ORNL Neutron Cross Section Measurements on Zr for NCSP ND-1 Task

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Applications

Basic science

ORNL Data Support for Nuclear Applications

Computational modeling

Evaluated Nuclear Data File (ENDF)/B

Nuclear astrophysics

SAMMY

Cross section evaluations

RPI

ORELA data

σ (n, γ) (b)

Energy (keV)

ampX
GELINA

- **Time-of-flight facility**
- **Pulsed white neutron source**
  
  \(10 \text{ meV} < E_n < 20 \text{ MeV}\)
- **Multi-user facility with 10 flight paths (10–400 m)**
- Measurement stations have special equipment to perform the following:
  - Total cross section measurements
  - Partial cross section measurements

**Specifications:**

- **Pulse width:** 1 ns
- **Frequency:** 40–800 Hz
- **Average current:** 4.7–75 \(\mu\text{A}\)
- **Neutron intensity:** 1.6 \(10^{12}\)–2.5 \(10^{13}\) n/s
Neutron production

- $e^-$ accelerated to $E_{e^-,\text{max}} \approx 140$ MeV
- $(e^-, \gamma)$ Bremsstrahlung in U-target (rotating & cooled with liquid Hg)
- $(\gamma,n)$, $(\gamma,f)$ in U-target
- Low energy neutrons by water moderator in Be-canning
Neutron capture and total cross section experiments at a white neutron source

- Time-of-flight technique is used to determine incident neutron energy. “Clocks” used have typically 1 nsec resolution.

- Pulsed electron beam of the accelerator starts the clock; γ-ray or neutron detector stops the clock
  \[ v_n = \frac{L}{t} \]
  \[ E_n = m_n v^2 / 2 \]

- Filters are used to reduce frame-overlap background from low-energy neutrons, reduce γ-flash effects, and determine background.
Capture cross section measurements at GELINA

Total energy detection principle

- C$_6$D$_6$ liquid scintillators
  - 125°
  - Pulse height weighting technique
  - Weighting function from Monte Carlo simulations

- Flux measurements (IC)
  - $^{10}$B(n,α)
  - $^{235}$U(n,f)

\[
Y_{exp} = N \sigma_\varphi \frac{C_w - B_w}{C_\varphi - B_\varphi}
\]
Total cross section/transmission measurements

Sample and background filters

Detector stations
Moderated: $L = 30\text{ m}, 50\text{ m} (100\text{ m}, 200\text{ m})$
Fast: $L = 400\text{ m}$

Detector

Low energy: $^6\text{Li}(n,t)\alpha$ Li-glass
High energy: $H(n,n)H$ plastic scintillator

$$T = \frac{C_{\text{in}}}{C_{\text{out}}} \approx e^{-n\sigma_{\text{tot}}}$$
Oak Ridge National Laboratory measurement activities for Zr

- Zr has 5 stable isotopes; at least 4 major isotopes should be measured
- Good high-resolution Oak Ridge National Laboratory (ORNL) total cross section data for the separated isotopes are available, even for the long-lived radioactive fission product $^{93}$Zr; data were retrieved from the Jack Harvey archive
- Therefore, only neutron capture experiments must be performed using isotopically enriched samples
- Experiments with natural samples have been performed: list mode data sorted into time-of-flight (TOF) spectra for data reduction
- Natural sample data serve as a good sanity check for ENDFs for separated isotopes
ORNL measurement activities for Zr

• The combination of the natural sample capture data with the total cross section of the separated isotopes will help to obtain parameters for the strong capture resonances even, without data from enriched samples

• Because travel was cancelled due to COVID-19, a contingency plan was devised with the European Commission (EC) Joint Research Centre (JRC) to perform experiments

• Raw experimental data will be acquired by JRC-Geel and shipped to ORNL, where all data sorting and reduction will be performed on special software to be installed on ORNL computers

• A $^{90}$Zr metallic sample was produced by ORNL’s Isotope Science and Engineering Directorate and shipped in September 2020 to JRC-Geel
$^{90}$Zr sample

- Metallic samples are the first choice for capture experiments, as they help reduce backgrounds from sample scattered neutrons due to the lack of scattering compound material such as H,O and C
- The sample is not very uniform and is warped, but for capture experiments, this is not an issue
- Transmission samples should be uniform, but with good transmission data, this is not an issue
- However, the nonuniform transmission data could be used to test program data correction procedures, and results can be compared to existing transmission data
ORNL measurement activities for Zr

- Transmission experiments with different Zr samples are performed using the FP4 50 m station
- Experiments are performed using different background filter combinations
Background determination in transmission using black resonance filters
ORNL measurement activities for Zr (continued)

Neutron capture at FP14, 60 m
Old ORNL $^{90}$Zr data

Resolved resonances are visible above 1 MeV by a factor of 3 more than previous experiments.
Old ORNL $^{93}$Zr data

Total cross section of $^{93}$ZrO$_2$ resolved resonances well above 100 keV
## Status of NCSP experiments at EC-JRC Geel

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People supporting JRC experiments and evaluations

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