RPI High Energy Neutron Scattering Measurements and Zirconium Evaluations

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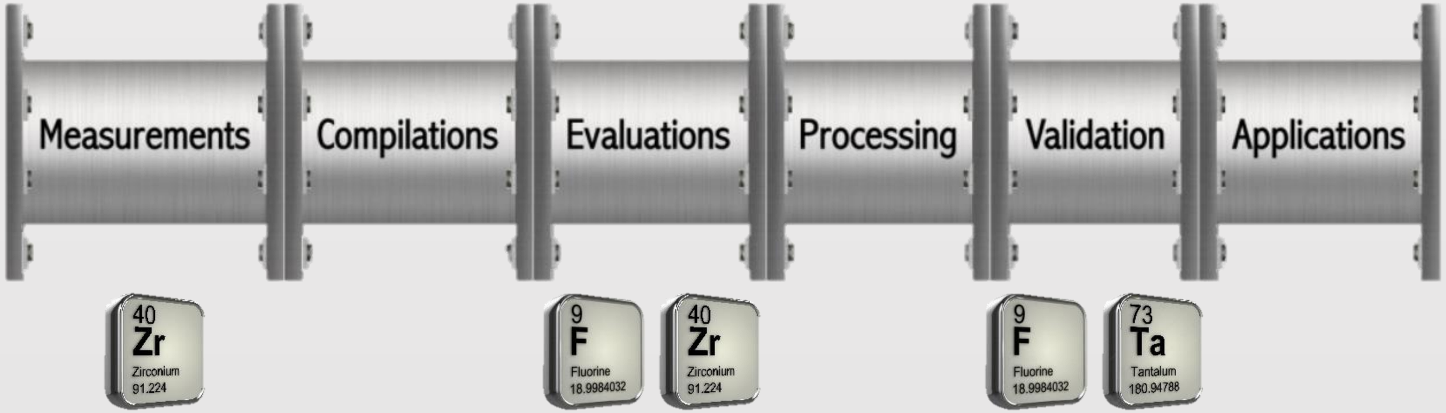
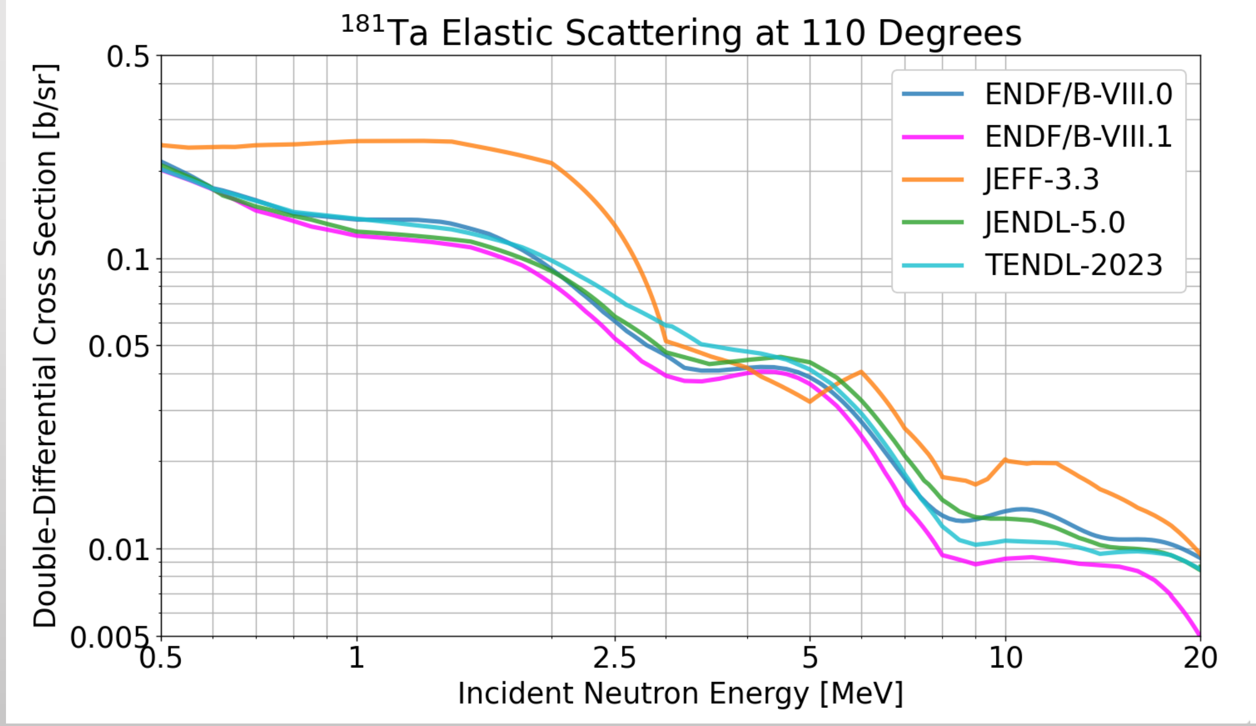
Introduction



- New evaluations of the stable zirconium isotopes will reduce uncertainty in criticality safety and reactor physics calculations
- Tantalum and Teflon $(CF_2)_n$ measurements motivated by:
  - Validating new ENDF/B-VIII.1 evaluations
  - Reducing uncertainty in criticality safety calculations for U and Pu production processes
- ^{19}F also present in Generation-IV and fusion reactor concepts



Recent RPI Neutron Scattering Measurements

Co-Authors: S. Singh[1], A. Daskalakis[2], K. Keparutis[1], P. Brain[1,*], B. Wang[1], M. Rapp[2], D. Barry[2], and R. Block[1]

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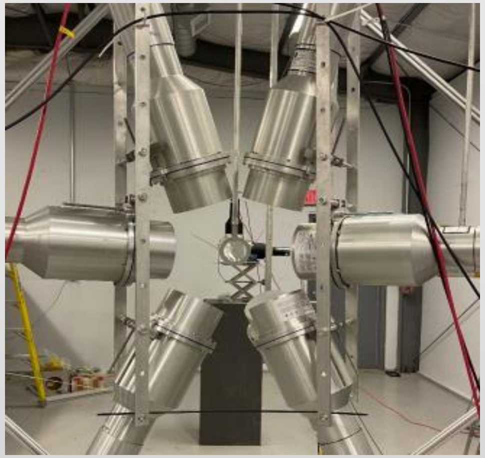
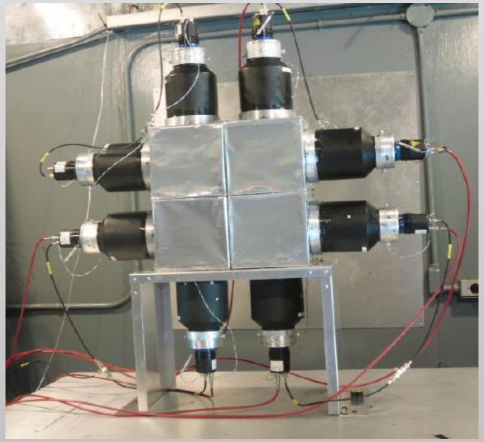
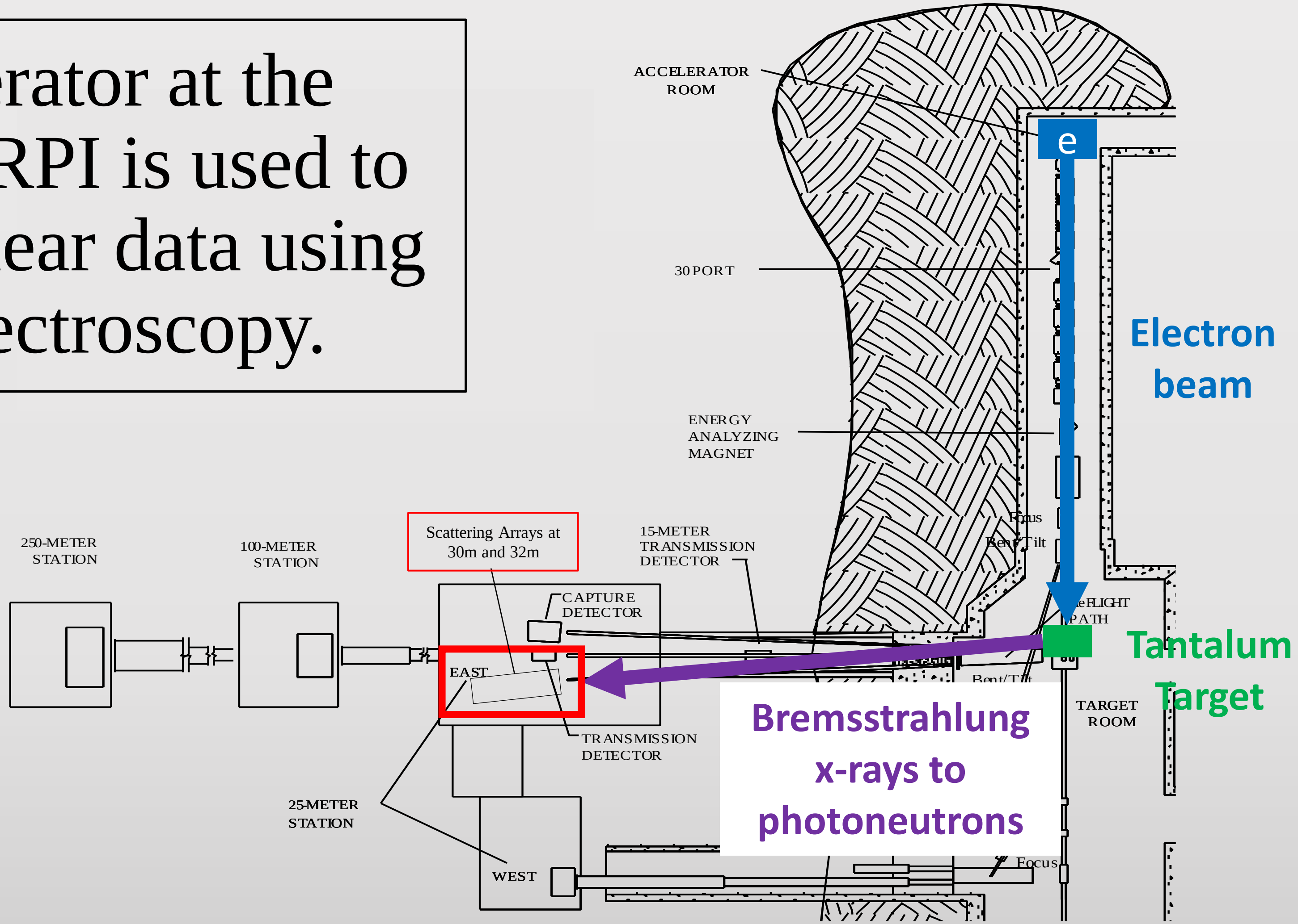
The electron linear accelerator at the Gaerttner LINAC center at RPI is used to produce high resolution nuclear data using neutron time-of-flight spectroscopy.





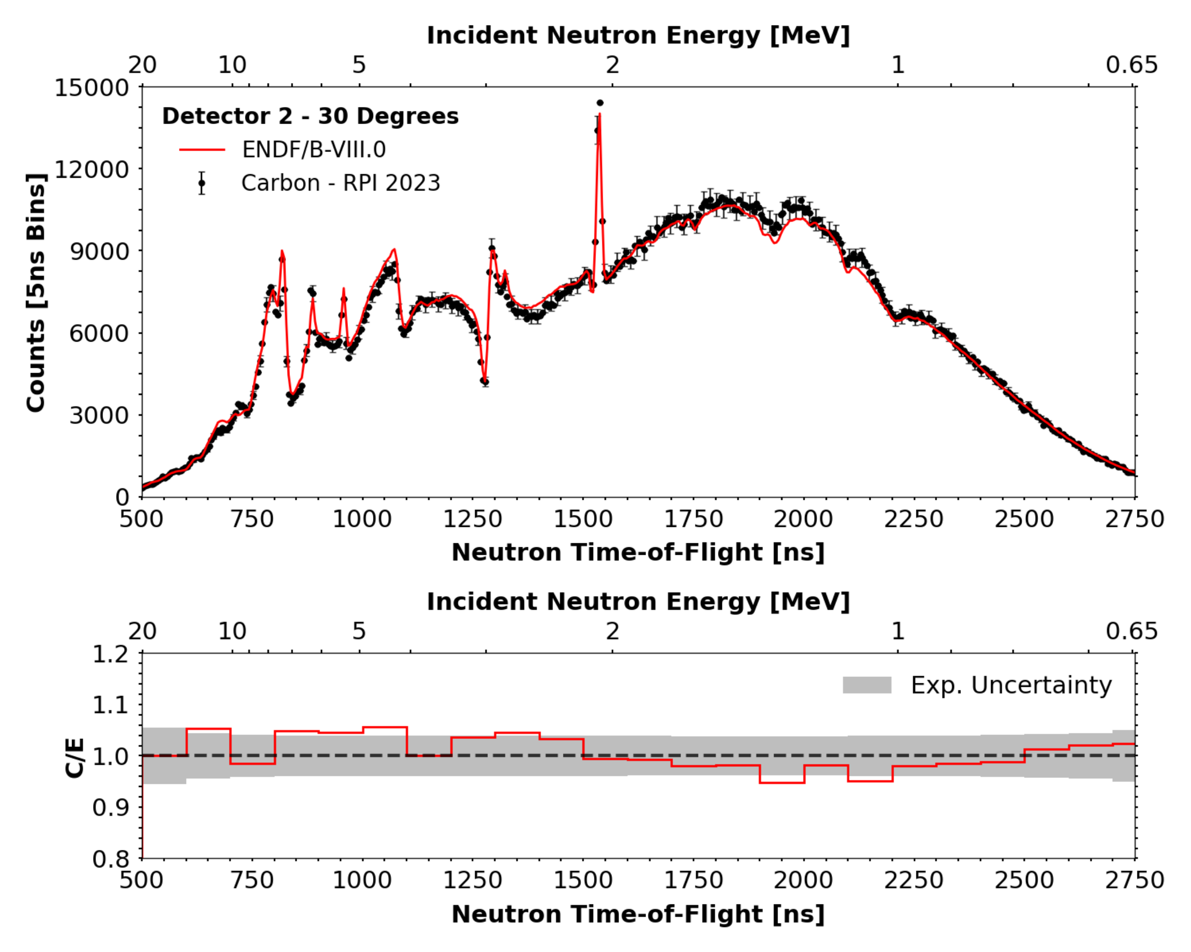


Quasi-Differential Measurement Methodology

1. Conduct differential neutron time-of-flight experiment on sample of interest, validation sample, and open beam
   - Due to sample size, the signal is dominated by multiple scattering interactions
   - Determine neutron flux and neutron detection efficiencies via modeling or experiment
2. Perform MCNP transport calculation of validation (Carbon) measurement using measured neutron flux and detector efficiencies
   - This validates experimental geometry and reproduction of known validations sample
   - Used to estimate the systematic uncertainty of the measurement
3. Perform MCNP transport calculation of sample of interest measurement using measured neutron flux and detector efficiencies
   - Differences present in nuclear data evaluations of the sample of interest are compared to the experimental data to validate performance or show needs for improvement

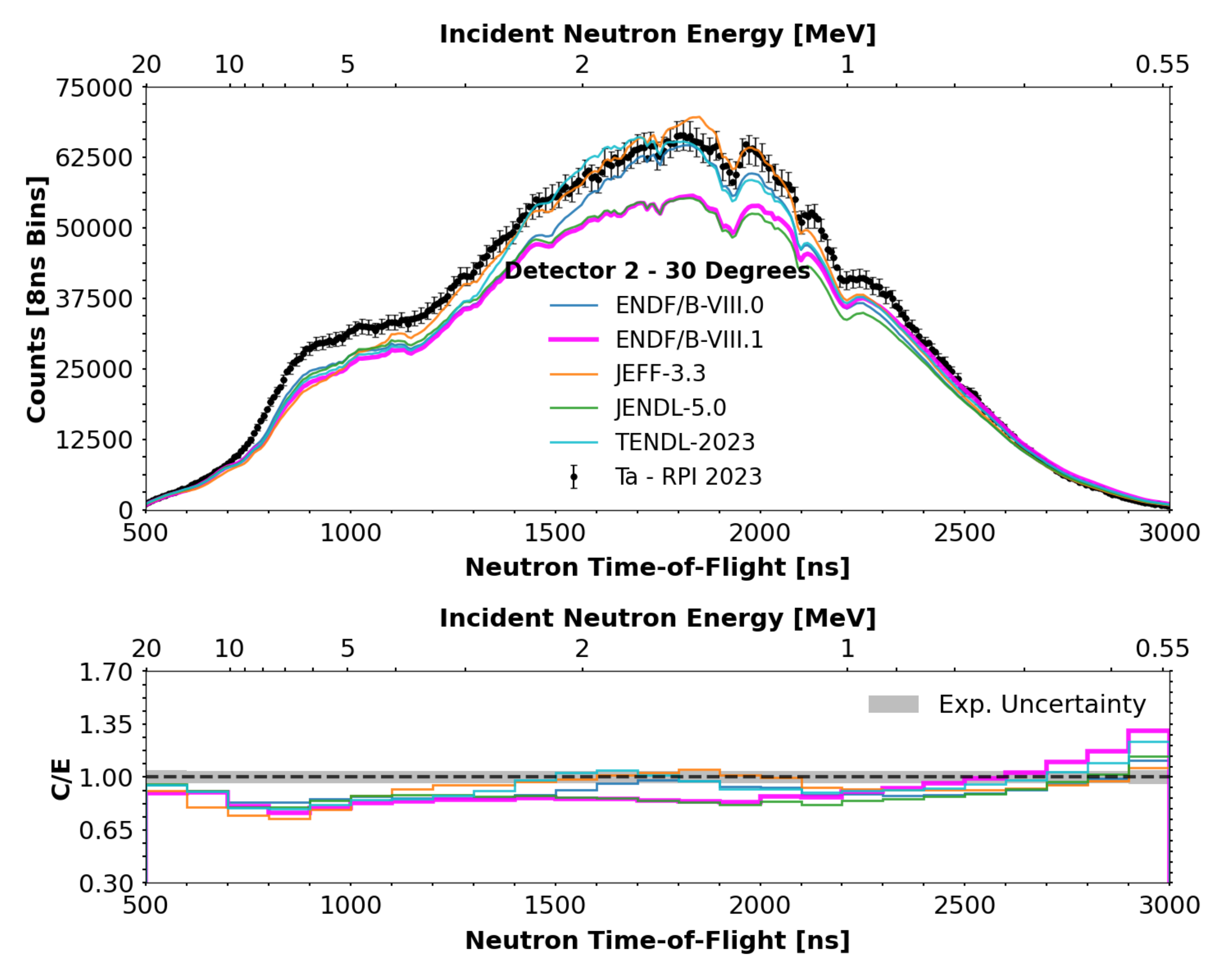
Validation Measurements of a Carbon Sample

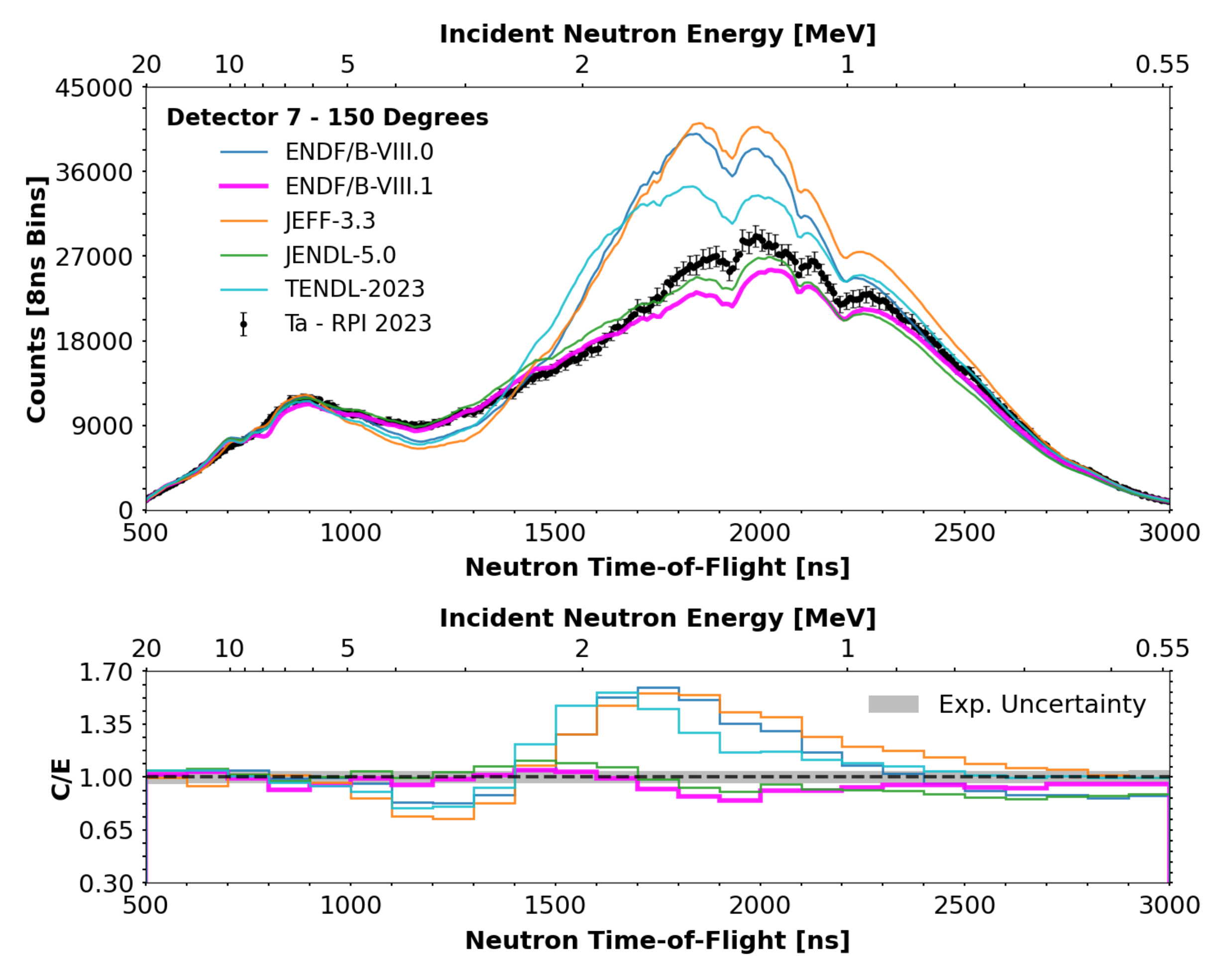
- Deviations of measured carbon data from evaluation adopted as experiment systematic uncertainty
  - 3.9% and 3.4% for Ta and Teflon experiments respectively
  - Improved from previous measurements[1,2] where systematics were ~6%
- Detector efficiencies determined from in-beam measurements
- Deadtime correction utilized legacy RPI algorithms recently validated for SIS-3305 digitizer[3]



1. Blain E. et. al, *Nucl. Sci. and Eng.*, **196**, 2, 121-132 (2022)
2. Daskalakis A. et. al, *Ann. Nucl. Eng.* **110**, 603-12 (2017)
3. McDermott B. J., *Ph.D. Thesis, Rensselaer Polytechnic Institute (2016)*

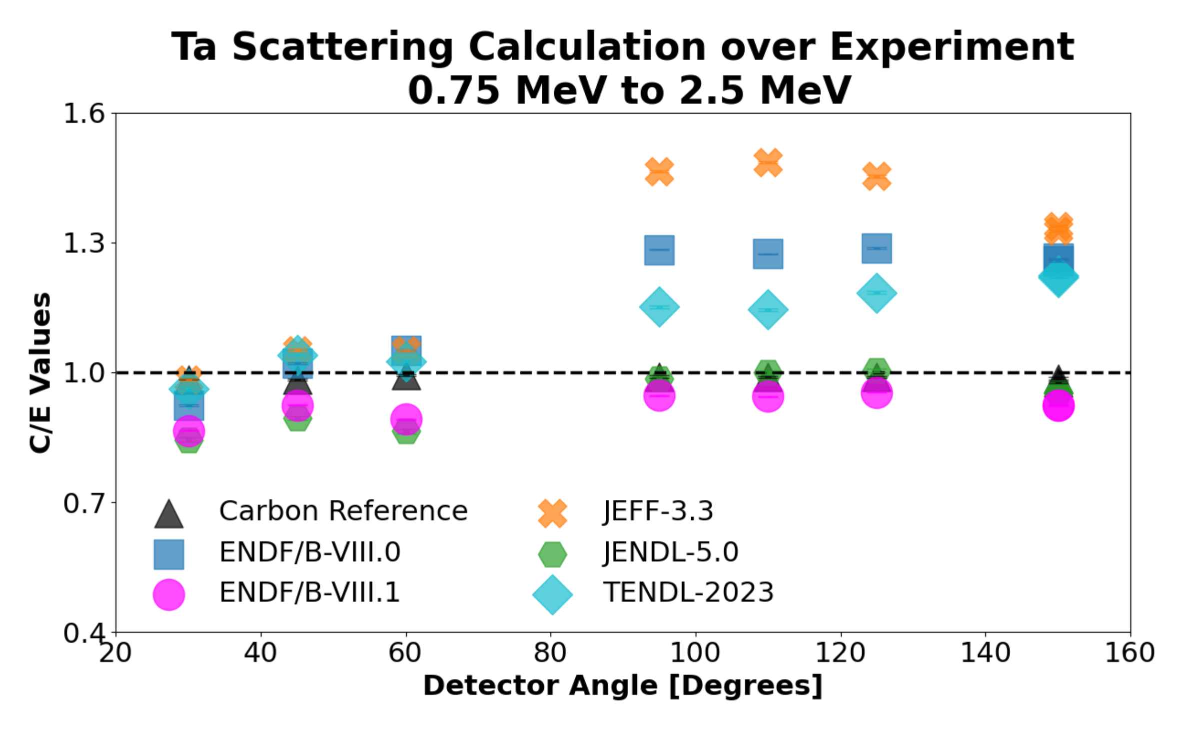
Ta - Some Issues Remain at Very Forward Angles, but Large Improvements in Backward Angles

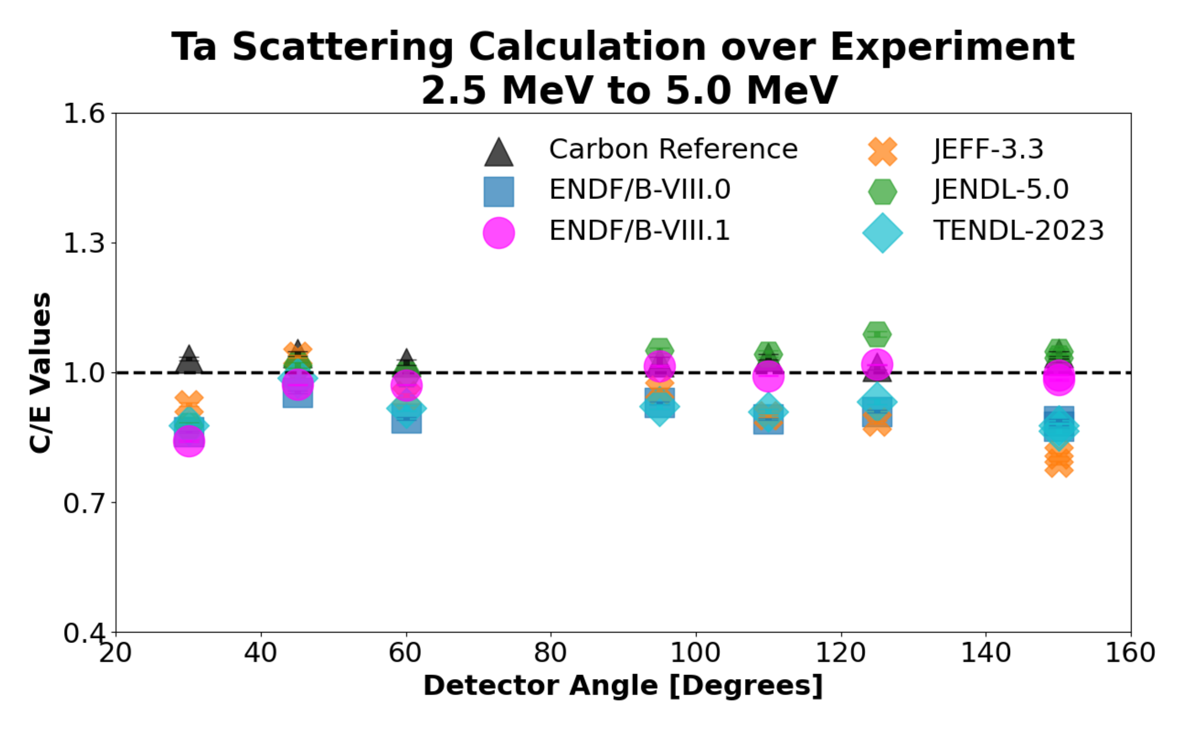




Tantalum Scattering Kernel Performance

Improvements made over previous ENDF/B-VIII.0 ^{181}Ta evaluation to resolve the significant overprediction of neutron scattering at backward angles in the energy region of neutron born of fission.

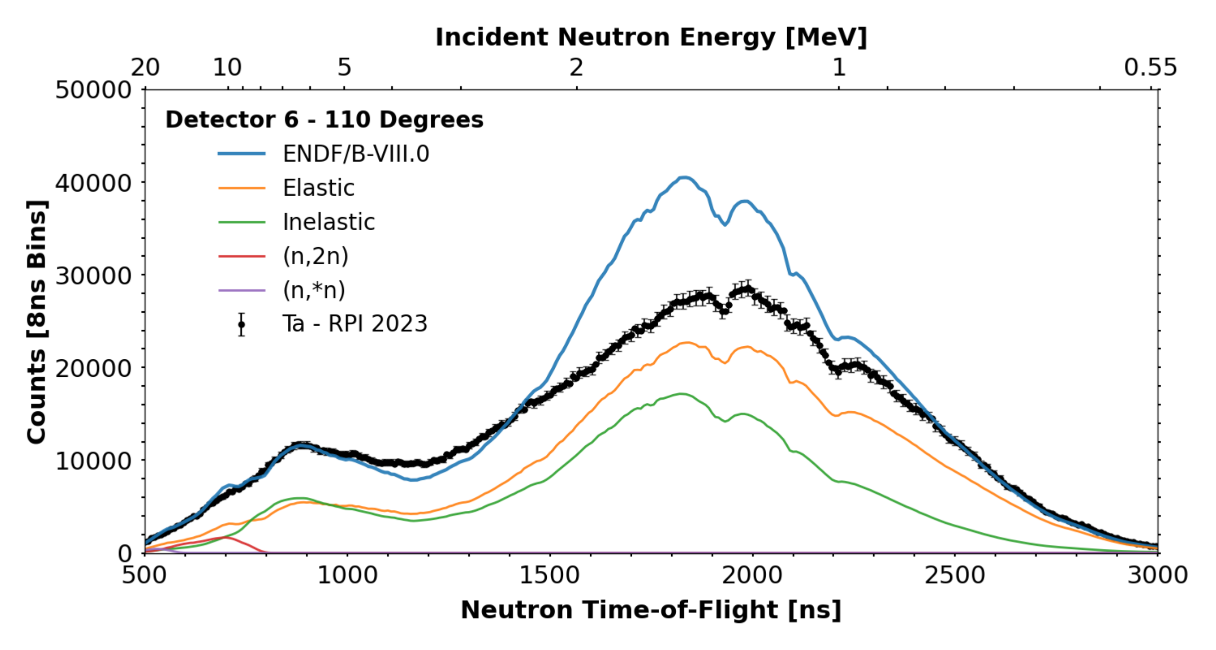


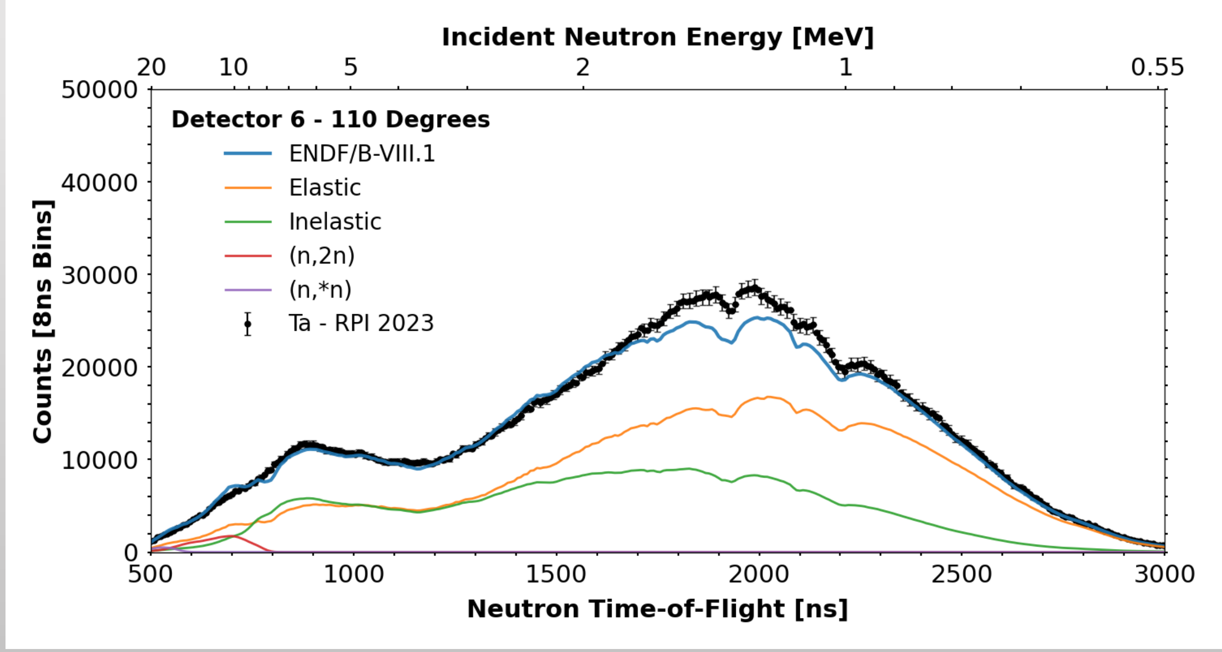


Changes Observed in Scattering Channels

Moving from ENDF/B-VIII.0 to ENDF/B-VIII.1 a large reduction of both elastic and inelastic neutron scattering is observed below 3 MeV at backward scattering angles to correct the large imbalance in the tantalum scattering kernel.

ENDF/B-VIII.0 → ENDF/B-VIII.1





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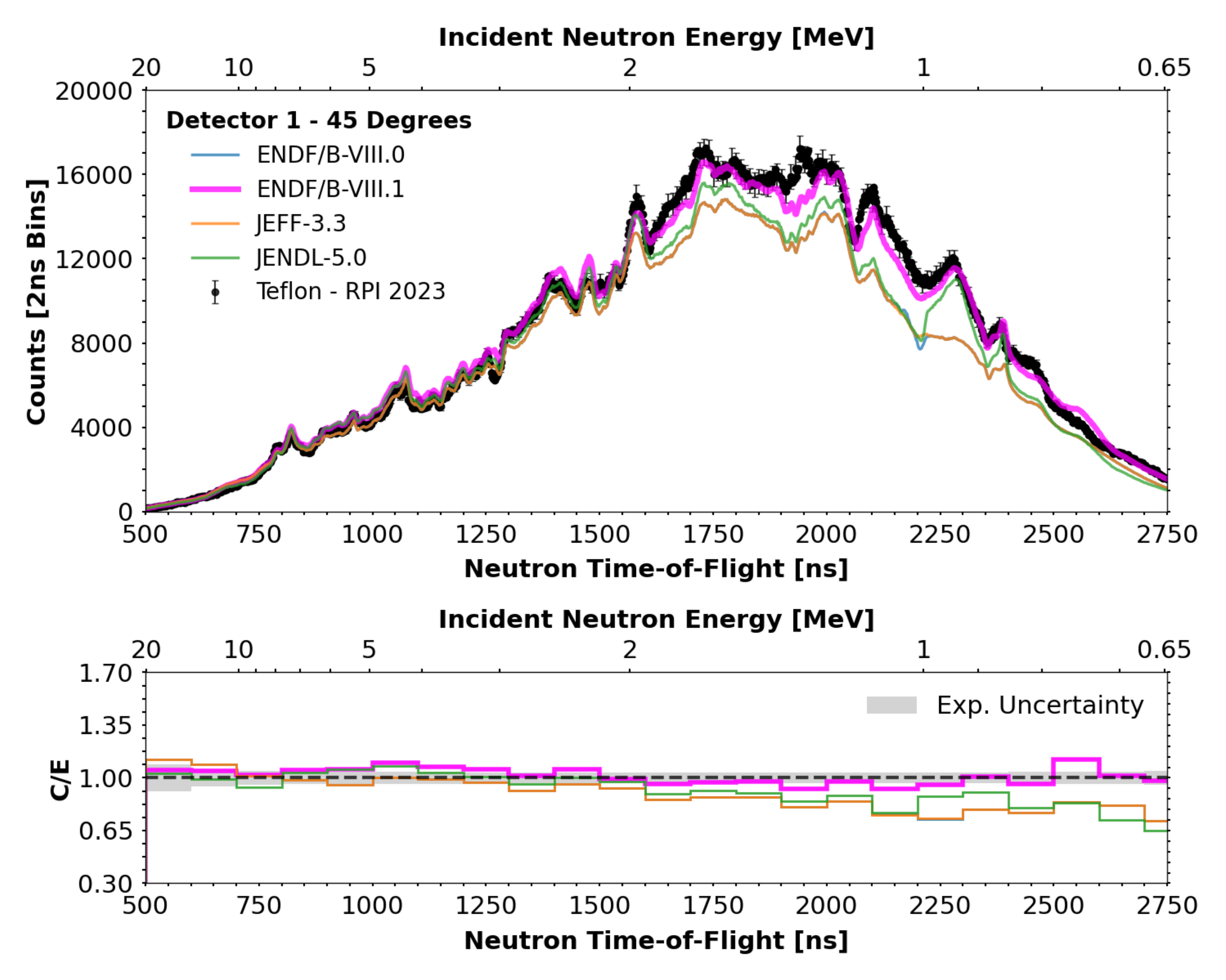
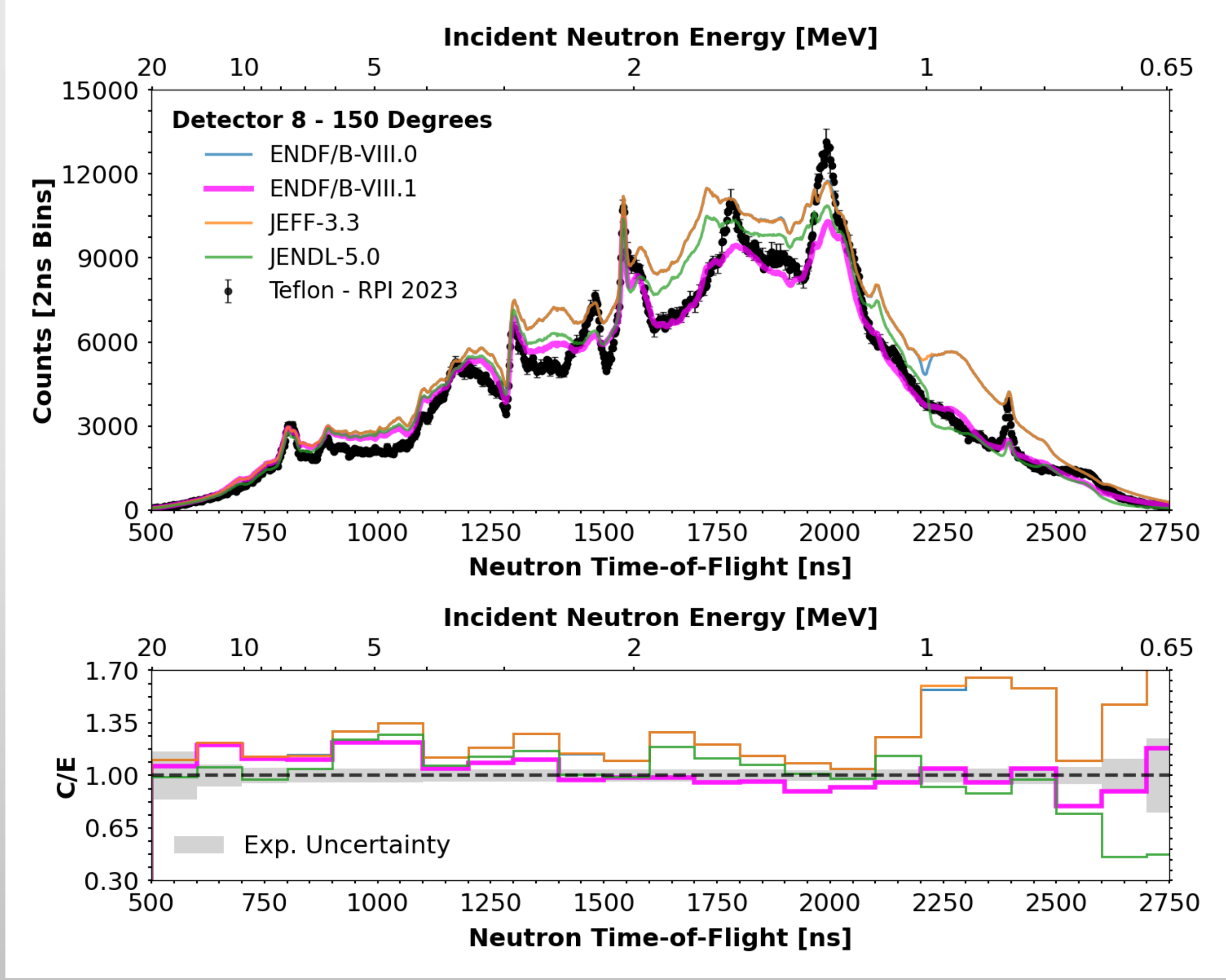
Teflon (^{19}F) – Good Performance at Forward Angles, Issues Predicting Resonances at Backward Angles





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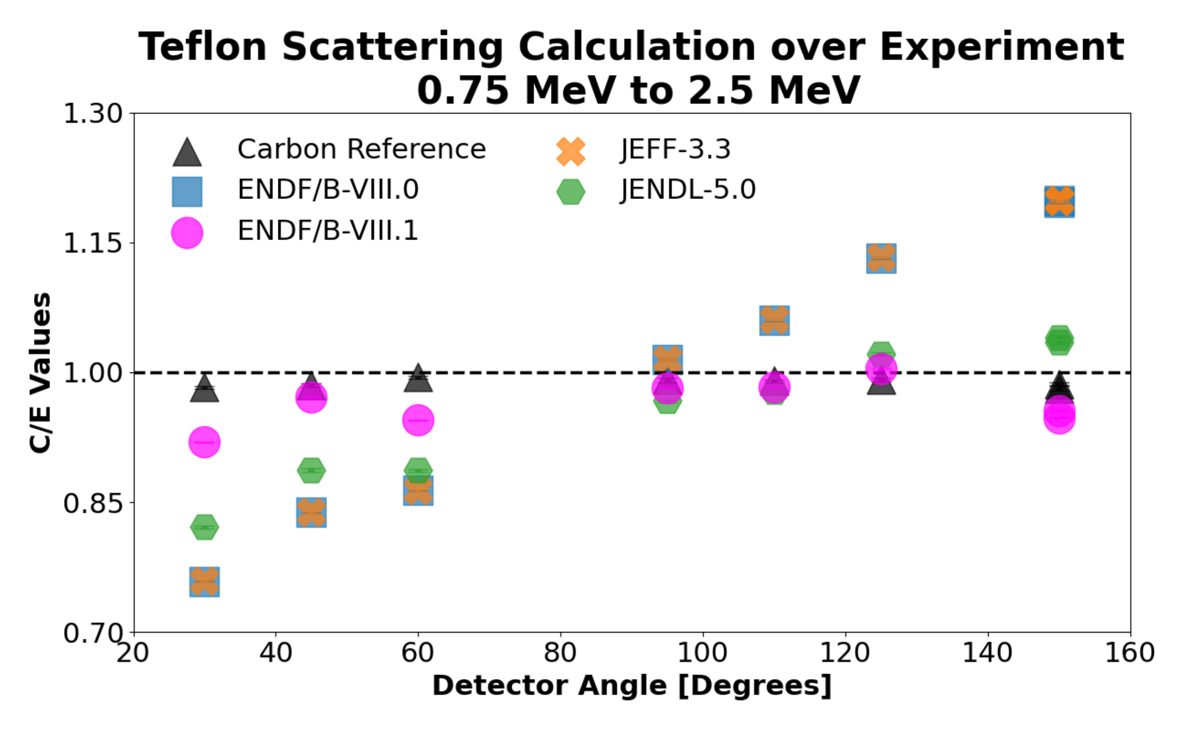
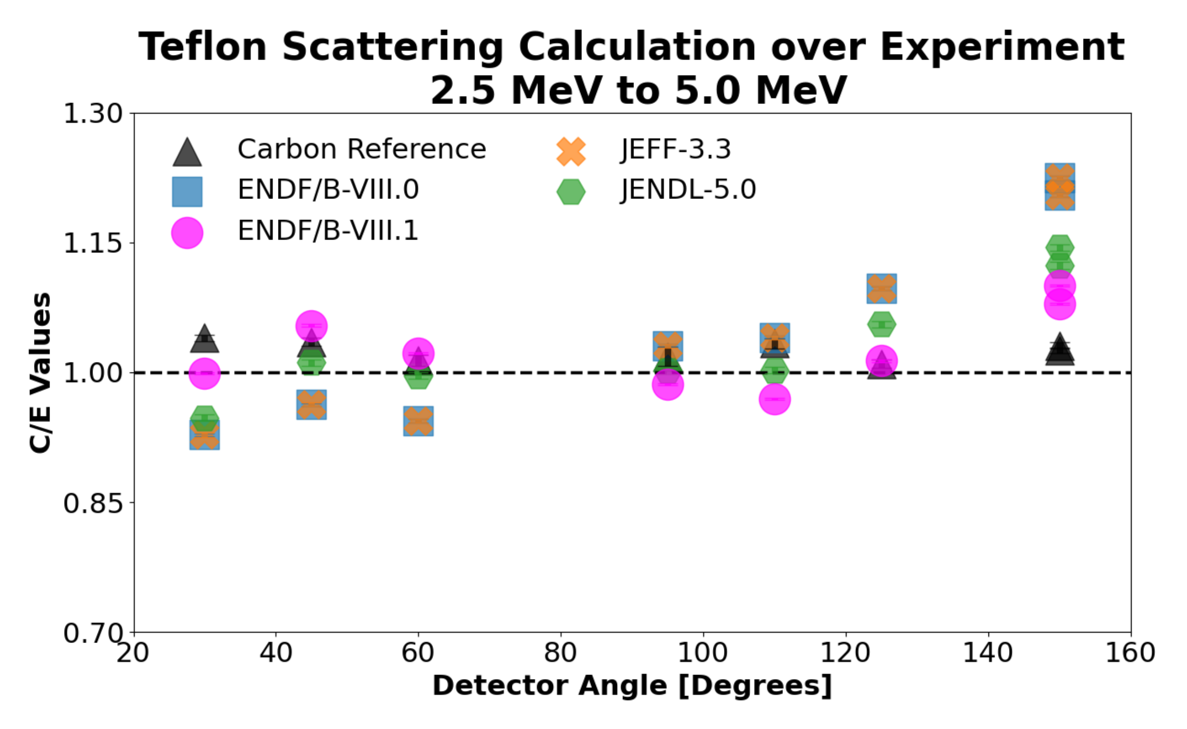
^{19}Fluorine Scattering Kernel Performance

Adoption of the INDEN ^{19}F evaluation in ENDF/B-VIII.1 yields improvement over previous ENDF/B-VIII.0 ^{19}F evaluation with respect to the experimental data by addressing large scattering kernel imbalance in the fission neutron energy region.





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Zirconium Evaluations

Co-Authors: D Barry[1], L. Leal[2], J. Brown[2], K. Guber[2], G. Nobre[3], and D. Brown[3]

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[3]Brookhaven National Laboratory – Upton, NY

New Zirconium Evaluations for ENDF/B-IX

RRR: New evaluations will use R-Matrix resonance parameterization determination over MLBW.
Evaluations will incorporate new ORNL isotopic transmission and capture measurements.

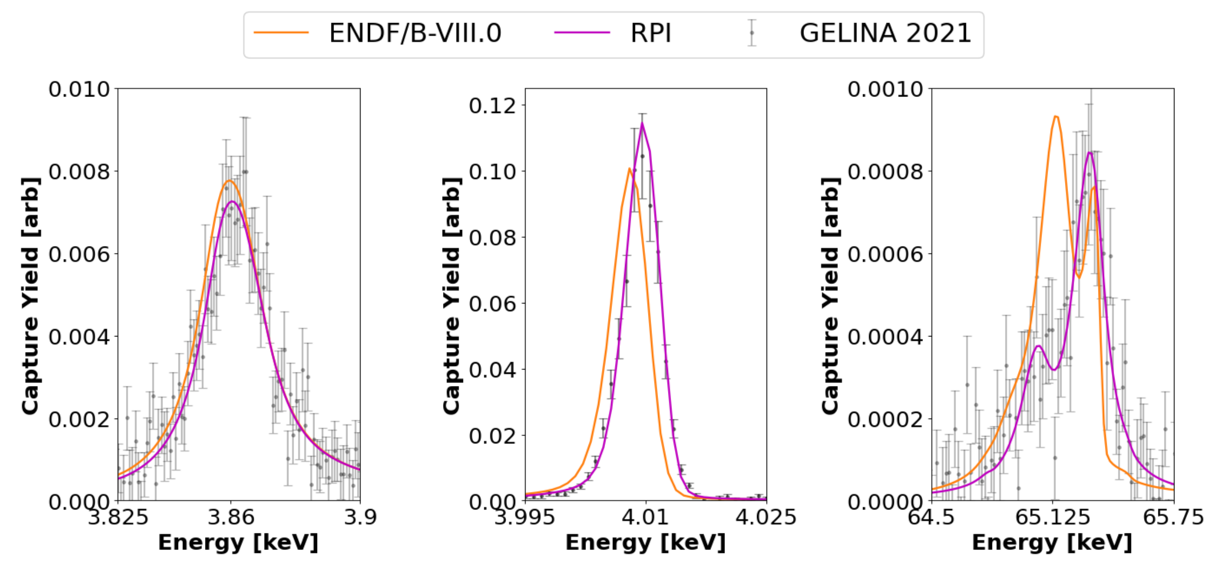
URR: New evaluations will leverage the new implementation of `SESH` in `SAMMY`.

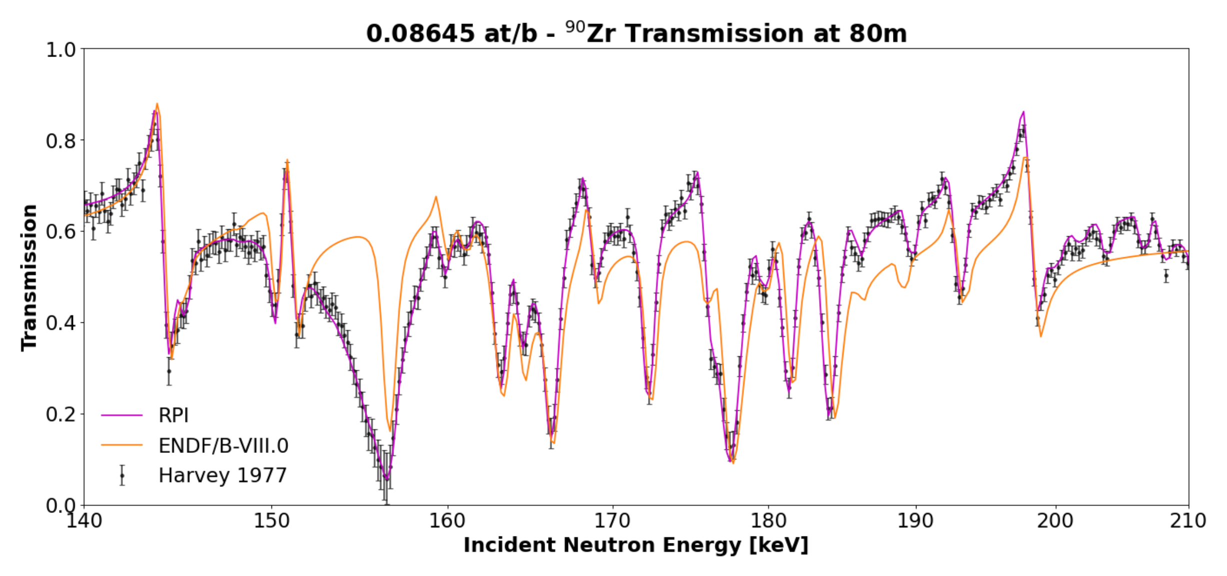
Fast: New evaluations with modern version of EMPIRE using new soft-rotor OMP developed for Zr.
Evaluations will leverage new ^{nat}Zr transmission from RPI, DT validation data from China, and others.

Isotope	New ORNL Measurement Status	Final Data Reduction	RRR Evaluation	URR Evaluation?	Fast Evaluation
Zr-90	Complete	Complete	RPI – NNL - ORNL	RPI – NNL - ORNL	RPI – BNL
Zr-91	Complete	In Progress	RPI – NNL - ORNL	RPI – NNL - ORNL	RPI – BNL
Zr-92	2025/2026	N/A	ORNL	NNL - ORNL	BNL
Zr-94	2025/2026	N/A	ORNL	NNL - ORNL	BNL
Zr-96	N/A	N/A	ORNL	NNL - ORNL	BNL

^{90}Zr Resonance Evaluation

- Datasets fitted in evaluation:
  - **Transmission:**
    1. Musgrove, et al. 1977[1] - 0.08645 at/b metallic enriched ^{90}Zr @ 80m (^{6}Li)
    2. Musgrove, et al. 1977[1] - 0.08645 at/b metallic enriched ^{90}Zr @ 200m (NE110)
  - **Capture:**
    1. GELINA 2021 - 0.00558 at/b metallic enriched ^{90}Zr @ 48m (C_6D_6)
- Channel radius of 6.31 *fm* adopted from Fröhner recommendation[2]
  - Distant levels to represent R_∞





1. Musgrove A. R. de L., Harvey J., and Good W. *Neutron Resonance Parameters of ^{90}Zr Below 300 keV,* Aust. J. Phys, 1977, **30,** 379-89
2. Frohner F. and Bouland O. *Treatment of External Levels in Neutron Resonance Fitting: Application to the Nonfissile Nuclide 52Cr* Nucl. Sci. Eng. 2001, **137,** 70-88

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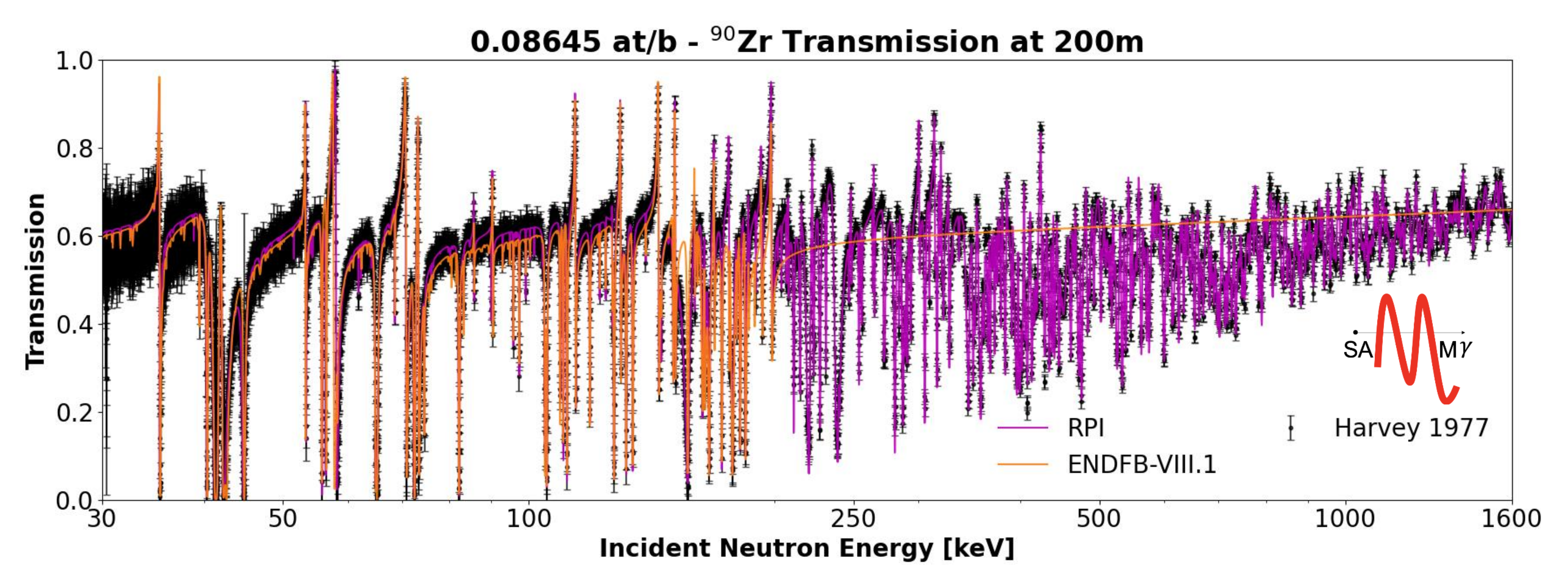
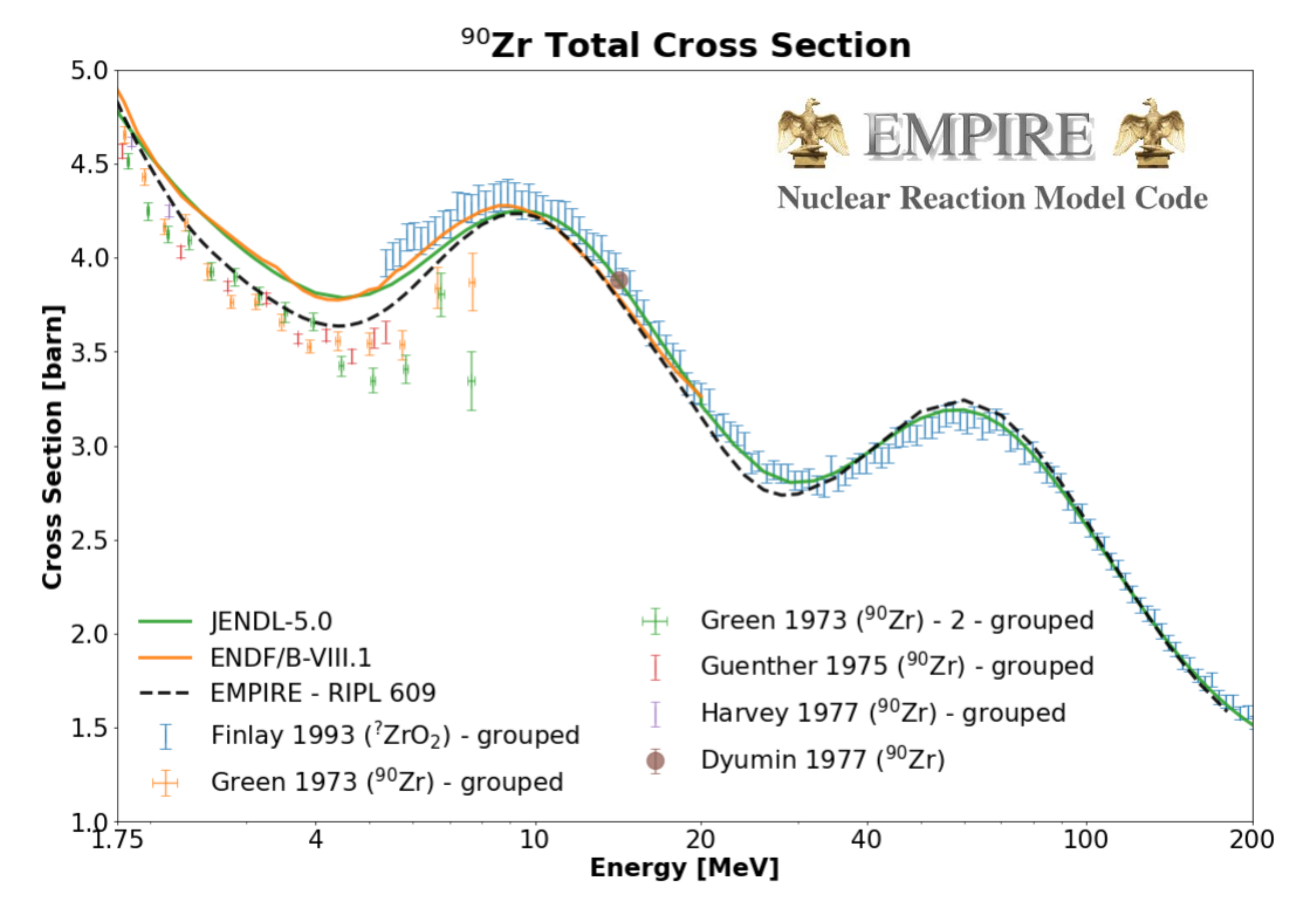
^{90}Zr Resolved Resonance Region Extension

Resonance parameters fit to ^{90}Zr transmission data up to first excited state, 1764 keV. Limit of current ENDF/B-VIII.1 RRR is 200 keV.



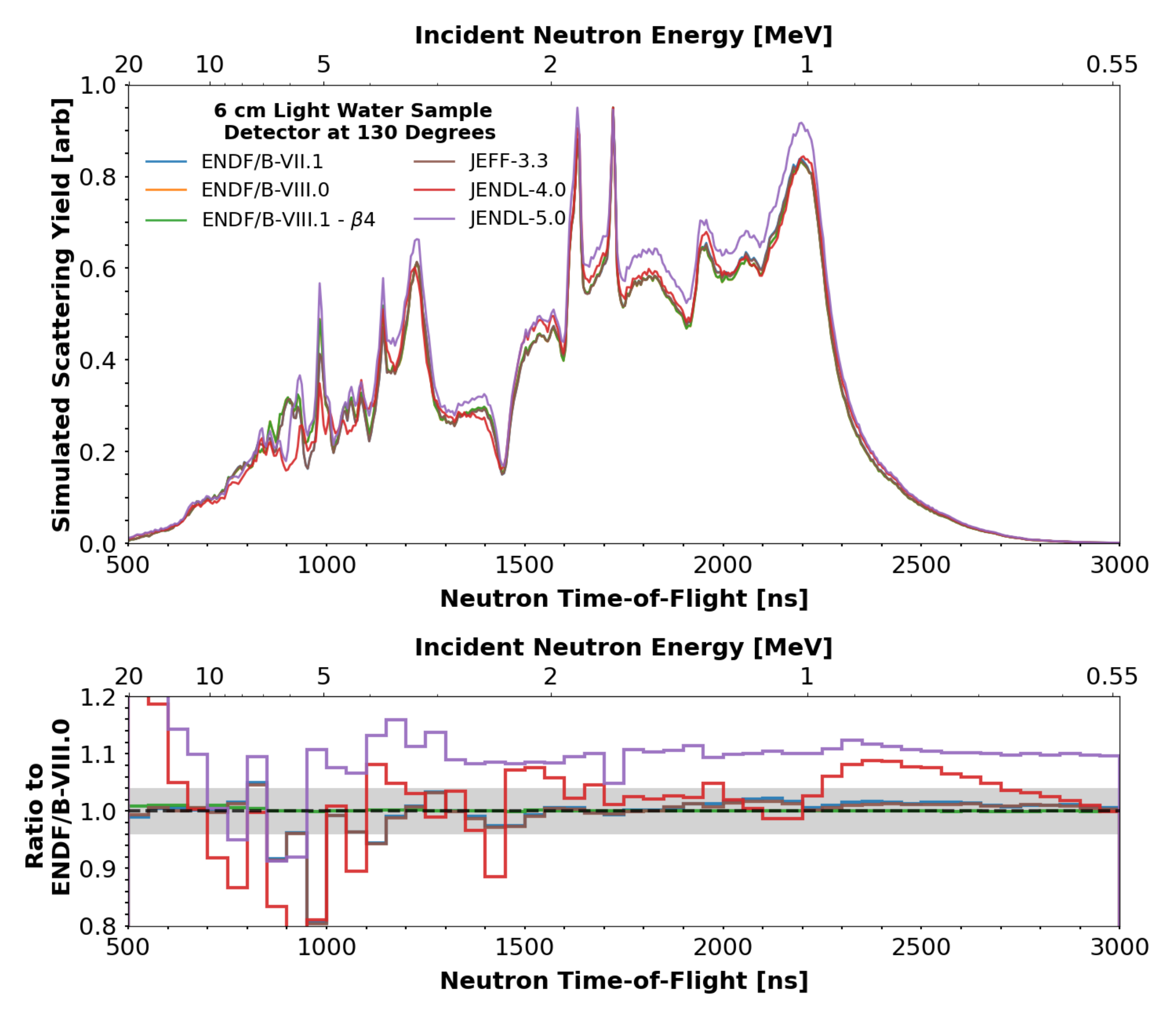
Beginning ^{90}Zr Fast Region Evaluation

- New soft rotational coupled-channels optical model potential (OMP) developed by Capote and Soukhovitskii for Zr isotopes (RIPL 609)
- RIPL 609 shows good agreement to experiment, particularly below 10 MeV
- Finlay 1993 sample measured suspected to be elemental Zr abundance rather than enriched $^{90}ZrO_2$



Conclusions and Upcoming Work

- Fast neutron scattering measurements of tantalum and Teflon provide validation for the ENDF/B-VIII.1 library and its use in criticality safety calculations
  - Manuscript for Ta measurement paper in internal review, and Teflon manuscript is in preparation
  - Another coming manuscript identifies several instances of conflicting evaluated MeV neutron scattering datasets addressable with RPI quasi-differential scattering measurements for fusion:
    - ^{6,7}Li, B, N, O, Na, Mg, Al, Si, Cl, Ti, V, Ni, Cr, Mn, Y, Nb, Ba, Sn, Hf, W (most on five-year plan)
- ^{90}Zr resonance parameters fit to 1.7 MeV using ORELA and new ORNL/GELINA capture measurement
  - Spin assignment verification and other checks upcoming, then move to ^{91}Zr



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