Validation of an Indirect Method for Constraining Neutron-Capture Cross Sections

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Introduction

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P-27: Nuclear Astrophysics and Structure

Focus Area: Nuclear and Particle Physics
Crosscutting Area: Nuclear Data
Application and Measurement of \((n, \gamma)\) Cross Sections

Neutron-capture cross sections are valuable for various nuclear data applications.

- Nuclear energy
- Reaction networks and astrophysics
- Non-proliferation

Direct measurement on short-lived nuclei are challenging

- Radioactive targets or neutron targets are not feasible
- Many cross-sections are not well known

Indirect technique

- Statistical model – Hauser-Feshbach
- Use theoretically calculated nuclear properties to determine cross sections

Artist rendering of neutron star merger from NASA website
Uncertainties of nuclear properties

- Many theoretical models to choose from
- Large range of possible cross sections introduces a large uncertainty

Example: Impact on astrophysical calculation of abundance patterns

$Liddick \ et. \ al., \ PRL \ 116, \ 242502 \ (2016)$.
Experimentally constraining inputs with $\beta$-decay

- **Measure $\gamma$-decay – $\beta$-Oslo Method**
  - Need individual $\gamma$-ray energy and total excitation energy of nucleus
  - Extract nuclear level density (NLD) and $\gamma$-ray strength function ($\gamma$SF)

- Extracted NLD and $\gamma$SF inserted into statistical reaction model to constrain cross section

- Need a high efficiency detector

Need a validation in a higher mass region!

82Se

STABLE

$^n$ 22.3 M

$\beta$: 100%

83Se

$\beta$: 100%

83As

$\beta$: 13.4 S
NSCL Experiment Studying the Decay of $^{83}\text{As}$

- $^{86}\text{Kr}$ primary beam – 140 MeV/u
- $^9\text{Be}$ target
- $^{83}\text{As}$ secondary beam
β-Oslo Method

Nuclear Level Density Normalization

![Graph showing level density vs excitation energy for $^{83}$Se]
Reduction of Level Density

\gamma\text{-ray Strength Function Normalization}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{gamma_strength_function_normalization.png}
\caption{Graph showing the \gamma\text{-ray Energy $E_\gamma$ (MeV) against $f(E_\gamma)$ (MeV$^3$)) with various data points and labels.}
\end{figure}
TALYS calculation

\( ^{82}\text{Se}(n,\gamma)^{83}\text{Se} \)

\[ \sigma(E_n) \text{(mb)} \]

\[ E_n \text{ (MeV)} \]

- Present work
- Upper and lower limits
- Igashira (2011)
- Herman (1981)
- Chaubey (1966)
- Trofimov (1987)
Direct Measurements at LANSCE

- Detector for Advanced Neutron Capture Experiments (DANCE) – $\gamma$-ray calorimeter
- 160 BaF$_2$ crystals
- 3.5$\pi$ coverage
Neutron Energy vs. Total Energy
Subtraction of Contaminants
Yield of neutron capture on $^{82}$Se

Preliminary
Summary

- \( \beta \)-Oslo method needs to be validated against a directly measured neutron capture cross section
- The NLD and \( \gamma \)SF have been constrained for \(^{83}\text{Se}\) using the \( \beta \)-Oslo method
- The neutron capture cross section of \(^{82}\text{Se}(n,\gamma)^{83}\text{Se}\) has been calculated using the constrained NLD and \( \gamma \)SF
- Analysis of directly measured cross section with DANCE is ongoing
S.N. Liddick, B.P. Crider, R. Lewis, S. Lyons, A. Spyrou, A.C. Dombos, F. Naqvi, A. Richard


D.L. Bleuel

S. Quinn

G. Perdikakis
NSSC Experience

- PNNL Radiation Detection for Nuclear Security Summer School, June 2019

- Nuclear Science and Security Consortium Fall Workshop and Advisory Board Meeting, October 2019

- APS Division of Nuclear Physics Fall Meeting, October 2019

Many trips out to Los Alamos National Laboratory!
Acknowledgements

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Backup Slides
SuN - Total Absorption Spectrometer

- High efficiency, lower resolution
  - Resolution at 1 MeV - 6%
  - Efficiency at 1 MeV - 85%
- Segments give individual $\gamma$-ray energies
- Summing of all $\gamma$-rays give initial excitation energy

Validation of the $\beta$–Oslo Method

- $\beta$-Oslo method has already been used to constrain the neutron capture cross section of $^{75}$Ge, $^{68}$Ni, $^{69}$Ni, $^{73}$Zn, and $^{50}$Ti

1. Target nucleus must be able to be produced by neutron capture and $\beta$-decay
2. $\beta$-decay parent must have $Q_{\beta}$ large enough to populate high energies
3. Ability to produce parent nucleus and study its $\beta$-decay

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<tr>
<th></th>
<th>$^{82}$Br</th>
<th>$^{83}$Br</th>
<th>$^{84}$Br</th>
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<tr>
<td>$\beta$-</td>
<td>100%</td>
<td>100%</td>
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<tr>
<td>$n$</td>
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<td>18.45 M</td>
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Liddick et al. (accepted).
Spyrou et al. PRL 113, 232502 (2014).
Liddick et al. PRL 116, 242502 (2016).
Lewis et al. PRC 99, 34601 (2019).