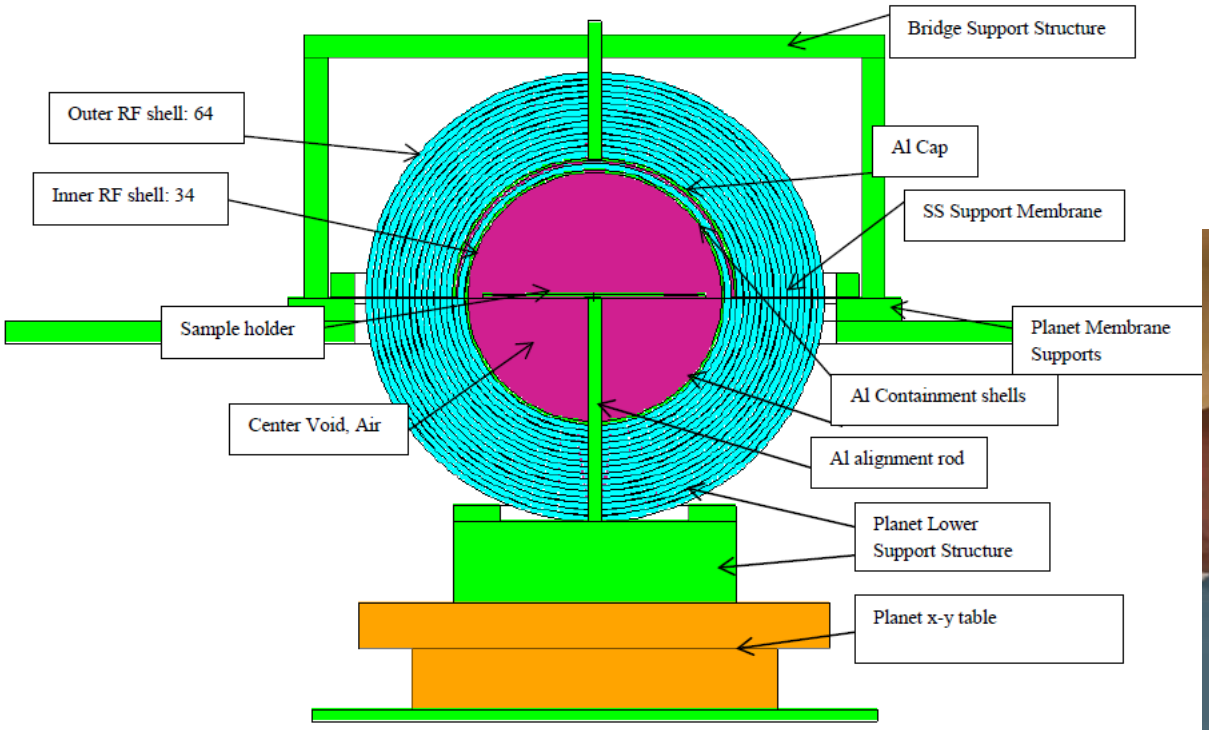
A photograph of a subset of the Rocky Flats Uranium shells

# Physical Characteristics of Rocky Flats Shells 33-64

| | |
|---|---|
| **Average Thickness (cm)** | 0.32 |
| **Average Gap Thickness (cm)** | 0.0098 |
| **Average Density (g/cm3)** | 18.65 |
| **Shell 33 IR (cm)** | 7.006 |
| **Shell 64 OR (cm)** | 12.336 |
| **Total Mass of HEU Shells (kg)** | 114.3 |
| **Mass of HEU shells above Support Membrane (kg)** | 54.15 |

# Overview of Model

- Simulations performed in MCNP6® using ENDF/B-VII cross sections

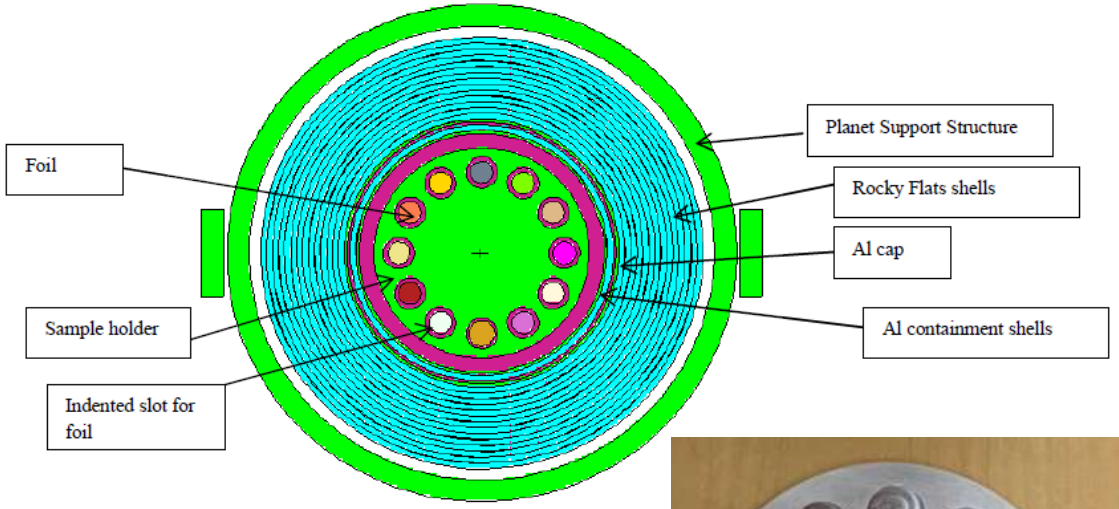


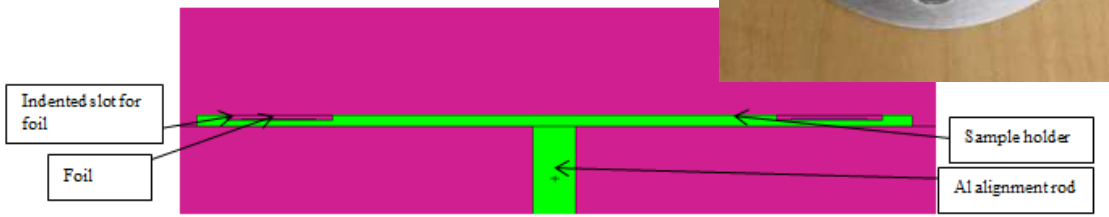

Green=Aluminum, Orange=Steel, Teal= Uranium, Pink=Air.

# The Sample Holder

| | |
|---|---|
| **Plate Radius** | **6.00** |
| **Plate Thickness** | 0.15875 |
| **Indent Depth** | 0.0375 |
| **Radius to Center of Indents** | 0.4611 |
| **Indent Radius** | 0.889 |
| **Foil Radius** | 0.635 |
| **Alignment Rod Radius** | 0.357 |

Dimensions in cm



# Description of MCNP6® Simulations

- **ENDF/B-VII cross sections**
- **Foils modeled as pure samples with naturally occurring isotopic distributions**
  - Based on previous examination of foils from Shieldwerx
- **Composition of Rocky Flats Shells and Planet structure come from ICSBEP benchmarks**
  - Density of Rocky Flats shells conserve mass which is necessary because the lateral holes were neglected
  - Consistent with other reports
- **Includes 11 of the candidate foil materials which cover the full energy range of interest**
- **Reaction rate tallies segmented into 130 discrete energy bins, spanning 0 to 21 MeV**
  - Aim to find mean neutron interaction energy (E_50)
- **Keff=1.00833 ± 0.00003**

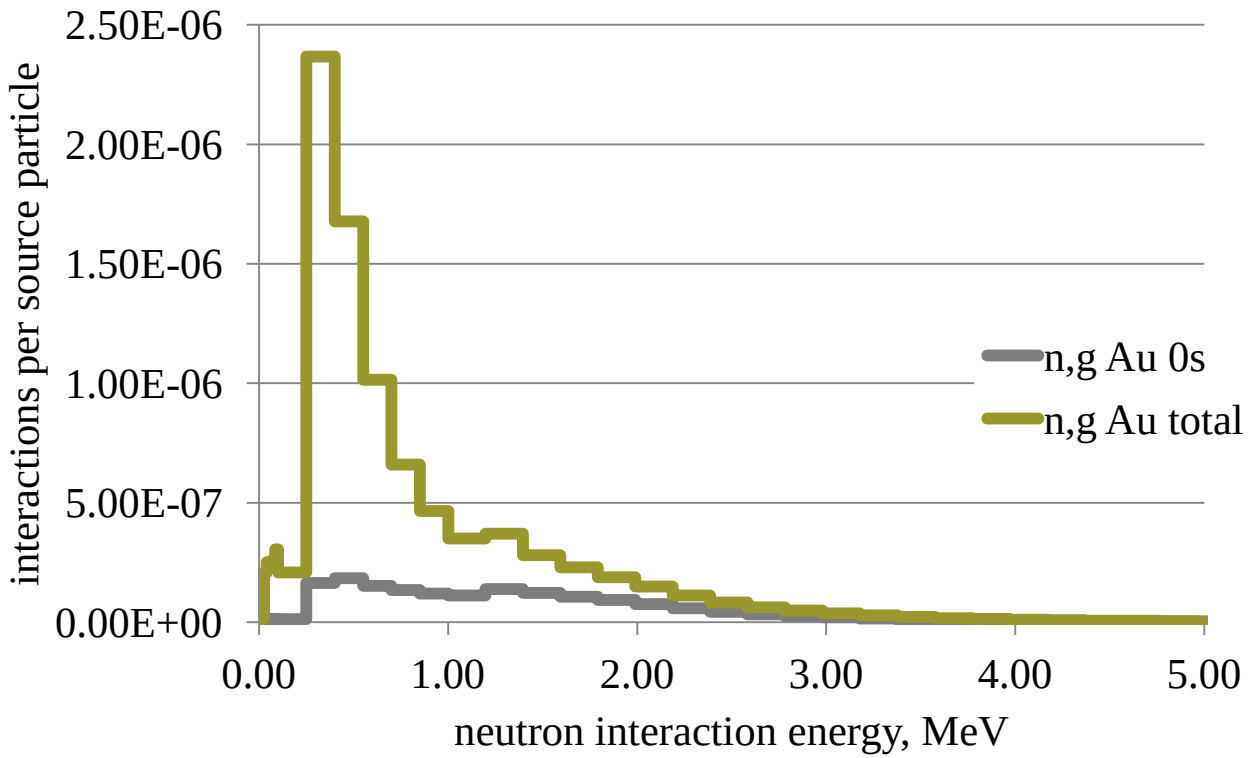
# Foil Materials and Activation Reactions

| Foil Material | Foil thickness, mil | Isotope of Interest | % Natural Abundance of Isotope of Interest | Reaction | Cross Section, [b] | E_50 [MeV] | Nucleus | Half-life |
|---|---|---|---|---|---|---|---|---|
| DU | 5 | 238U | 99 | 238U(n,f)FP | 0.31539 | 2.73 | / | / |
| Iron | 5 | 54Fe | 5.85 | 54Fe(n,p)54Mn | 0.08692 | 4.23 | 54Mn | 2.58 h |
| Nickel | 10 | 58Ni | 68.0769 | 58Ni(n,p)58Co | 0.118 | 3.94 | 58Co | 2.73 y |
| Copper | 10 | 63Cu | 69.17 | 63Cu(n,a)60Co | 0.000689 | 7.24 | 60Co | 9.67 m |
| | 10 | 65Cu | 69.17 | 65Cu(n,2n)64Cu | 0.000689 | 12.64 | 64Cu | 14.9 h |
| Aluminum | 10 | 27Al | 100 | 27Al(n,a)24Na | 0.001017 | 8.40 | 24Na | 9.462 m |
| Gold | 1 | 197Au | 100 | 197Au(n,γ)198Au | 0.078 | 0.75 | 198Au | 9.6 h |
| Gold with 4 mil Cd cover | 1 | 197Au | 100 | 197Au(n,γ)198Au | 0.078 | 0.75 | 198Au | 9.6 h |
| | 1 | 197Au | 100 | 197Au(n,2n)196Au | 0.00051 | 10.61 | 196Au | 12.7 h |
| Cobalt | 2 | 59Co | 100 | 59Co(n,α)56Mn | 0.000222 | 8.36 | 56Mn | 70.86 d |
| Vanadium | 2 | 51V | 99.75 | 51V(n,p)51Ti | 0.000649 | 6.44 | 51Ti | 43.67 h |
| | 2 | 51V | 99.75 | 51V(n,α)48Sc | 0.000039 | 9.10 | 48Sc | 14.9 h |
| Magnesium | 5 | 24Mg | 78.99 | 24Mg(n,p)24Na | 0.002 | 8.25 | 24Na | 13.11 h |
| Zirconium | 5 | 90Zr | 51.45 | 90Zr(n,2n)89Zr | 0.000221 | 14.41 | 89Zr | 249 d |
| Titanium | 5 | 46Ti | 8.25 | 46Ti(n,p)46Sc | 0.01409 | 5.90 | 46Sc | 83.7 d |

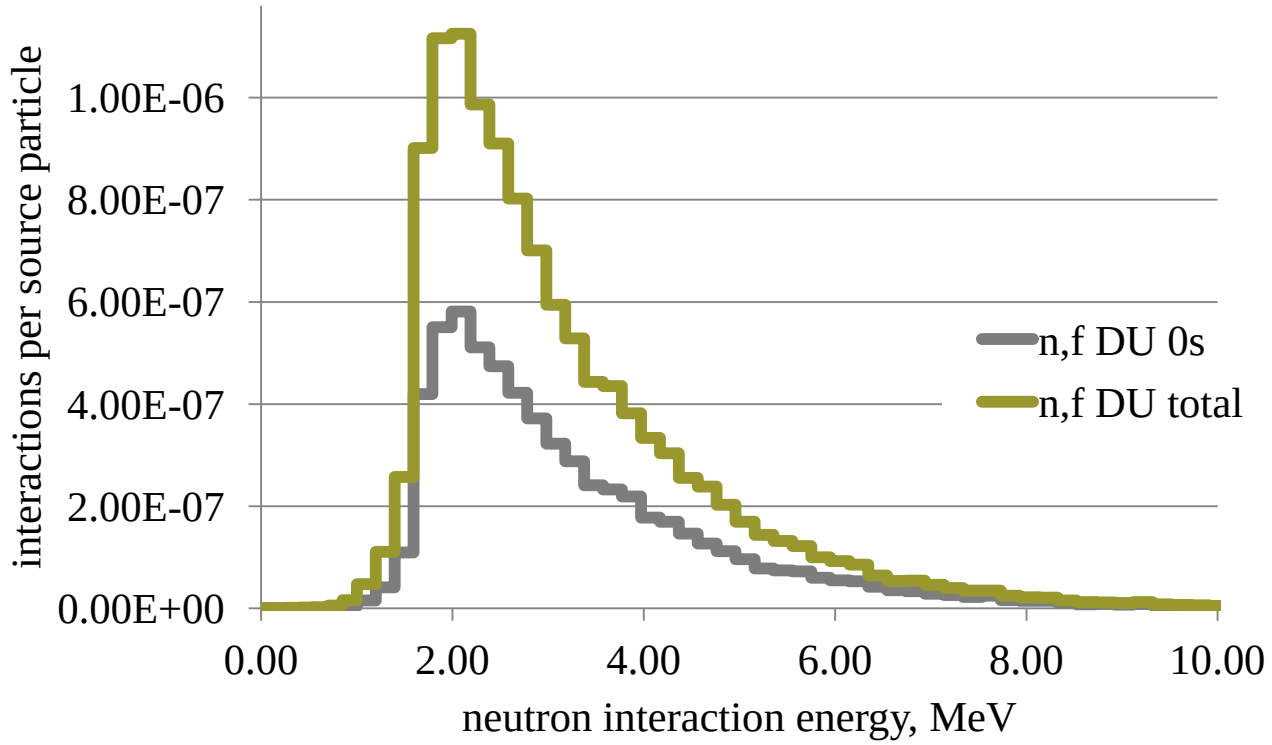
# Foil Selection

- **All reactions come from International Reactor Dosimetry and Fusion File (IRDFF) v.1.03 Cf-252 Spontaneous Fission Library**
- **Prior experience with reaction rate foils**
- **Shieldwerx Catalog**
- **Full Energy Spectrum with Mean Interaction Energy up to 13 MeV**
  - Thermal/epithermal range
  - High energy range
- **Considered effects of competing n,γ low energy interactions**
- **Percent of interactions from unscattered neutrons**
- **High energy interactions primarily (n,2n); (n,p); (n,α)**

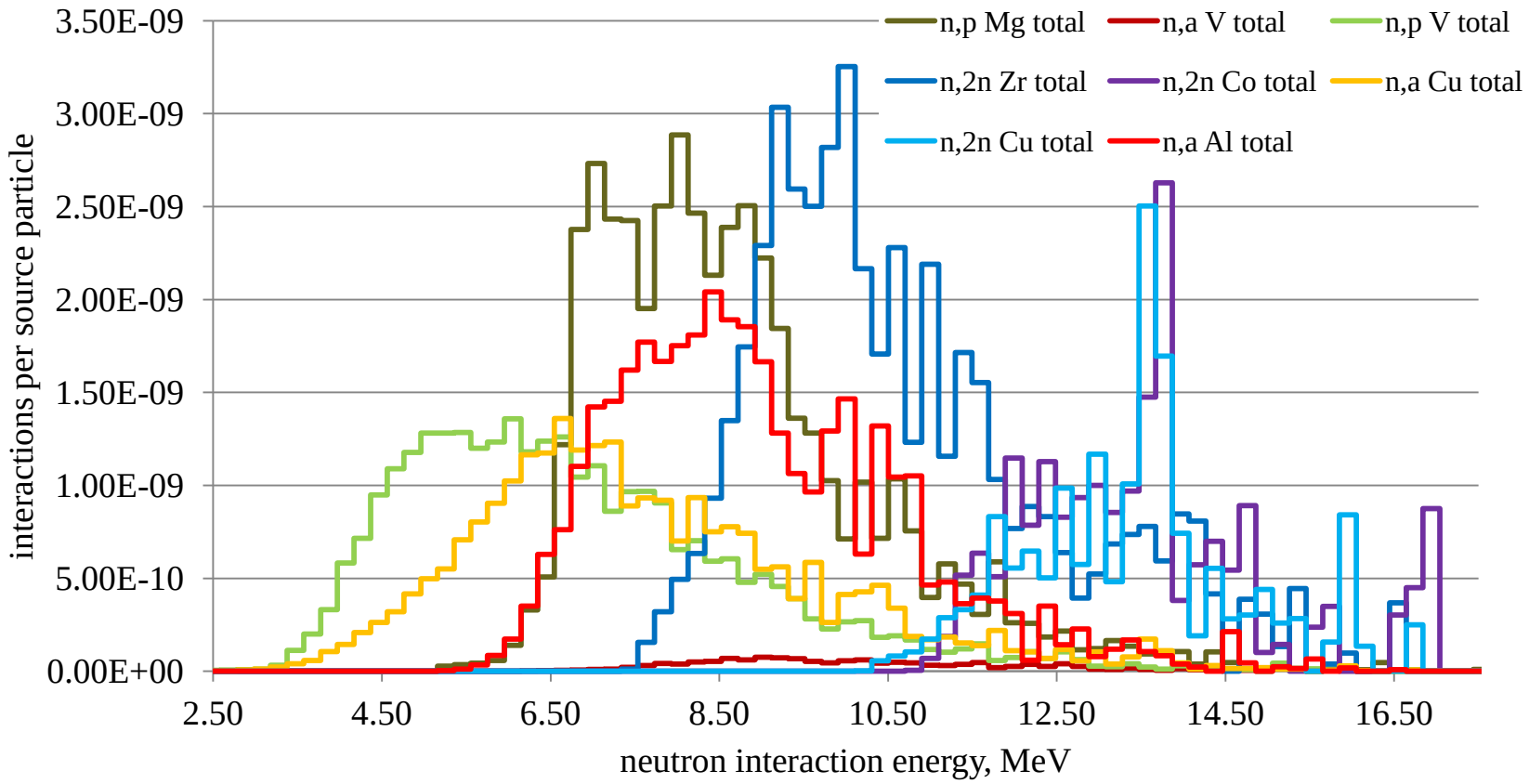
# Gold Relative Reaction Rate



# DU Relative Reaction Rate



# Threshold Reactions



# Acknowledgement

**This work was supported by the Department of Energy Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.**