New Cross Section Measurements and Evaluations of Zirconium Isotopes

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Presentation Overview

1. Accomplishments Made in 2022
2. Motivation for investigation, new measurements, and re-evaluation of the Zr isotopes
3. Preliminary Evaluation Results from RPI $^{90}$Zr Evaluation
4. Preliminary Results from Eigenvalue Sensitivity Study on Zr Sensitive Critical Benchmark Experiments
Major Accomplishments in 2022

Jan. – June
1. Completed data reduction of $^{90}\text{Zr}$ transmission data from 2021 ORNL/JRC-Geel experiment
2. Determined preliminary resonance parameters for $^{90}\text{Zr}$ from 3.8 keV – 500 keV from ORNL/JRC-Geel 2021, and ORNL 1977 transmission experiments

June – Sept.
1. Fulfilled an internship with XCP-5 at LANL
   - Contributed to NJOY and ACEtk development
   - Developed software to verify proper nuclear data replication in MCNP6.3

Sept. – Dec./Jan. 2023
1. Extensive eigenvalue sensitivity analysis performed on critical benchmark experiments with Zr
   - A more comprehensive methodology was employed to examine direct contributions to eigenvalue differences due to specific areas of an isotopic nuclear data evaluation
   - New knowledge of compensating errors in evaluated nuclear data libraries for Zr isotopes
Motivation for Zirconium Investigation

- Zirconium is **used in nearly all** commercial light water reactors in the US as fuel rod cladding and is being explored for advanced reactor concepts.

- Conflicts in nuclear data evaluation between ENDF, JEFF, and JENDL exist in:
  - **Cross Sections**
    - Resolved and unresolved resonance parameters
    - High energy region
  - **Angular Distributions**
    - Elastic and inelastic scattering angular distributions
Current Zr Critical Benchmark Experiments

- High fidelity integral experiments are required to validate evaluation performance of Zr
  - Validation most important in energy range of fission neutron emission
  - Many Zr sensitive benchmark experiments are large thermal systems and/or do not meet modern evaluation standards

- Lack of differential and integral data can lead to non-physical evaluations

*A score on this point corresponds to a sensitivity coefficient greater than or equal to 1e-3 at a given energy*
Current Zr Integral Benchmark Experiments

- Lacking high fidelity fast integral experiments to validate Zr evaluations
- $\Delta K_{\text{eff}}$ of current thermal systems is mostly attributed to high energy neutron interactions
Current $^{90}$Zr Differential Cross Section Data

- Lacking high resolution transmission ($E > 85$ keV) data to verify Harvey, et al. 1977 measurements
- Disagreement between Harvey and Good + Newson transmission
- Good, Newson, and (raw) Bartolome data have poor energy resolution

*Energy region for new ORNL measurements only verified for $^{90}$Zr transmission*
Data Reduction and Evaluation of ORNL/JRC-Geel $^{90}$Zr Transmission Measurements
Reduction of Geel 2021 $^{90}$Zr Transmission Experiment

Data processed using Geel AGL reduced and verified to production level at RPI using AGS

$^{59}$Co @ 132eV
R-Matrix Resonance Analysis – ORNL/Geel 2021

$^{90}$Zr transmission measured by ORNL at JRC-Geel in 2021 at 45m

- Deadtime correction ratio issues with this experiment limit resonance parameter determination at ~86 keV
R-Matrix Resonance Analysis – ORNL 1977

$^{90}\text{Zr}$ transmission measured by Harvey, et. al at 80m and 200m in 1977 at ORELA

- 80m data used from first resonance (3.8 keV) to ~200 keV
- 200m data used from ~30 keV to 500 keV – (Preliminary)
  - 300 keV extension of RRR over current ENDF/B-VIII.0 evaluation
Time-Independent Eigenvalue Sensitivity Study
Critical Benchmark Eigenvalue Sensitivity Study Using Zr

Methodology developed with MCNP KSEN to propagate differences in cross sections between nuclear data evaluations to differences in the eigenvalues of critical benchmark experiments.

\[ \Delta k_{\text{eff}}(\Sigma_i(E)) = \left[ S_{\text{eff}}(\Sigma_i^{E8}(E)) \times \left( \frac{\Sigma_i^{E8}(E) - \Sigma_i^{J5}(E))}{\Sigma_i^{E8}(E)} \right) \right] \times k_{\text{eff}}(\Sigma_i^{E8}(E)) \]

- \( \Delta k_{\text{eff}}(\Sigma_i(E)) \): Difference in Eigenvalue from Cross Section for Reaction Channel \( i \) at Energy \( E \)
- \( S_{\text{eff}}(\Sigma_i^{E8}(E)) \): Eigenvalue sensitivity to ENDF/B-VIII.0 Cross Section at Energy \( E \)
- \( \Sigma_i^{E}(E) \): Evaluation \( x \) Cross Section for Reaction Channel \( i \) at Energy \( E \)
Cross Section Contribution to Eigenvalue Difference

$K_{\text{eff}}$ Driven Primarily by $^{91,92}\text{Zr}$ Thermal Capture + All Isotopes Elastic and Inelastic Scattering in Fission Spectra
Cross Section Contribution to Eigenvalue Difference

$K_{\text{eff}}$ Driven Primarily by $^{90}\text{Zr}$ Elastic and Inelastic Scattering in Fission Neutron Energy Emission Spectra
Elastic Scattering Angular Distribution Contribution to Eigenvalue Difference

* Energy in top x-axis corresponds to the energy corresponding to the average lethargy of a neutron causing fission
Project Takeaways and Goals For 2023

Accomplishments from 2022

1. Preliminary resonance parameters determined for RPI $^{90}$Zr evaluation
2. Development and employment of eigenvalue sensitivity analysis on critical experiments
   - ~50% of eigenvalue differences between evaluations attributable to elastic scattering angular distributions
   - Major disagreements observed in all Zr isotope cross section evaluations
     - Fission neutron emission energy spectrum/neutron slowing down region (~100 keV – 5 MeV) most influential region of evaluation for NCSP applications

Goals for 2023

1. Obtain final set of resonance parameters for RPI $^{90}$Zr evaluation using new ORNL/Geel 2021 capture experiment
2. Complete eigenvalue sensitivity study
   - Validate current cross section findings with manual perturbations
   - Further quantify angular distribution contributions
3. Assess current nuclear data in most discrepant evaluation regions
   - Conclude if new experiments are needed for resolution
4. Determine level of RPI involvement in URR and fast region $^{90}$Zr evaluation
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