Los Alamos NATIONAL LABORATORY

IER 153: PFUNS Execution and Preliminary Analysis

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Presented by R. Weldon

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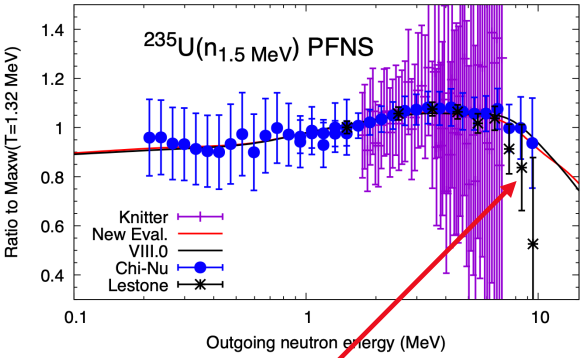
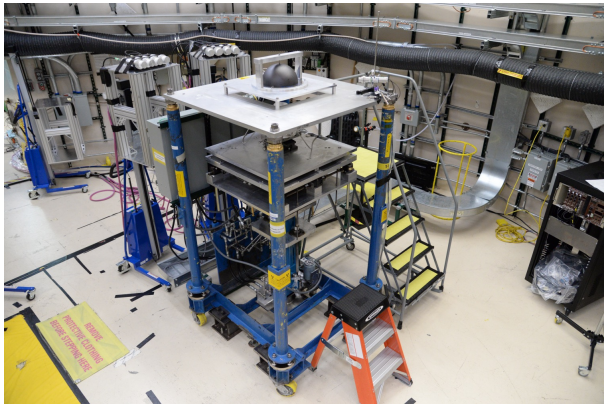
Motivation

- In 2011, two experiments were proposed on parallel paths
  - Differential measurements at LANSCE
  - Integral experiment at NCERC
- Goal: improve understanding and reduce uncertainty in ^{235}U prompt fission neutron spectrum (PFNS)
- The LANSCE experiment used the LANL/LLNL Chi-Nu detector and was published in 2022
- This data significantly improves the PFNS nuclear data from previous measurements up to 10 MeV
  - Above 8 MeV there are still large uncertainties
- Prompt Fission Uranium Neutron Spectrum (PFUNS) goal: reduce uncertainty at/above 8 MeV



Large uncertainty and lack of data at high energies in differential experiments

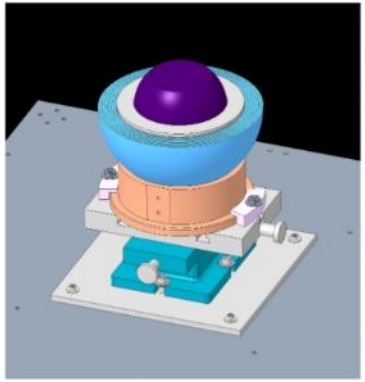


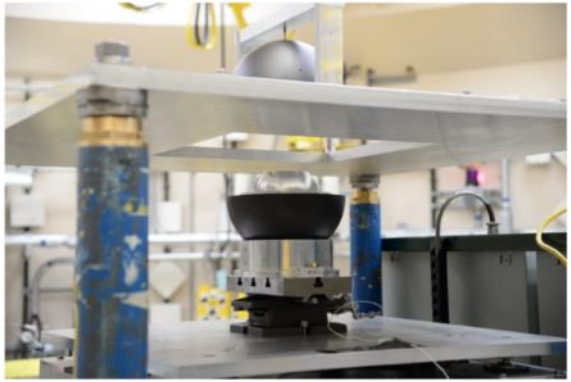
Experiment overview

- Performed at the National Criticality Experiments Research Center (NCERC)
  - Planet critical assembly machine
- Configuration of highly enriched uranium (HEU) metal hemishells
  - Rocky Flats (RF) hemishells, similar to the MUSiC experiment
  - 108 kg critical mass for PFUNS versus 59 kg maximum for MUSiC
- Activation foils placed in a central void region
  - Chosen based on energy thresholds
- This presentation: describes experiment execution of four critical configurations and two irradiations in 2024

Critical configurations

- Four benchmark configurations
- One utilized RF33,35-63 (108 kg) with no spacers
- Three included RF64 (114 kg) with different spacer sizes
- Benchmark configurations removed unnecessary components (sample plate, exterior RTDs, and mounting components)





HEU		RF33,35-63	RF33,35-64	RF33,35-64	RF33,35-64
Spacer		None	265 mil	275 mil	285 mil
Reactivity (cents)	LC1	8.68 ± 0.02	31.94 ± 0.12	19.18 ± 0.10	7.60 ± 0.03
	LC2	8.61 ± 0.02	31.87 ± 0.10	19.16 ± 0.06	7.55 ± 0.02
	LC3	8.63 ± 0.02	31.92 ± 0.12	19.15 ± 0.06	7.56 ± 0.02
	SU1	8.17 ± 0.08	31.43 ± 0.12	19.02 ± 0.13	7.29 ± 0.04
	SU2	8.19 ± 0.08	31.40 ± 0.09	18.84 ± 0.13	7.31 ± 0.04
	SU3	8.32 ± 0.08	31.25 ± 0.14	18.64 ± 0.13	7.28 ± 0.04
	SU4	8.60 ± 0.09	31.85 ± 0.12	19.36 ± 0.17	7.57 ± 0.05
	LC avg	8.63 ± 0.01	31.90 ± 0.07	19.16 ± 0.04	7.57 ± 0.01
	SU avg	8.30 ± 0.04	31.48 ± 0.06	18.91 ± 0.07	7.35 ± 0.02
Reactor period (sec)	LC1	112.58 ± 0.38	15.09 ± 0.12	37.25 ± 0.30	132.62 ± 0.55
	LC2	113.73 ± 0.30	15.16 ± 0.10	37.32 ± 0.19	133.67 ± 0.41
	LC3	113.43 ± 0.38	15.11 ± 0.12	37.34 ± 0.19	133.58 ± 0.45
	SU1	121.35 ± 1.45	15.58 ± 0.12	37.75 ± 0.40	139.69 ± 1.02
	SU2	121.01 ± 1.46	15.61 ± 0.09	38.31 ± 0.40	139.22 ± 0.99
	SU3	118.74 ± 1.39	15.76 ± 0.14	38.98 ± 0.42	139.79 ± 1.01
	SU4	113.82 ± 1.51	15.17 ± 0.12	36.70 ± 0.53	133.40 ± 1.02
	LC avg	113.33 ± 0.20	15.12 ± 0.06	37.31 ± 0.12	133.39 ± 0.26
	SU avg	118.81 ± 0.73	15.53 ± 0.06	38.06 ± 0.21	138.03 ± 0.51

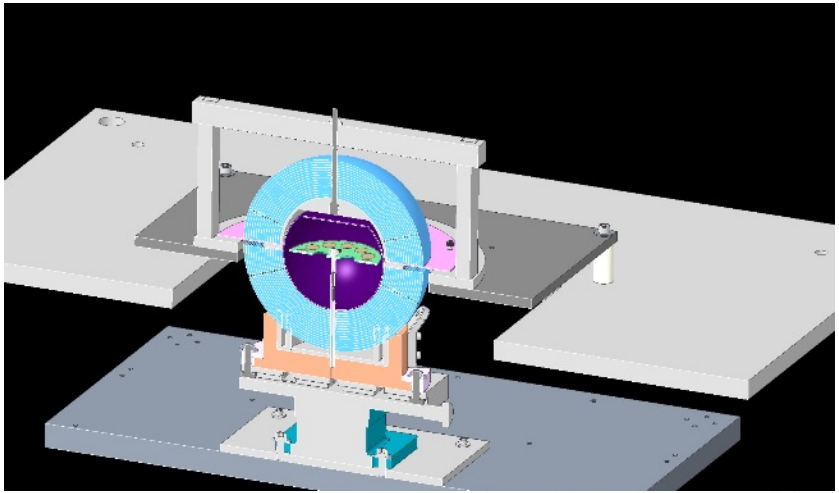
Diagnostics

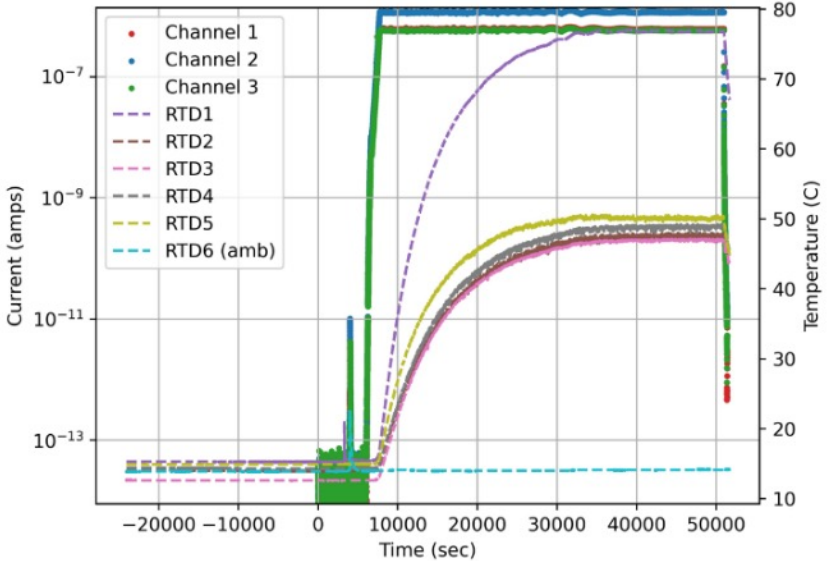
Activation foils, neutron leakage spectra, TLDs, coordinate-measuring machine (CMM)

Foil Irradiations

- Two irradiations
- Summary info of irradiations below

Date	2/20/2024	2/21/2024
HEU mass (kg)	114	114
Number of foils	20	22
Duration (hrs)	2	12
Temperature rise: center of assembly (°C)	20.2	61.8
Temperature rise: outer surface bottom (°C)	10.1	34.5
Temperature rise: outer surface top (°C)	12.0	35.7
LC 2 current (amps)	5.20E-07	1.15E-06
LC 2 amp-s	3.80E-03	5.04E-02
RMS3 dose rate (R/hr)	35	72
fissions	1.6E+16	2.1E+17
Estimated Watts	69	153
cents/°K	-0.26	-0.29
Reactivity used (cents)	5	18
Excess reactivity available (cents)	30	43



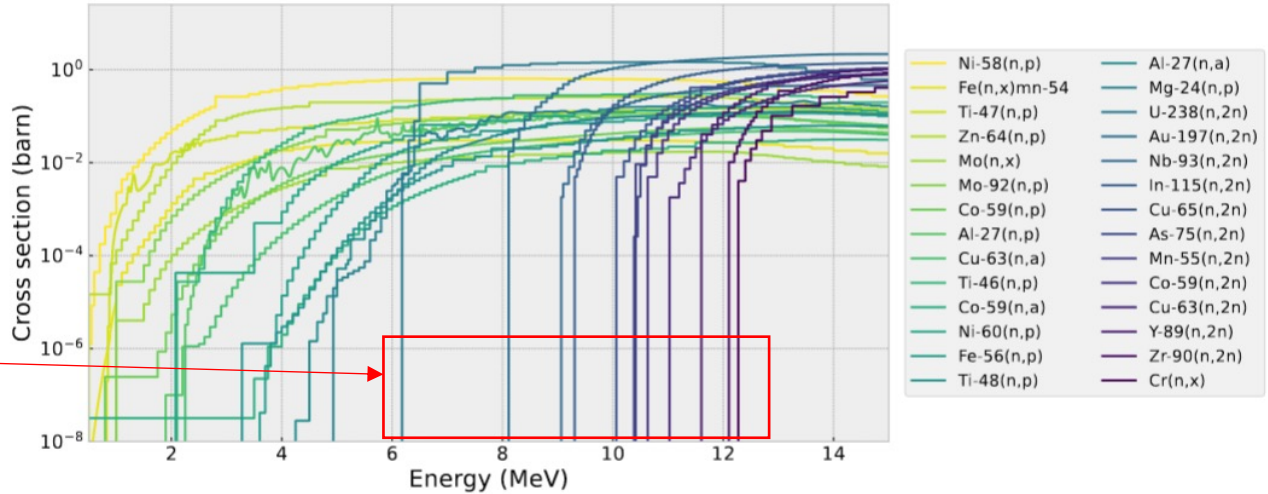


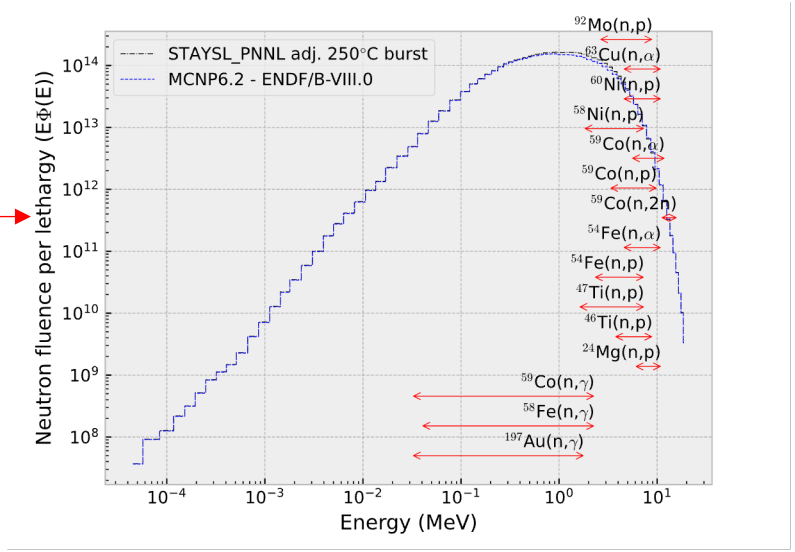
Foil loadout

- Short (2 hr) irradiation focused on fission foils and short-lived activation foils (left)
- Long (12 hr) irradiation focused on activation foils with high thresholds and/or long half-lives (right)
- Mass measurements and pre-irradiation gamma spec performed

Foil loadout

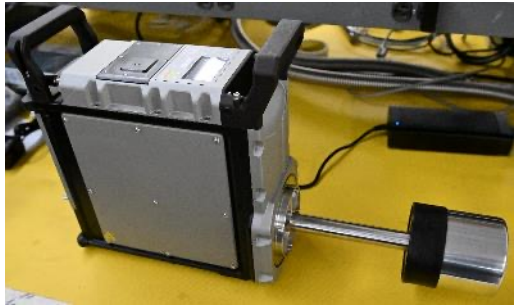
- Foils specifically chosen to ensure coverage of different threshold energies
- Multiple foil responses used for spectrum adjustment
- Example of spectrum adjustment for Godiva IV





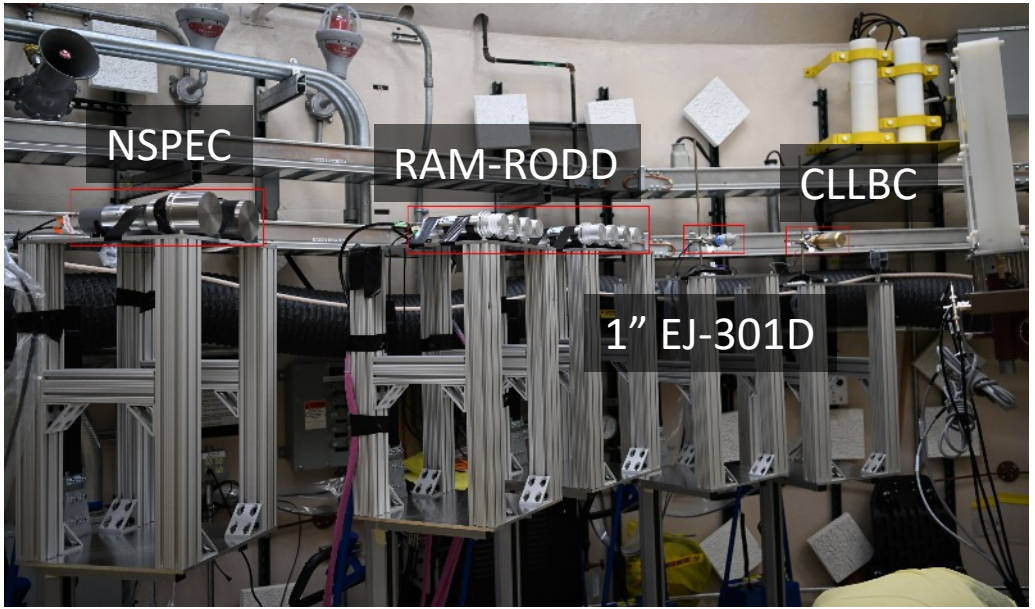
Gamma counting

- **>3600 hrs of gamma counting performed on 10+ HPGe systems**
- Founding of NCERC Counting Laboratory (NCERC-CL)
- Measurements at NCERC-CL DAF, TA-48, NCERC-CL NISC
- Recent count lab upgrades were essential to PFUNS success
- Will benefit future experiments



Neutron leakage spectra measurements

- **Performed using organic scintillator detector systems**
  - RAM-RODD (8 EJ-309 detectors)
  - NSPEC 2, 3" EJ-301D detectors
  - NSPEC 1" RCC of EJ-301D
  - CLLBC inorganic scintillation detector
- **16 hours of data was collected!**

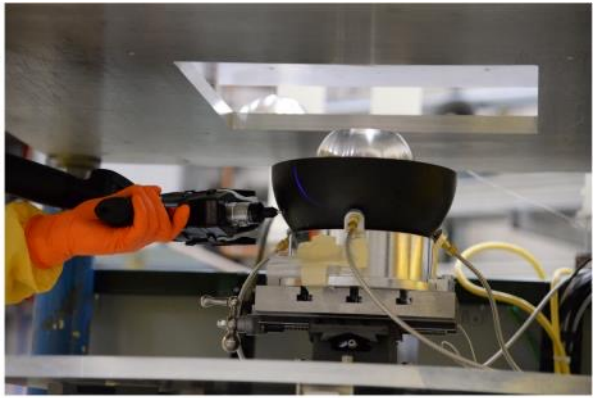


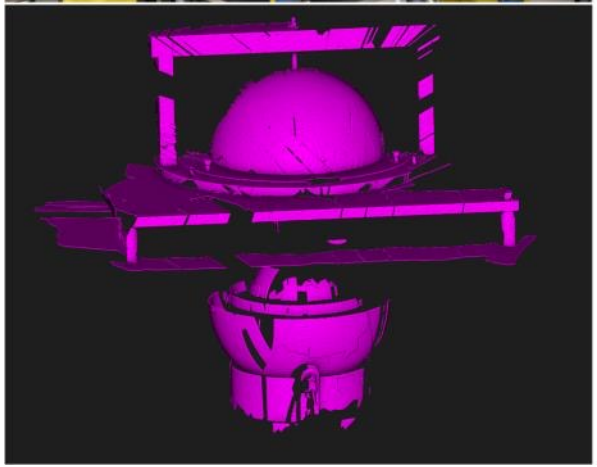
TLD measurements

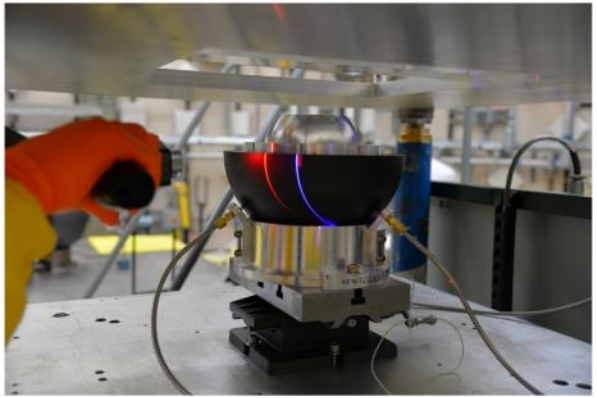
- **Over 20 TLDs deployed for each irradiation**
- **Results will be used for**
  - Planning future NCERC operations
  - Understanding failure rates of electronic components

CMM measurements

- CMM and other measuring devices used to measure experiment position information
- Precision reduces benchmark uncertainties

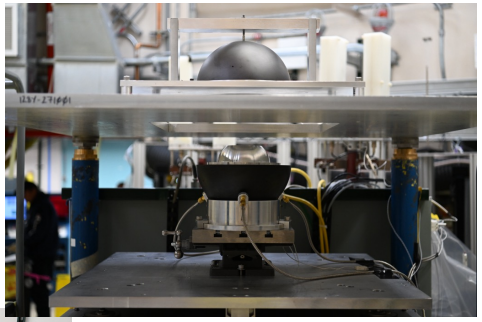






Conclusions

- PFUNS will help reduce uncertainties in high energy ^{235}U PFNS
- Experiment execution in 2024 included
  - Four critical configurations
  - Two foil irradiations
    - The 12 hr irradiation produced 2e17 fissions, more than any NCERC operation other than KRUSTY
    - Gamma counting for thousands of hours over ~6 months
  - Neutron leakage spectra measurements
  - Reactor kinetics measurements
  - TLD measurements
  - CMM measurements



Future work

- PFUNS work continues:
  - Benchmark evaluation for critical configurations
  - Analysis of activation foil data
  - Neutron spectrum adjustment (analysis will be discussed in the next talk by PhD candidate Ryan Charrette)
  - Nuclear data evaluation

Acknowledgements

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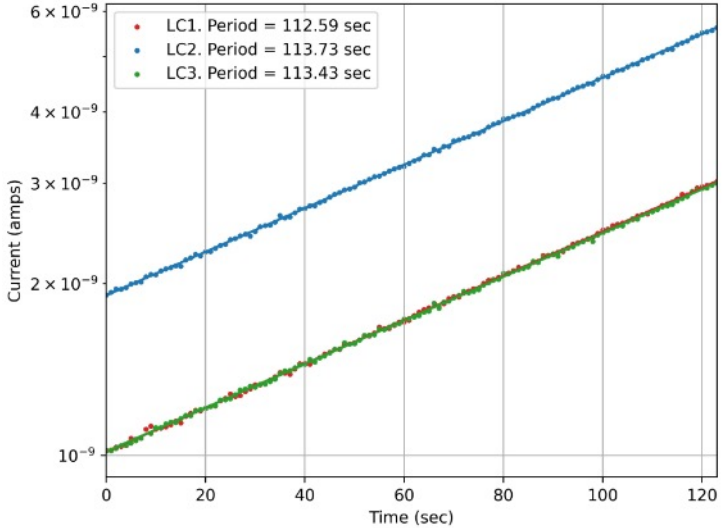
Reactivity measurements

- ^{3}He (called startups, SU) and compensated ion chambers (Linear Channels, LC) systems used
  - Measure exponential rise in neutron population for super-critical systems
- This is fit to determine reactor period (T)
- The Inhour equation is used to determine the reactivity (ρ) from the reactor period
  - Also depends on neutron generation time (Λ) and delayed neutron parameters (λ and β terms)



$$\rho = \frac{\Lambda}{T\beta_{eff}} + \sum_{i=1}^{6} \frac{(\frac{\beta_i}{\beta})}{1 + \lambda_i T}$$

^{235}U fast fission delayed neutron parameters

Group i	Decay Constant $\lambda_i(s^{-1})$	Relative Abundance (β_i/β)
1	0.0127 ± 0.0002	0.038 ± 0.003
2	0.0317 ± 0.0008	0.213 ± 0.005
3	0.115 ± 0.003	0.188 ± 0.016
4	0.311 ± 0.008	0.407 ± 0.007
5	1.14 ± 0.081	0.128 ± 0.008
6	3.87 ± 0.369	0.026 ± 0.003