Neutron Capture and Transmission Measurements and Evaluation of $^{54}\text{Fe}$ at the RPI LINAC

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Major Accomplishments in 2022

- Completed RPI $^{54}\text{Fe}$ transmission data reduction.
  - Compared data to other experiments and completed preliminary evaluation work.
- Selected useful $^{54}\text{Fe}$ capture and transmission experiments from EXFOR for preliminary evaluation.
  - Reproduced experiments using SAMMY and resonance parameters were fit to some data.
- Identified and fixed discrepancy between n_TOF and RPI capture measurements.
  - Corrected absolute normalization issue in n_TOF data on EXFOR.
- Developing a neutron beam imaging system to improve future capture measurements.
- Completed RPI candidacy exam in December 2022.
**Project Overview**

- **Motivation:**
  - Criticality safety calculations require high accuracy nuclear data to reduce uncertainties
  - $^{54}\text{Fe}$ neutron cross sections have not been well-studied relative to $^{56}\text{Fe}$.
    - Iron is important in shielding, criticality safety, and stellar nucleosynthesis
- **Project Goals:**
  - Perform resonance analysis and fitting for $^{54}\text{Fe}$ cross section in the keV region using RPI and EXFOR nuclear data
  - Perform radiative capture and transmission measurements of $^{54}\text{Fe}$ in the keV energy region
Iron is very important to study with respect to radiation shielding, criticality safety, and stellar nucleosynthesis.

Since Iron is an important structural material in nuclear reactors, benchmarks can be shown to have sensitivity to natFe cross sections.

In the minima of \(^{56}\text{Fe}\) cross sections, neutrons can stream through a shielding wall and pose a health risk. The cross sections of minor isotopes is important in the minima of \(^{56}\text{Fe}\).
**Existing $^{54}$Fe Measurements**

- Examination of existing measurements on EXFOR was completed, some of these measurements will be used in the RPI RRR evaluation.

  - **Radiative Capture:**
    - A single high-resolution dataset from n_TOF was uploaded to EXFOR following RPI capture measurements.
    - Data are reported up to 1 MeV, will be used in RPI evaluation.

  - **Transmission:**
    - Several excellent transmission measurements exist in EXFOR, with varying energy resolution.
    - Pandey data below 30 keV has issues that need to be investigated.
    - All three measurements shown will eventually be considered in the RPI $^{54}$Fe evaluation.
RPI $^{54}$Fe Measurement Campaign Overview

- The RPI capture and transmission measurements both provide valuable insight and address deficiencies in EXFOR.
- RPI capture measurement provides additional data for evaluation work and comparison to the n_TOF experiment.
- RPI transmission measurement provides valuable data below 30 keV, a region where prominent capture resonance occur
  - Will help in evaluation work.
**RPI $^{54}$Fe Measurement Campaign Overview**

- Capture data were taken of a ~0.021 [a/b] 96% enriched $^{54}$Fe sample.
  - Open, Pb samples used for background corrections
  - $B_4C$ sample used for the relative flux shape.
  - Absolute normalization was made to a Au sample.
  - 11.2 ns pulse width was selected as a trade-off between beam power and resolution.
  - $C_6D_6$ capture array was used with digital electronics for data collection.

- Transmission measurement was done using the same enriched sample.
  - Li-glass detector was used with a depleted uranium sample for validation, open, and $^{nat}$Fe sample.
  - Analog electronics used to collect data.
RPI Capture Data Reduction

- Reduction of the raw digital capture data to a yield is very tedious.
- Pulse height weighting technique (PHWT) is used to weight each detector pulse.
  - Needed to ensure unbiased capture measurements are being taken.

\[
Y_i = \frac{R_{Fe}^i - R_{O}^i \frac{M_{Fe}}{M_O} - k_p (R_{Pb}^i \frac{M_{Fe}}{M_{Pb}} - R_{O}^{Pb} \frac{M_{Fe}}{M_O})}{f_n \frac{R_{B4C}^{UW} - R_{O}^{UW} \frac{M_{B4C}}{M_O}}{Y_{B4C_i}}}
\]

\[
f_n = \text{Normalization Factor}
\]

\[
k_p = \text{In Beam Gamma Correction Factor}
\]

\[
R_Y^x = \text{Count Rate of sample y weighted by x}
\]

\[
M_x = \text{Monitor to trigger ratio of sample x}
\]

\[
Y_{B4C} = \text{MCNP calculated yield from } B_{4C} \text{ sample}
\]
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$^{54}$Fe (n, $\gamma$) Measurement – Results

- The RPI capture data was normalized to the saturated resonance of Au and weighted using the PHWT.
- The RPI capture yield disagrees with JEFF and ENDF evaluations at prominent capture resonances.
- Missing resonances from JEFF3.3 can be seen in RPI experiment.
- The energy resolution of the experiment is limited at higher energies (> 200 keV).
- Covariance matrix is being generated before data is released.
Transmission Data Reduction

• Reduction of the transmission data requires a background shape to be fit to each sample.
• Black notch resonances are observed in the raw transmission data, which can then be used to fit the background shapes
  – Co and Al fixed notches were kept in-beam throughout the duration of the experiment.
• Background shape was an exponential function
  – $B(t) = ae^{-bt} + B0$
54Fe Transmission Experiment - Results

- Experiment is most useful below 30 keV, where there is very limited previous data available.
- Data between 30-150 keV can be used to support higher energy resolution measurements.
- Limited energy resolution above 150 keV.
- RPI’s approach of combining capture and transmission data will improve resonance evaluation effort for 54Fe.
- Covariance matrix will be generated before data is fully released.
RPI Capture Yield Comparison

- n_TOF and RPI experiments can be fit simultaneously and show first-order agreement with one another.
- Radiation widths of p,d-wave resonances will need changes to fit both sets of available capture data.
- n_TOF data requires additional normalization for correct absolute capture yield.
- Work Needed: Extend RRR analysis to 1 MeV and consider RPI data covariances once available.
EXFOR Transmission Experiments

- RPI data is useful up to 150 keV, and can be supplemented with Pandey, Carlton, and Cornelius transmission measurements.
  - Carlton experiment has thicker sample and good resolution.
  - Pandey experiment has discrepancies between experiment and SAMMY calculation.

- Fitting of these other experiments will be completed following delivery of RPI measurement data.
**Neutron Beam Imaging System**

- **Motivation:** During capture measurements, it is difficult to align samples in the most intense part of the neutron beam.
- **Objective:** Develop a system to provide a time-dependent neutron beam image.
- **System:** 4 PMTs are coupled to a scintillator (EJ-204)
- **Methods:** Neural network has been trained on pulse integrals in coincidence events to predict \((x,y)\) coordinates of a source.
- Improvements to the physical system and algorithms can yield high resolution beam images.
Conclusions and Future Work

- $^{54}$Fe measurement campaign at RPI is near its conclusion, covariance matrix generation is needed for both experiments before data is made available and released. (Completion by April 2023).
- RPI will be conducting a full RRR evaluation following release of data. (Completion by September 2023).
  - Evaluation will make use of RPI and EXFOR measurements.
- Neutron beam imager shows promise in providing an easy way to align samples in the most intense part of the neutron beam.
- A new evaluation will offer improvements in crit safety, shielding, and stellar applications.
- RPI graduate school commitments need to be completed by May 2024.