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

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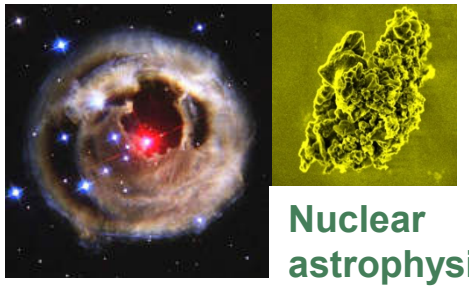
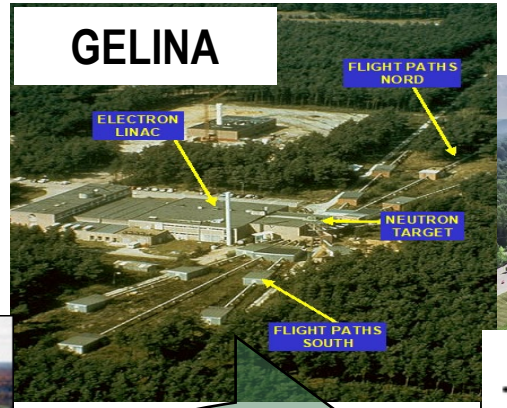
ORNL Data Support for Nuclear Applications



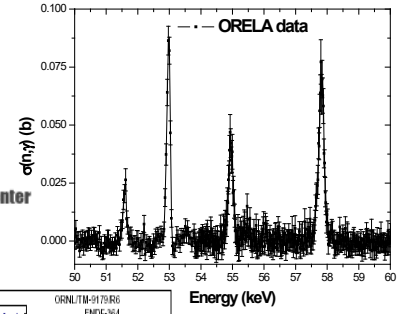
Nuclear astrophysics

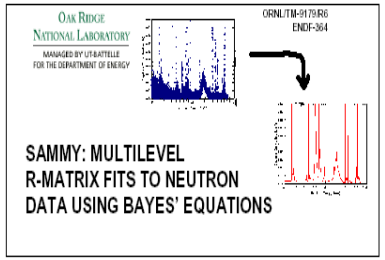


Basic science

RPI

linac The Gaerttner LINAC Center



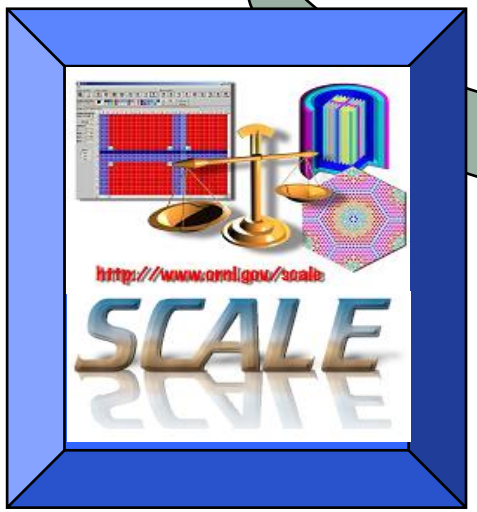


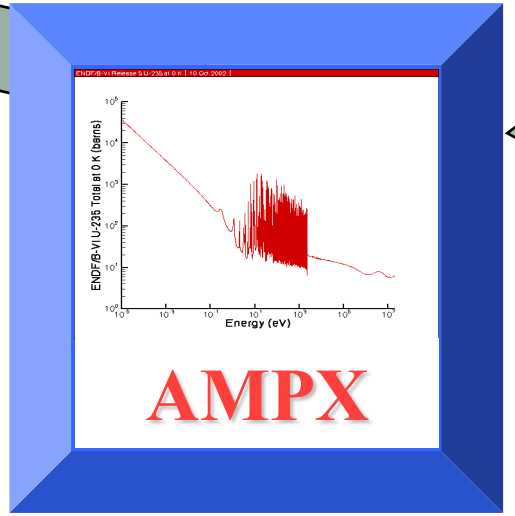
SAMMY

Cross section evaluations

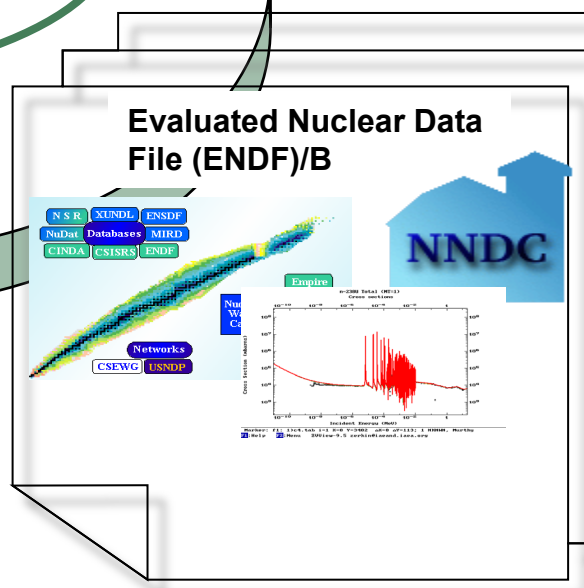
Applications

Computational modeling

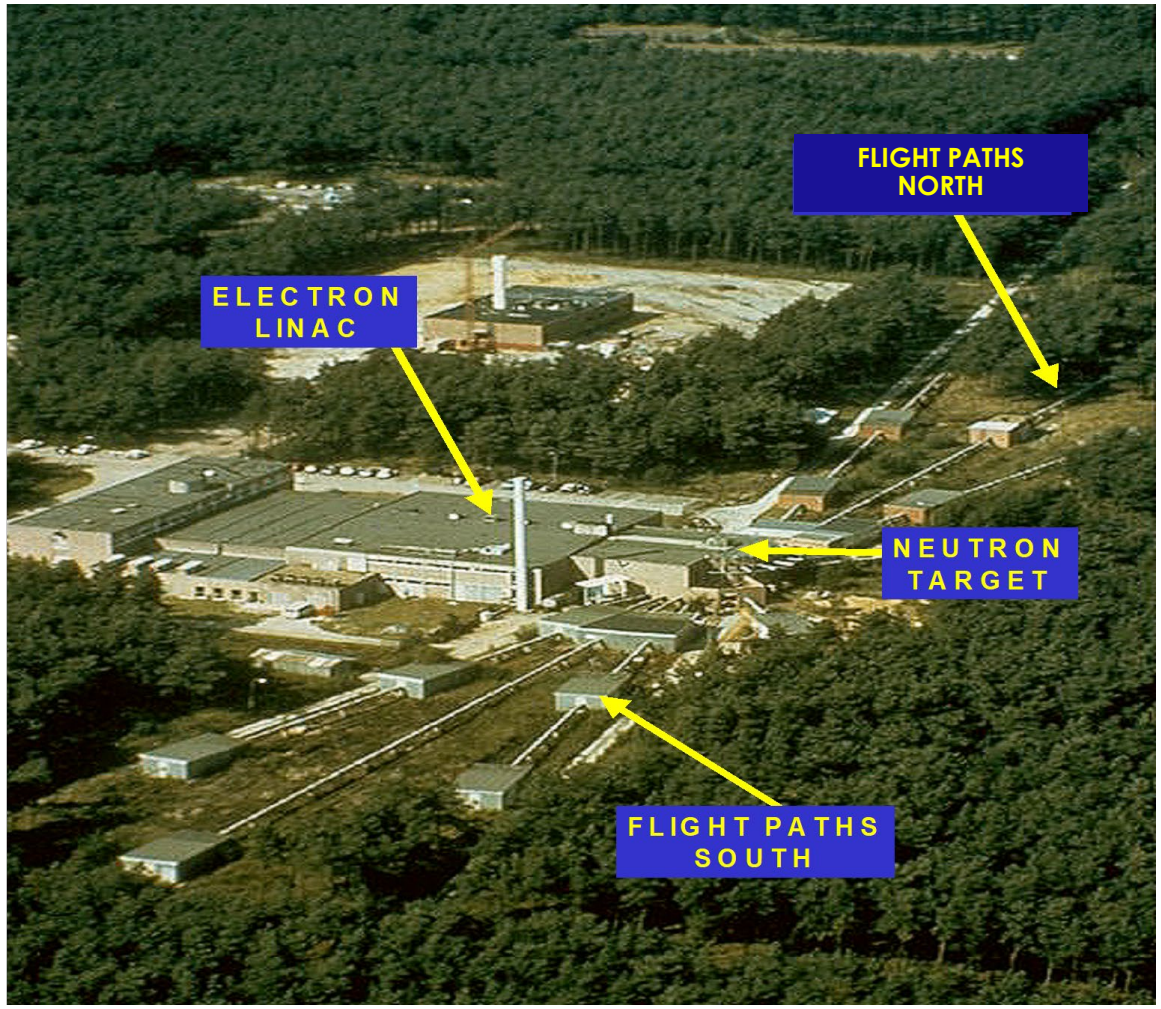




Evaluated Nuclear Data File (ENDF)/B



Oak Ridge National Laboratory



GELINA

- Time-of-flight facility
- Pulsed white neutron source

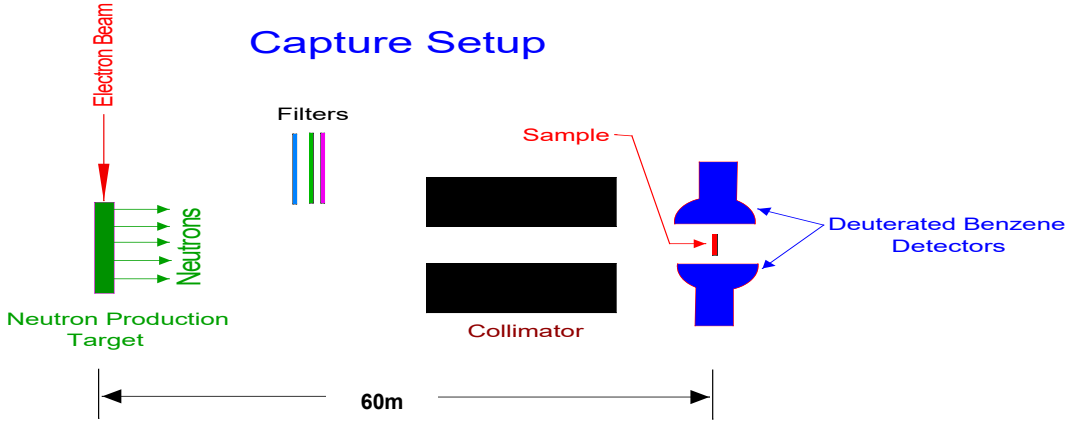
  (10 meV < E_n < 20 MeV)
- Multi-user facility with 10 flight paths (10–400 m)
- Measurement stations have special equipment to perform the following:
  - Total cross section measurements
  - Partial cross section measurements

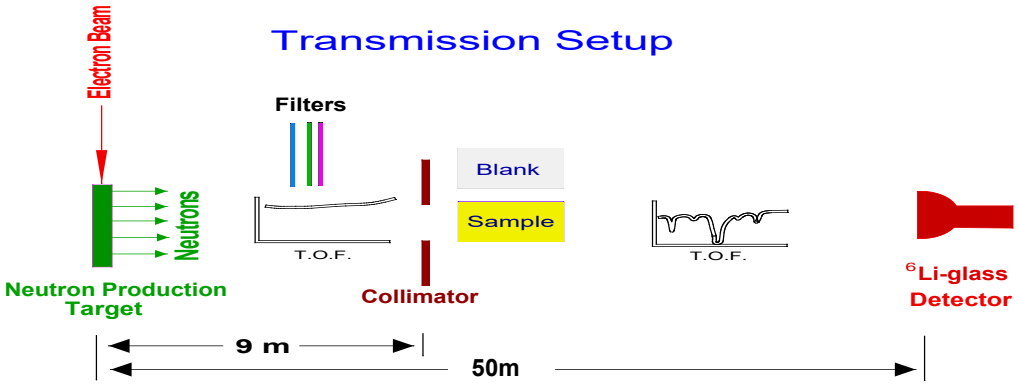
Pulse width	**: 1 ns**
Frequency	**: 40–800 Hz**
Average current	**: 4.7–75 μA**
Neutron intensity	**:1.6 10^{12}–2.5 10^{13} n/s**

Neutron production

- e^- accelerated to $E_{e-,max} \approx 140$ MeV
- (e^-, γ) Bremsstrahlung in U-target (rotating & cooled with liquid Hg)
- (γ,n) , (γ ,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 1nsec resolution
- Pulsed electron beam of the accelerator starts the clock; g-ray or neutron detector stops the clock
  - $v_n = L/t$
  - $E_n = m_n v^2/2$
- Filters are used to reduce frame-overlap background from low-energy neutrons, reduce g-flash effects, and determine background

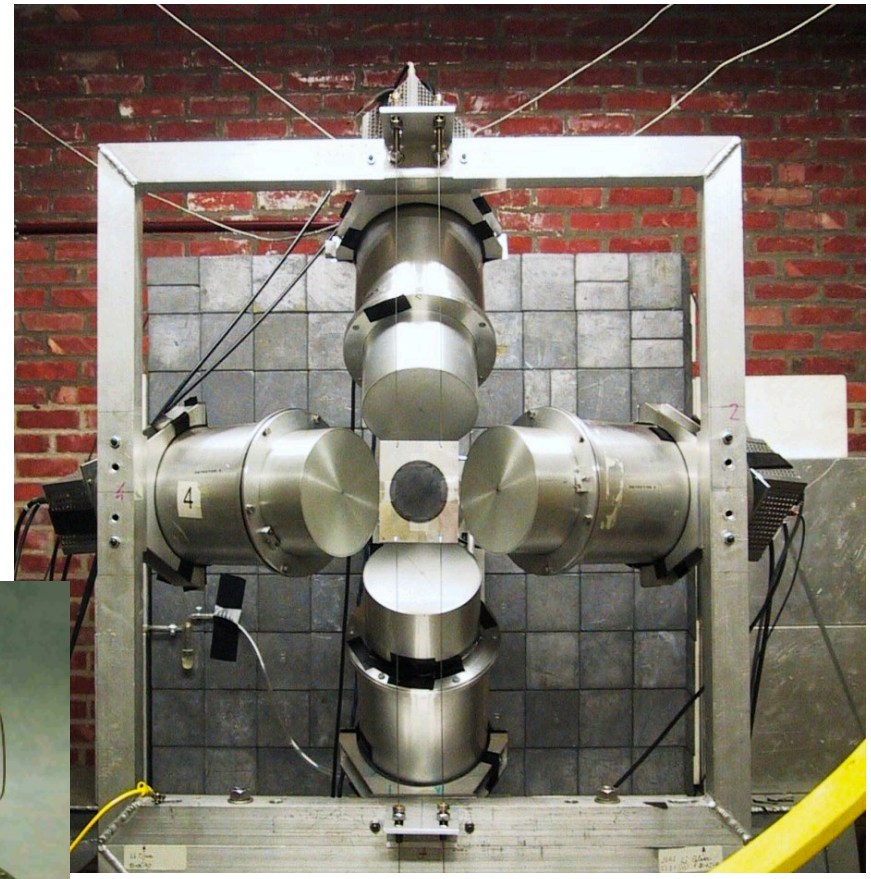
Capture cross section measurements at GELINA

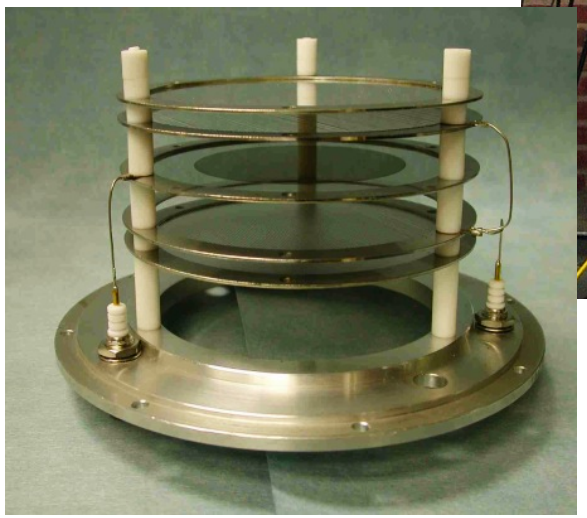
Total energy detection principle

- C_6D_6 liquid scintillators
  - 125°
  - Pulse height weighting technique
  - Weighting function from Monte Carlo simulations
- Flux measurements (IC)
  - $^{10}B(n,\alpha)$
  - $^{235}U(n,f)$

$$Y_{exp} = N\sigma_{\varphi}\frac{C_w - B_w}{C_{\varphi} - B_{\varphi}}$$

L = 10 m, 30 m, and 60 m

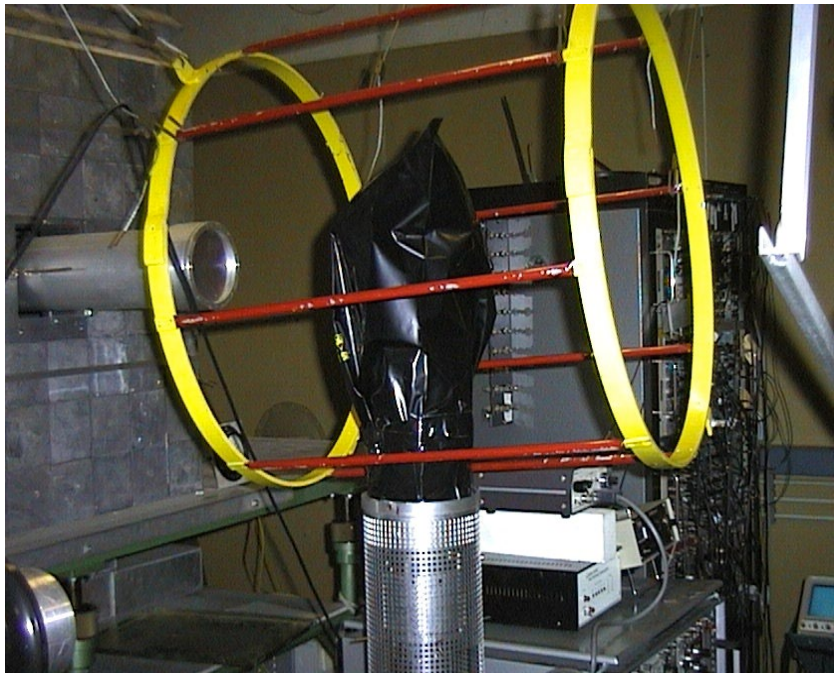




Total cross section/transmission measurements

Sample and background filters

Detector



Detector stations
Moderated: L = 30 m, 50 m (100 m, 200 m)
Fast: L = 400 m

Low energy : ^{6}Li(n,t)α Li-glass

High energy : H(n,n)H plastic scintillator

$$T = \frac{C_{in}}{C_{out}} \cong e^{-n\sigma_{tot}}$$

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

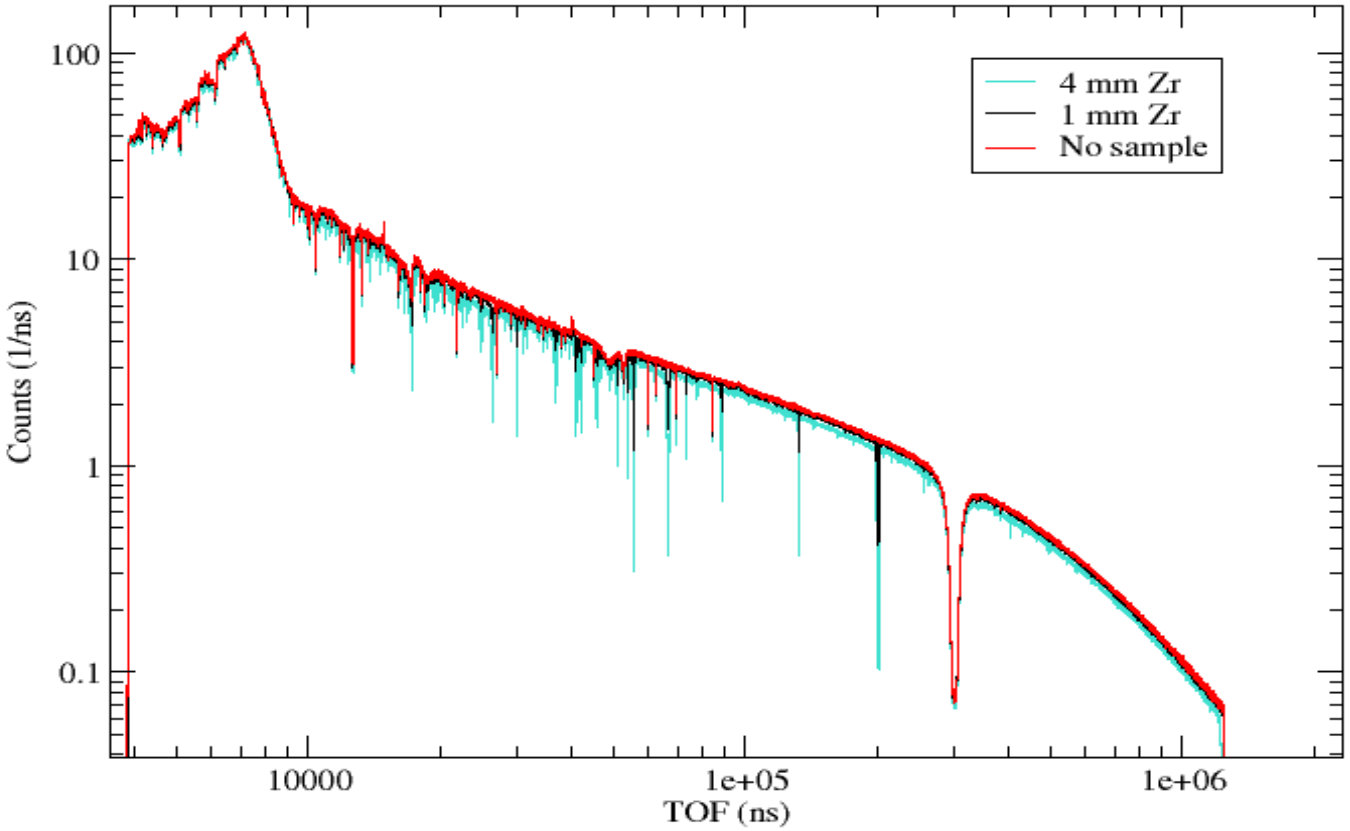
ORNL measurement activities for Zr

- 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

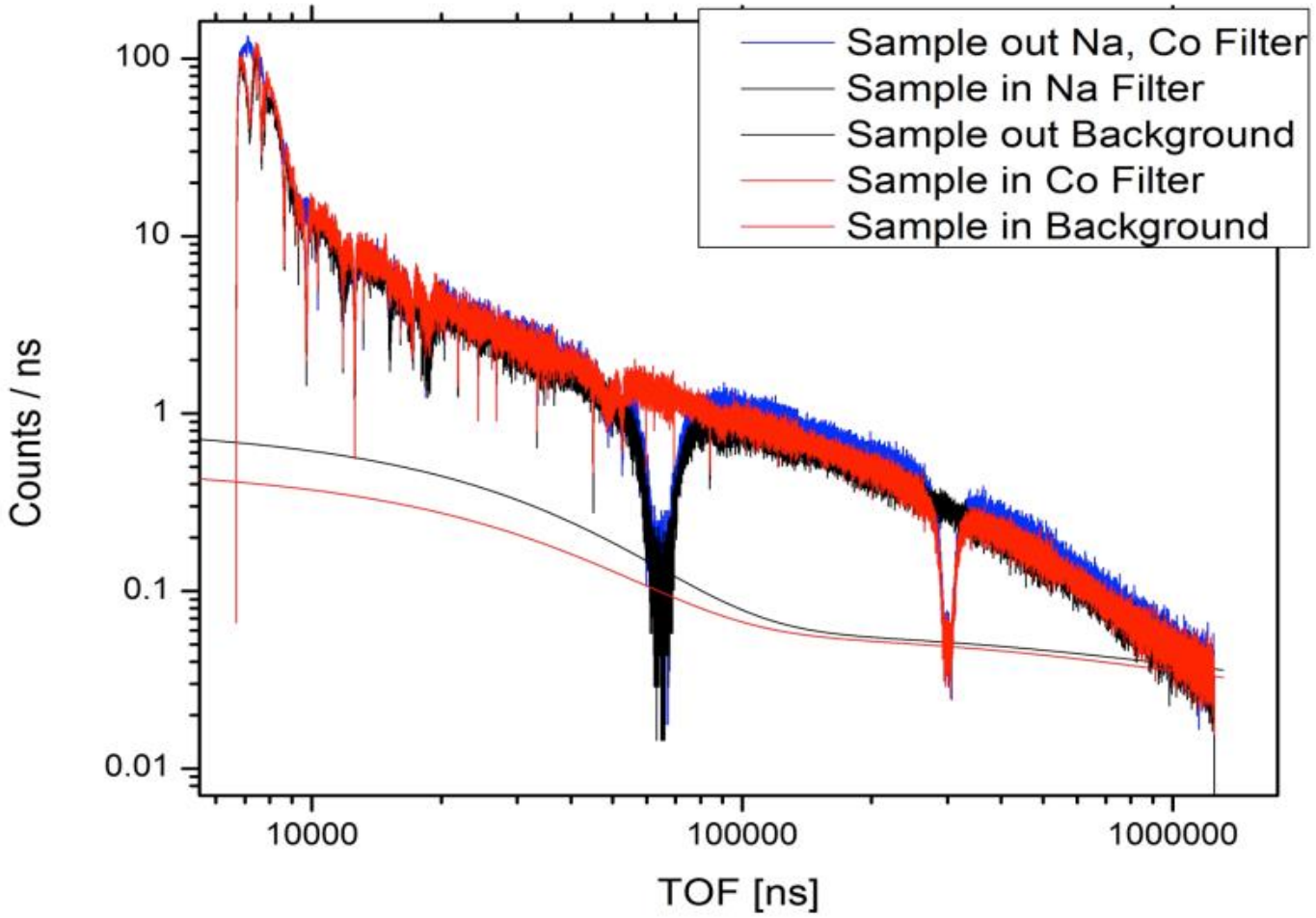
- Metallic samples are the first choice for capture experiments, as they help reduce backgrounds from sample scattered neutrons due to the lack of scattering compound material such as H,O and C
- The sample is not very uniform and is warped, but for capture experiments, this is not an issue
- Transmission 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

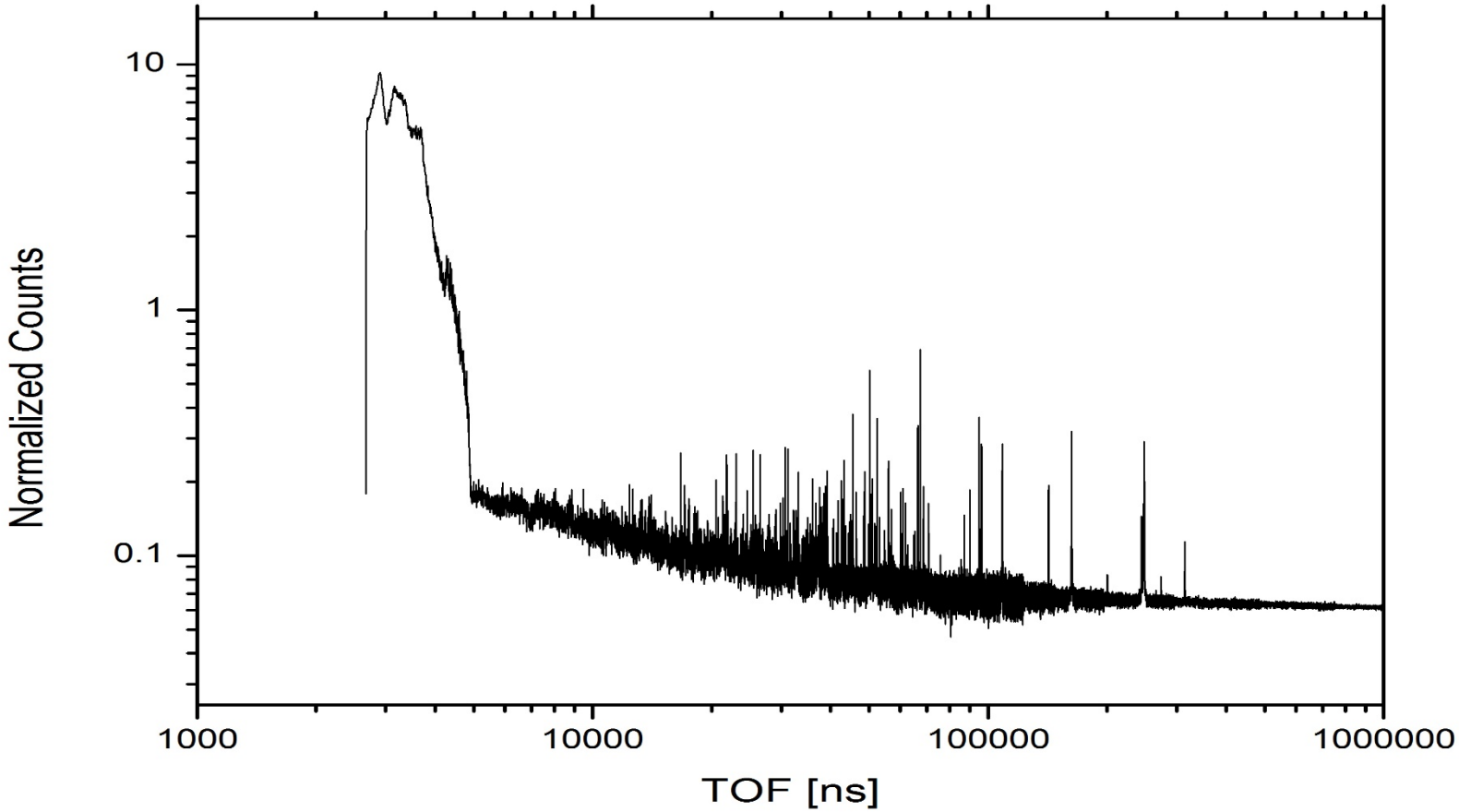


- Transmission experiments with different Zr samples are performed using the FP4 50 m station
- Experiments are performed using different background filter combinations

Background determination in transmission using black resonance filters

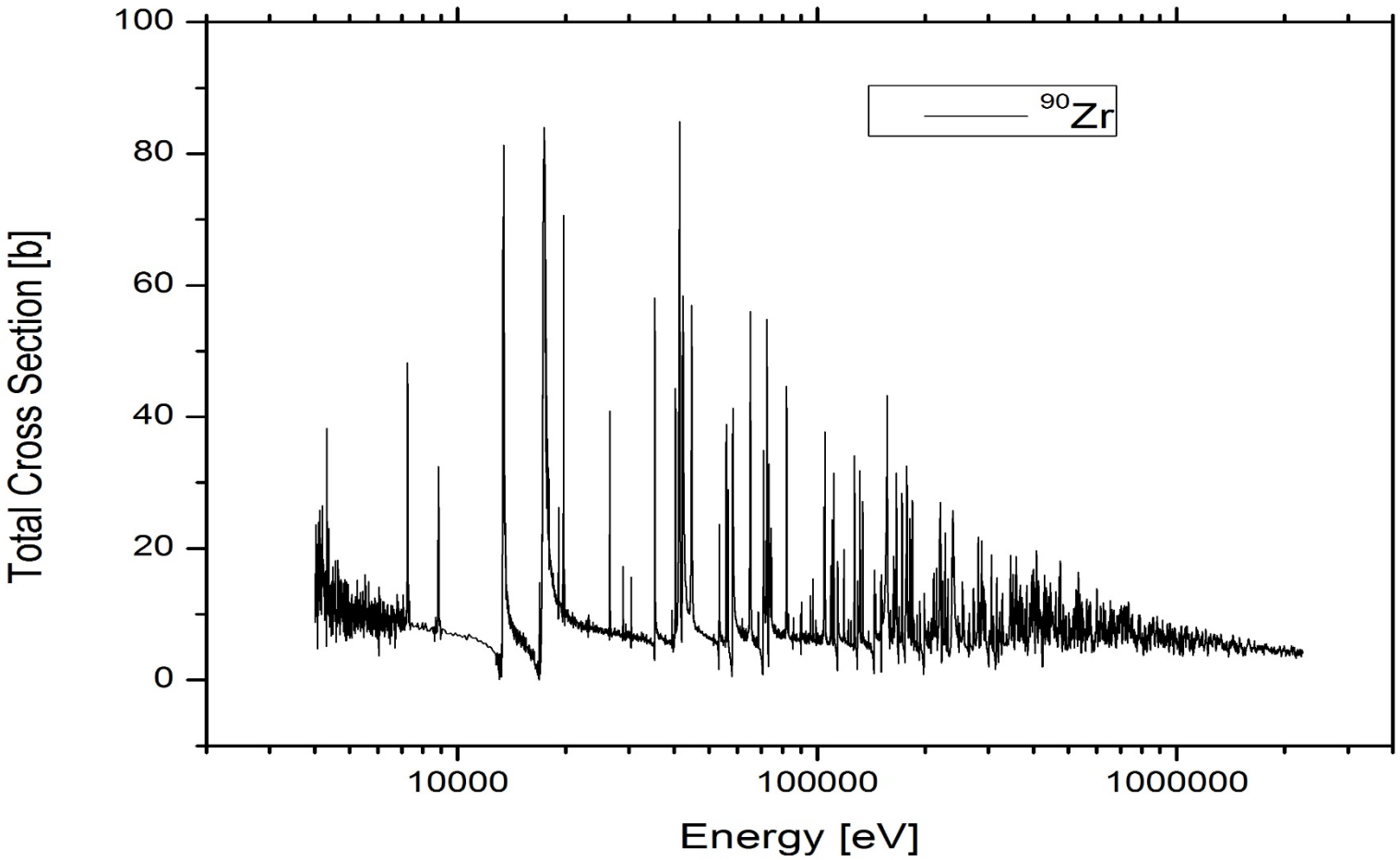


ORNL measurement activities for Zr (continued)



Neutron capture at FP14, 60 m

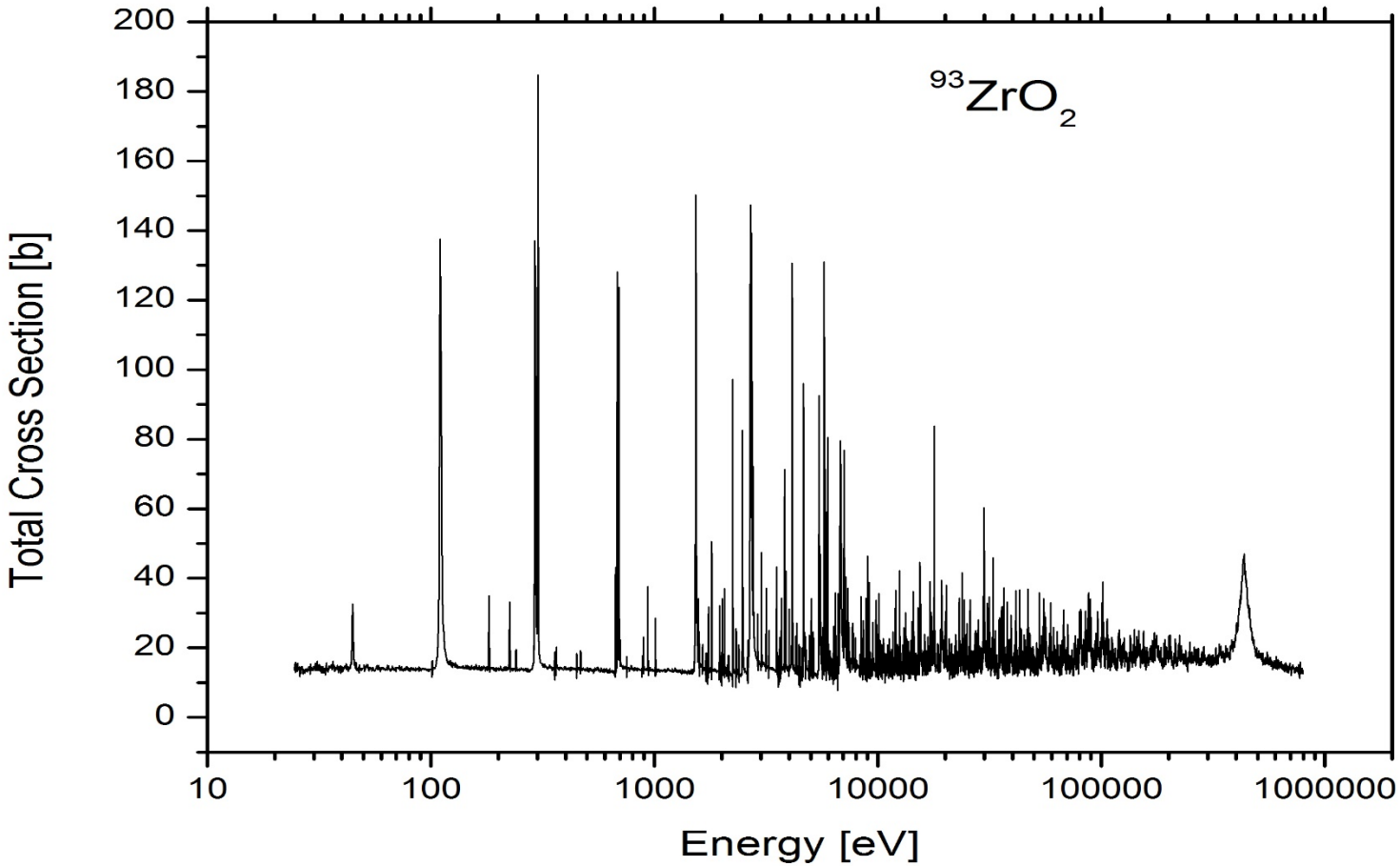
Old ORNL ^{90}Zr data



Total cross section of a metallic ^{90}Zr sample

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

	W	Cu	Ca	Ce	V	Zr	La
Sample	Metallic disks 182,183,184,186 2009–2011	Metallic disks 63 and 65 2011–2012	Metallic disks Nat Ca 2013–2014	Metallic disks Nat Ce, Ce-142 oxide 2014–2015 2018–2019	Metallic disks 2015–2016	Nat Zr metallic disks ^{90,91,92,94}Zr 2016–2017	Nat La metallic disks 2017–2018
Experiments GELINA	60 m, 30 m (n,γ) transmission	60 m (n,γ)	60 m (n,γ) transmission	Nat Ce 60 m (n,γ) Nat Ce transmission, ^{142}Ce experiments completed	60 m (n,γ) transmission	Nat Zr 60 m (n,γ) + transmission	60 m (n,γ) transmission
Data sorting	Finished 60 m + transmission	Finished 60 m	Finished 60 m transmission	Finished for thin and thick sample, ^{142}Ce data sorting finalized	Finished for thin and thick sample	Finished for thin and thick natural sample	Finalized
Reduced to cross section	X-section, transmission	X-section	X-section transmission 0.6, 1.0, 5 cm samples	2 mm X-section 2 mm transmission 10 mm transmission ^{142}Ce data	Thin X-section 0.35 and 2 mm, transmission		X-section, transmission
Data testing	Data ready for evaluation	Data ready for evaluation	Data ready for evaluation	In progress, data ready for evaluation	In progress, data ready for evaluation		In progress, data ready for evaluation
Analysis and evaluation	Finalized and submitted to National Nuclear Data Center	Finalized and submitted to National Nuclear Data Center	Finalized and submitted to National Nuclear Data Center	In progress	In progress		

People supporting JRC experiments and evaluations

- Peter Schillebeeckx, EC-JRC Geel
- Carlos Paradela, EC-JRC Geel
- Stefan Kopecky, EC-JRC Geel
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