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Neutron Capture and Transmission Measurements of ^{54}Fe at the RPI LINAC

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Abstract. ^{54}Fe radiative capture cross section and transmission measurements were conducted at the Rensselaer Polytechnic Institute (RPI) Gaerttner Linear Accelerator (LINAC) Center using an enriched ^{54}Fe sample in the keV energy region. ^{54}Fe is a constituent of natural iron, which is present in a large variety of nuclear grade materials. Therefore, it is important to have an accurate understanding of the cross sections of ^{54}Fe, which can be measured experimentally. In the time-of-flight measurements conducted at the LINAC, an array of four C_6D_6 detectors surrounded the sample and radiative capture data were collected using a digital data acquisition system. Additionally, a Li-glass detector was used to collect transmission data using an analog data acquisition system. The radiative capture yield of the ^{54}Fe measurements were normalized to saturated resonances observed in Au and Ta to obtain an absolute capture yield. The preliminary capture yield and preliminary transmission obtained can be compared to evaluations and existing experimental data. Some disagreements were observed in prominent d-wave capture resonances observed in ^{54}Fe in the low-keV neutron energy region. Both sets of experimental data along with pre-existing datasets will greatly enhance RPI's ability to perform resonance evaluation for ^{54}Fe up to roughly 1 MeV.

1 Introduction

Fe is an important part of various nuclear systems and has a variety of applications in fuel storage systems, reactors, and radiation shielding. As such, it is important to have highly accurate nuclear data that will reduce uncertainties. Natural Fe and ^{56}Fe cross sections have been studied extensively [1], unlike the less abundant ^{54}Fe. Prior to the measurements discussed in this work, there were no extensive radiative capture datasets available on the Experiment Nuclear Reaction Data (EXFOR) database [2], providing some motivation to perform new radiative capture cross sections for ^{54}Fe. Additionally, some discrepancies were observed between the capture cross sections reported in different evaluation nuclear data libraries, in particular ENDF/B-VIII [3] and JEFF3.3 [4]. As a result, neutron TOF measurements were conducted at the RPI LINAC to study both the radiative capture cross section and the total neutron cross section of ^{54}Fe. In the future, these data will be used in tandem with other relevant data from EXFOR to perform resonance analysis on ^{54}Fe.

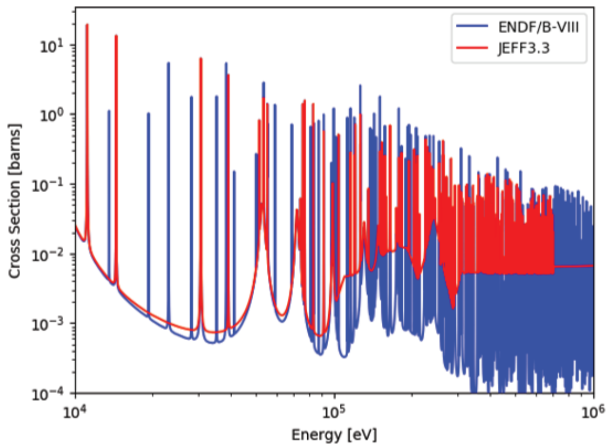

Figure 1. Neutron capture cross section of ^{54}Fe in ENDFB-VIII and JEFF3.3. Some resonances are missing in JEFF3.3 that are present in ENDF/B-VIII. There is also a different background treatment between the two evaluations. ENDF/B-VIII has an extended resolved resonance region compared to JEFF3.3.

2 Previous Measurements

Several previous measurements exist in EXFOR that can be compared to the RPI data and used for future resonance analysis. An overview of some of these measurements is shown in table 1. Following the start of the RPI capture measurements, a high-resolution radiative capture dataset from the neutron time-of-flight facility (nTOF) at the European Council for Nuclear Research (CERN) was uploaded to EXFOR. [5] These data are reported and useful up to 1 MeV. Additionally, several transmission measurements were found, each with varying resolutions and energy regions. All experiments were conducted enriched ^{54}Fe samples. The relative lack of radiative capture data provided motivation to perform a capture measurement,

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and discrepancies observed between some transmission datasets at low keV neutron energies also provided motivation for a transmission measurement.

Table 1. Overview of capture and transmission measurements on EXFOR for ^{54}Fe.

Reference	Facility	Year	Measurement Type	Sample Form
Giubrone[5]	nTOF	2014	Capture	Metal
Beer[6]	Karlsruhe	1974	Transmission	Metal
Pandey[7]	ORELA	1975	Transmission	Metal
Carlton[8]	ORELA	1985	Transmission	Metal
Cornelius[9]	GELINA	1995	Transmission	Oxide

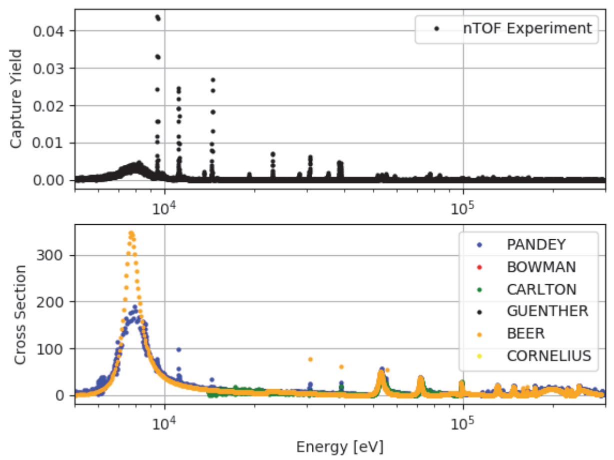

Figure 2. Various transmission and radiative capture datasets that are available in EXFOR for ^{54}Fe

3 Radiative Capture Measurement

Differential neutron capture cross section measurements were conducted at the RPI LINAC using the time-of-flight technique. For the capture measurements discusses in this work, an array of seven deuterated benzene (C_6D_6) liquid scintillators were used to measure the capture yield from a ^{54}Fe sample. These detectors are designed to have a low sensitivity to scattered neutrons, which is especially important for samples with large Γ_n/Γ_γ ratios. In the case of the RPI capture array, the system is mounted and supported by materials with low neutron capture cross sections, such as Al-6061. Work is currently underway to experimentally quantify the system's neutron sensitivity and validate previous MCNP results that show negligible neutron sensitivity. The detectors are placed at back angle of 125 degrees relative to the beam to remove any sensitivity to anisotropic capture cascades and reduce the in-beam time dependent gamma background which mostly scatters in a forward direction from the sample. Data acquisition is handled by a SIS-3305 10-bit digitizer that allows for all detector pulses to be saved for later robust analysis. The system is reliant on the total-energy detection (TED) principle [10], which requires a low overall photon detection efficiency. The details of this method, pulse height weighting technique, and the weighting methods used to reduce the raw capture data are further discussed in Refs. [11]. The capture yield is corrected for an in-beam gamma background shape, open beam background, as well as any beam intensity fluctuations via flux monitor normalizations. Additionally, due to the upgrade to seven total C_6D_6 modules, a coincidence algorithm was implemented to ensure only one photon capture event was being detected per cascade, which would otherwise invalidate the TED principle. An overview of the experiment is shown in Table 2. The raw count rate obtained from the ^{54}Fe sample along with the open sample and room background count rates are shown in Figure 3.

Discrepancies are shown in Figure 4 between the RPI

Table 2. Overview of RPI ^{54}Fe capture measurement parameters

^{54}Fe Density	0.021 at/barn
^{54}Fe Enrichment	95.76%
Flight Path	45.293 m
LINAC Burst Width	11 ns
Repitition Rate	400 Hz
Beam Current	15 uA
Normalization Sample	^{197}Au

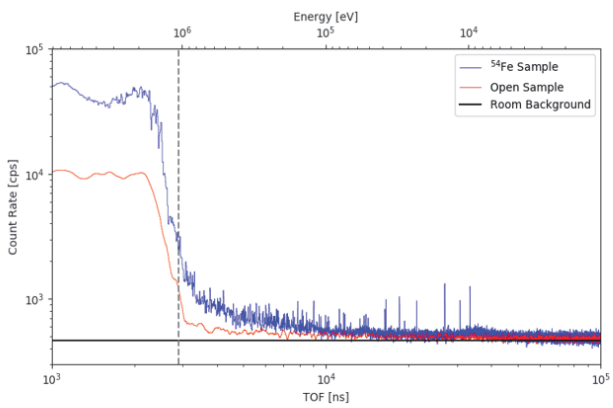

Figure 3. Unweighted count rates from ^{54}Fe. The largest d-wave capture resonances can be seen at TOF near 30µsec. At higher TOF values, room return is the dominant source of background, and the overall flux of neutrons is low, limiting the counting statistics of the measurement.

data and other evaluations, with the nTOF resonance parameters providing the best agreement to the preliminary RPI capture yield. To help resolve some of these differences and constrain the neutron width in resonance analysis, a transmission experiment was conducted with the same RPI Fe sample.

4 Transmission Measurement

A transmission experiment was conducted at the RPI LINAC using the 35m Li-6 glass DIABLO detector system [12]. An overview of the experiment is shown in Table 3. The transmission data was taken using an analog electronics setup and reduced using the methods described in

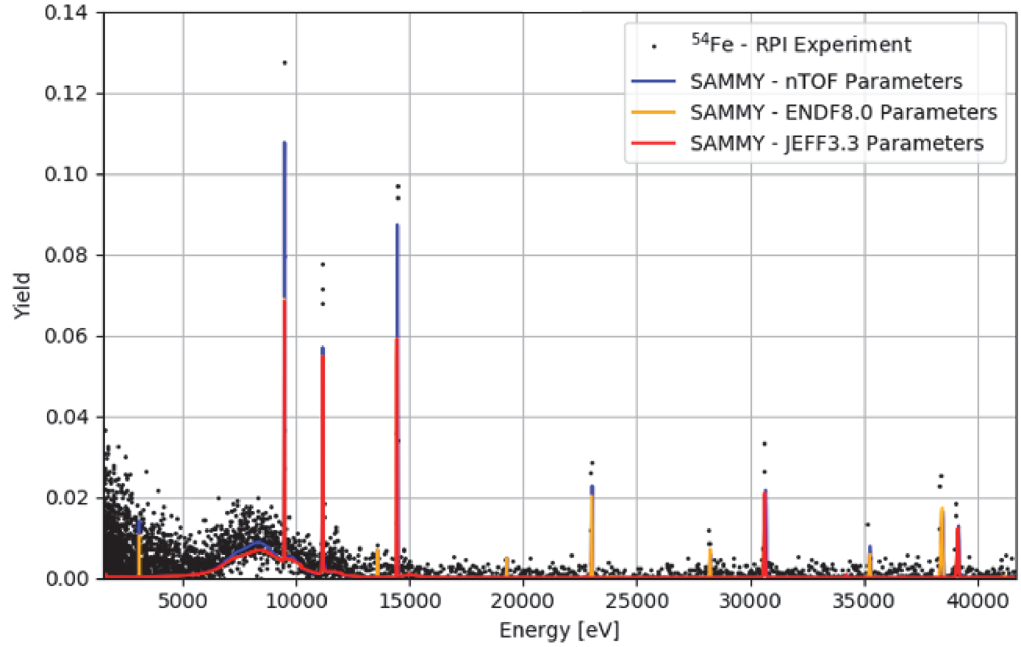

Figure 4. Absolute capture yield of ^{54}Fe. SAMMY calculations are conducted for several sets of evaluations, including ENDF/B-VIII, JEFF3.3, and published nTOF resonance parameters. Resonances missing from the JEFF evaluation are shown in both the ENDF evaluation and the RPI data. Large discrepancies are seen in the largest d-wave capture resonances at 9.5, 11, 14.5 keV between the RPI data and evaluations.

[13, 14]. In addition to the ^{54}Fe sample and open samples, a 2.0 cm thick natural Fe sample and a 625 mil depleted Uranium sample were also measured. To characterize the background shapes for each transmission sample, several fixed notch materials (Al + Co) were placed in-beam for the duration of the experiment. The presence of these materials create fixed depressions in the sample count rates corresponding to black resonances in the notch material's total neutron cross section, as shown in Figure 5. These fixed notch resonances, along with the presence of a flat constant background below an energy of 10 eV allow for characterization and subtraction of the neutron and gamma backgrounds for each sample. Transmission values can then be easily obtained for each sample after correcting for effects such as dead-time loss and beam intensity fluctuations followed by the background subtraction for each sample. Comparison of the RPI data to different evaluations, as shown in Figure 6 show that there is indeed room for improvement for some resonance parameters of existing evaluations, and highlights the importance of performing resonance evaluation while considering multiple datasets in both transmission and capture.

Table 3. Overview of RPI ^{54}Fe transmission measurement parameters

^{54}Fe Density	0.021 at/barn
^{54}Fe Enrichment	95.76%
Flight Path	35.14 m
LINAC Burst Width	11 ns
Repitition Rate	225 Hz
Beam Current	15 uA
Notch Filters	Al + Co

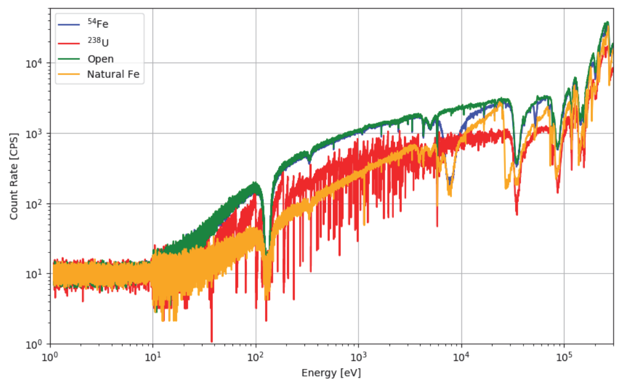

Figure 5. Count rates from various samples in the RPI transmission experiment. Notch resonances at 127 eV from Co, 35 keV from Al can easily be seen in all samples. Additionally, the constant room background rate can also be seen below 10 eV.

5 Conclusions

Preliminary neutron capture and transmission measurements of ^{54}Fe were conducted at the RPI LINAC. The current results show discrepancies between the RPI experiment and existing evaluations for prominent capture resonances in the low-keV neutron energy region. More work is currently underway to quantify the neutron sensitivity of the capture detector array and obtain final results and

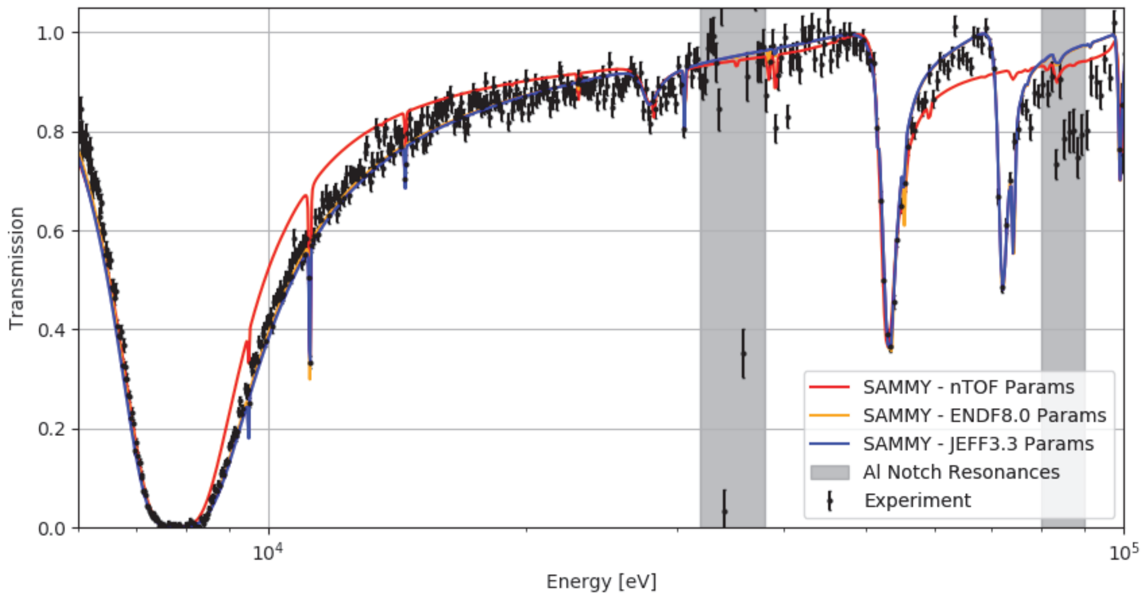

Figure 6. Preliminary transmission from ^{54}Fe. The RPI data suggests that slight adjustments can be made to widths of various resonances that are seen. The RPI transmission is not as sensitive to some of the prominent capture resonances, but can be used to fit the energies and neutron widths of observed resonances.

uncertainties for both sets of measurements. Moving forward, these new data will allow for more robust resonance analysis of ^{54}Fe.

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