ORNL Neutron Cross Section Measurements of ^{90}Zr

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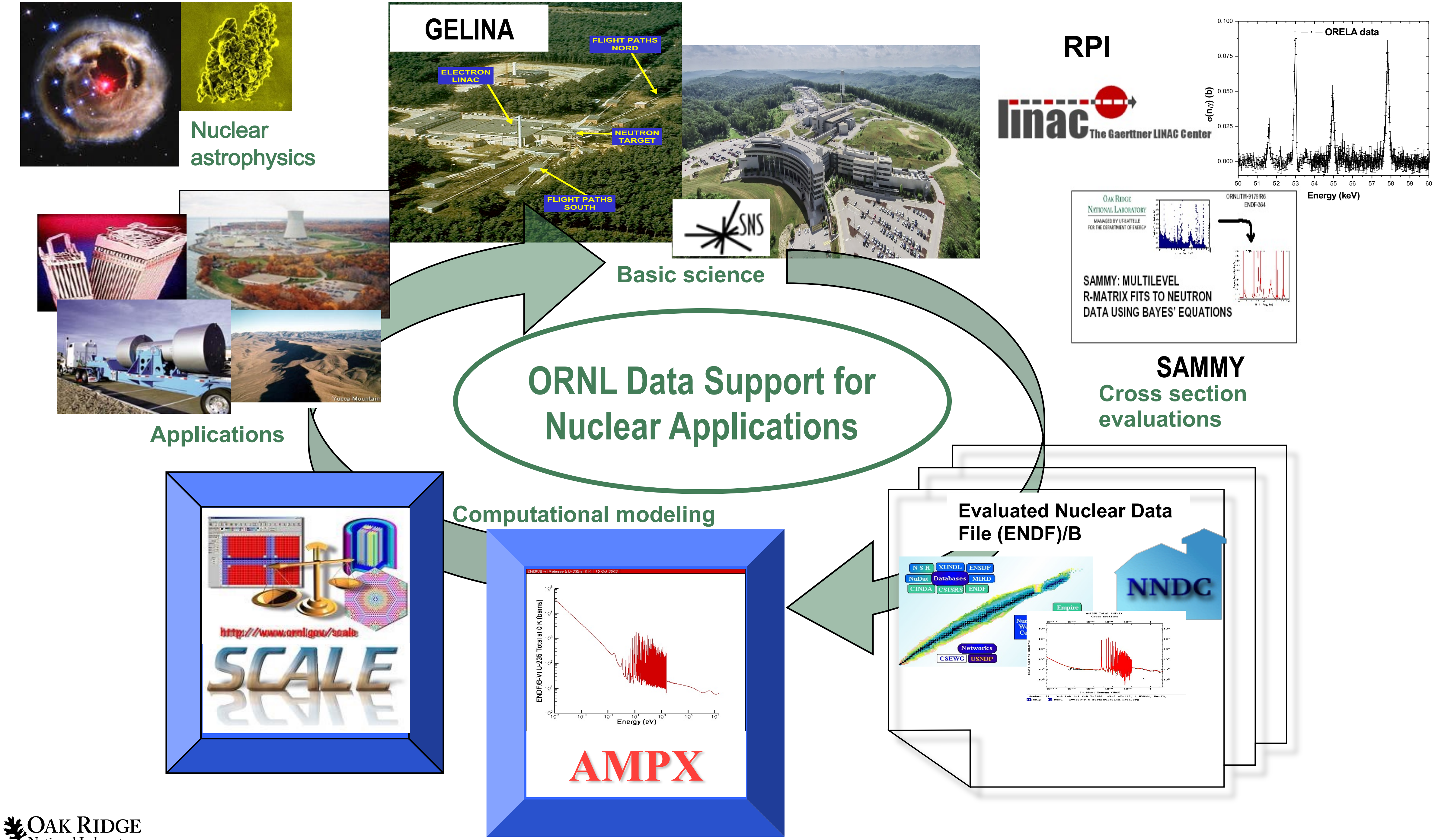
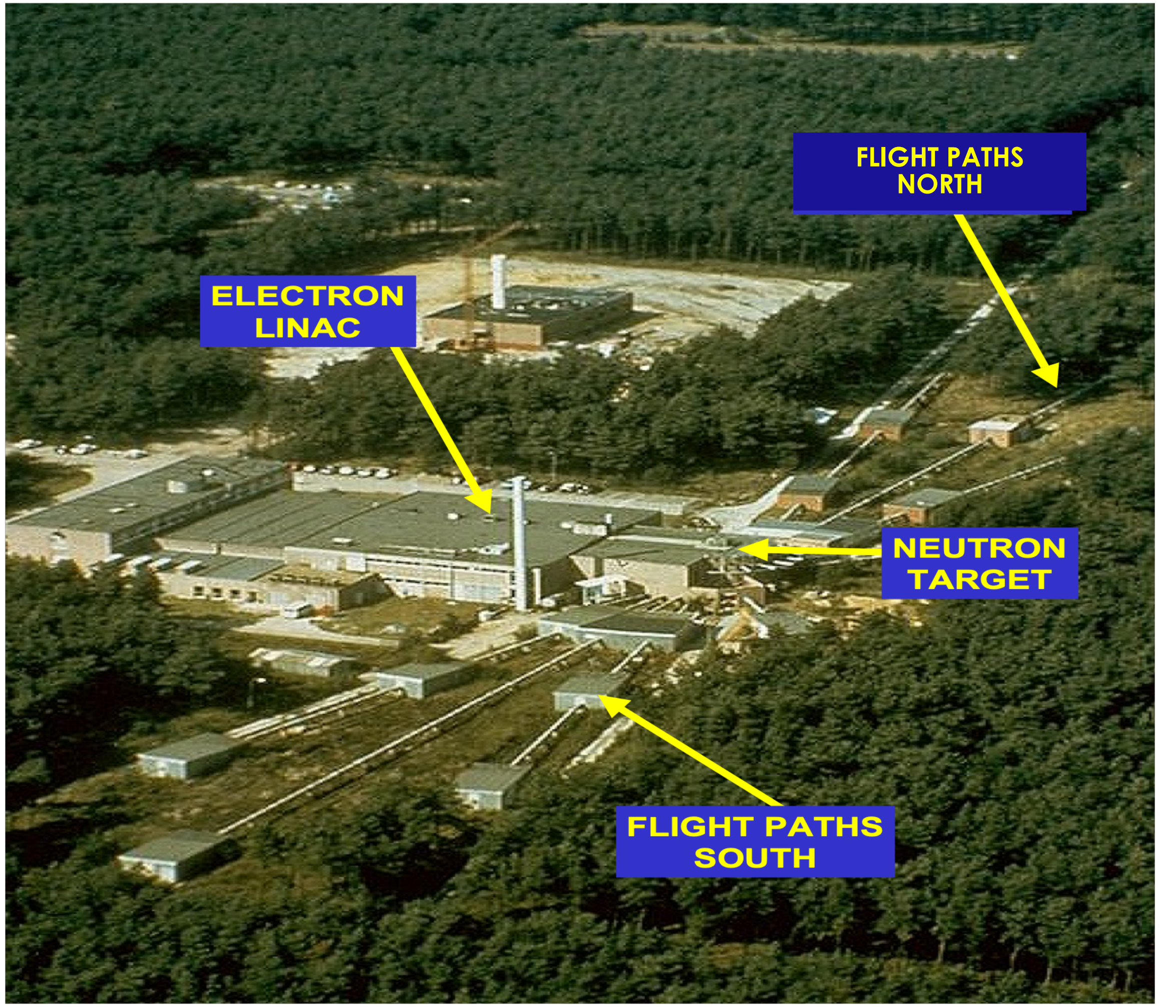

Nuclear astrophysics
GELINA
FLIGHT PATHS NORD
ELECTRON LINAC
NEUTRON TARGET
FLIGHT PATHS SOUTH
SNS
Basic science
RPI
linac The Gaertner LINAC Center
ORELA data
σ(n,γ) (b)
Energy (keV)
Oak Ridge National Laboratory
SAMMY: MULTILEVEL R-MATRIX FITS TO NEUTRON DATA USING BAYES' EQUATIONS
SAMMY
Cross section evaluations
Yucca Mountain
Applications
ORNL Data Support for Nuclear Applications
Computational modeling
http://www.ornl.gov/scale
SCALE
Energy (eV)
AMPX
Evaluated Nuclear Data File (ENDF)/B
NSR
XUNDL
ENSDF
NuDat
Databases
MIRD
CINDA
CSISRS
ENDF
Empire
Networks
CSEWG
USNDP
NNDC



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
- **NCSP-Y12 build a new neutron production target for GELINA**

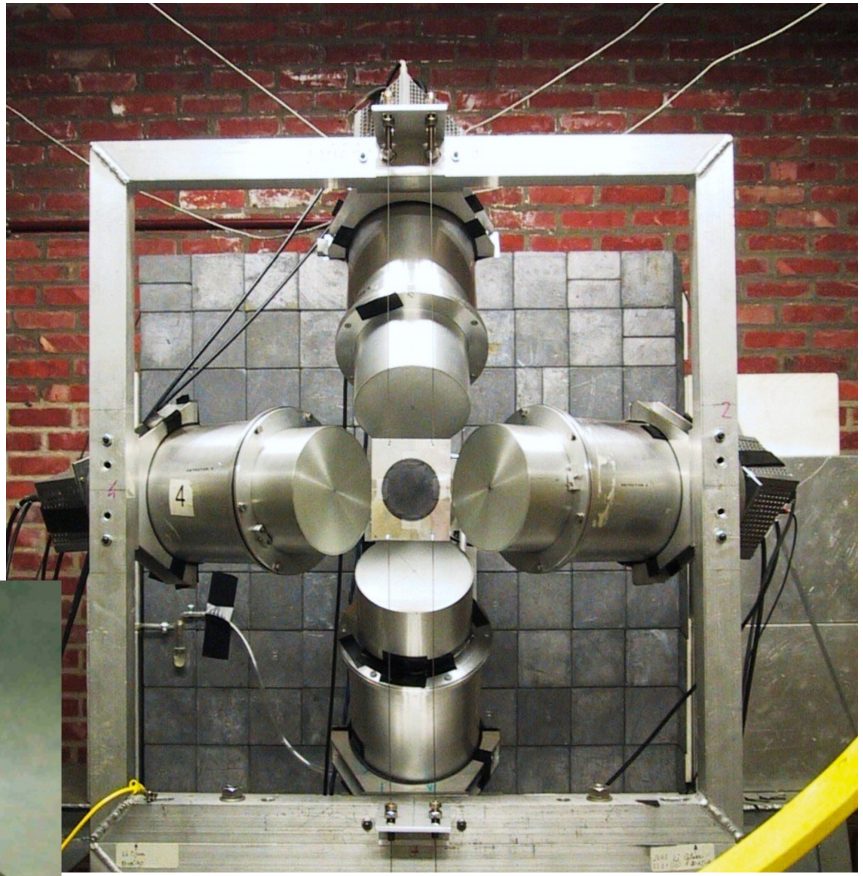
Capture cross section measurements at GELINA

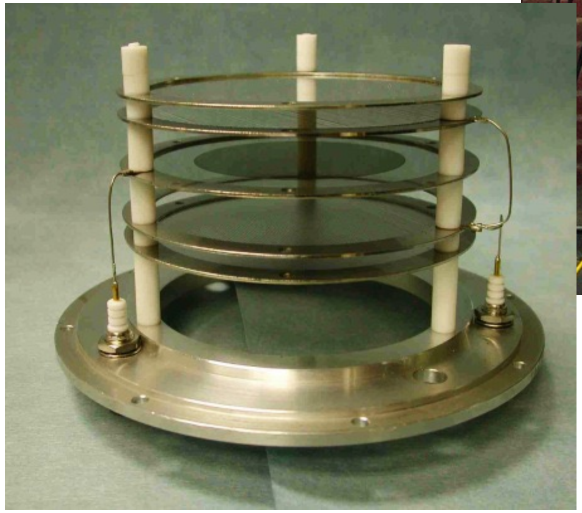
Total energy detection principle

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

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

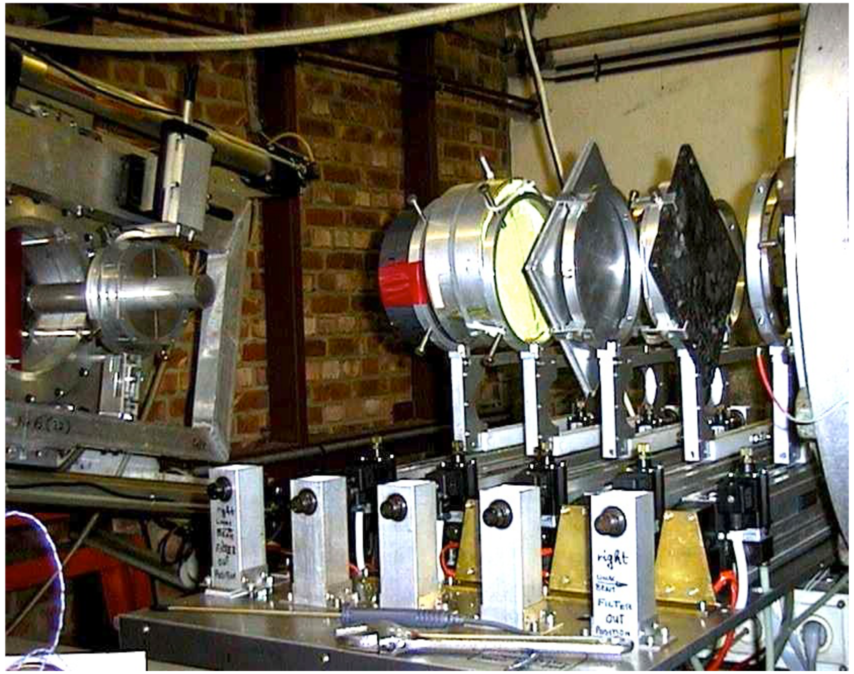
L = 10 m, 30 m, and 60 m



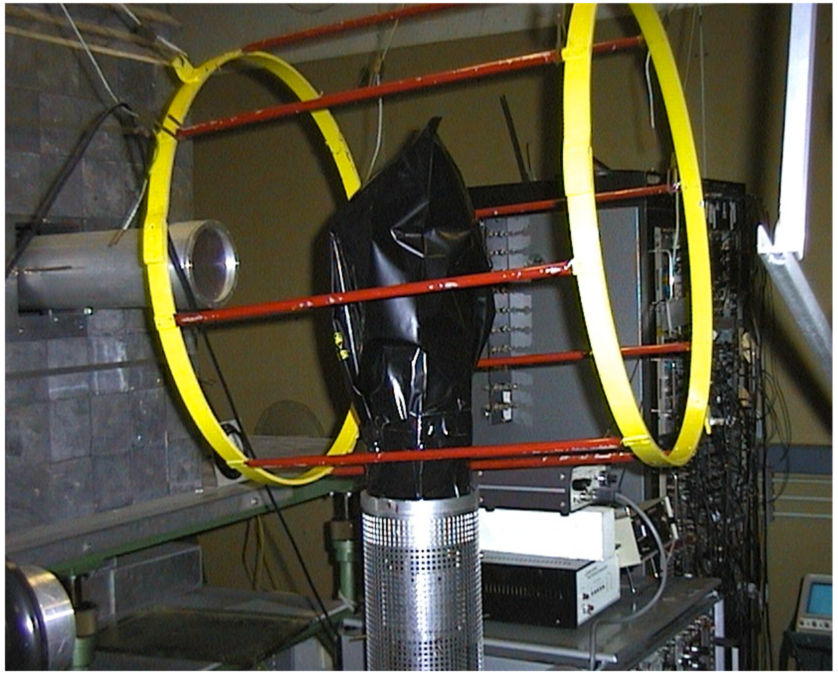


Total cross section/transmission measurements

Sample and background filters



Detector



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

Low energy : $^{6}Li(n,t)\alpha$ Li-glass

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

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

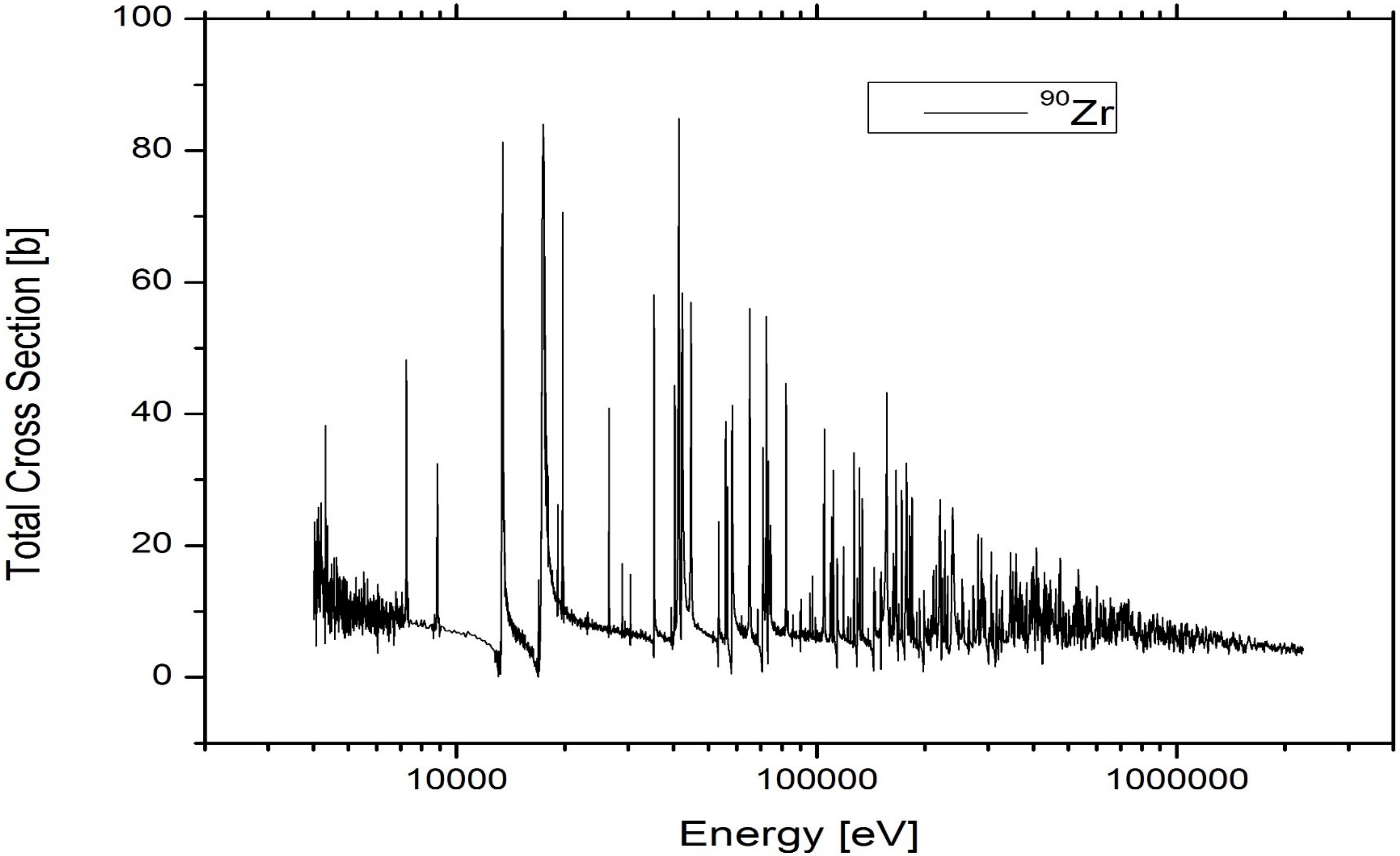
Oak Ridge National Laboratory measurement activities for Zr

- 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 separated isotopes are available, even for the long-lived radioactive fission product ^{93}Zr; data were retrieved from the Jack Harvey archive of ORELA experiments. Experiments were performed with metallic samples at 80 and 200m FP length.
- Therefore, only neutron capture experiments must be performed using isotopically enriched samples
- Transmission and (n,γ) Experiments with natural samples have been performed at GELINA: list mode data sorted into time-of-flight (TOF) spectra for data reduction
- Natural sample data serve as a good sanity check of the ENDF files 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 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
- Capture and transmission experiments were performed in 2021

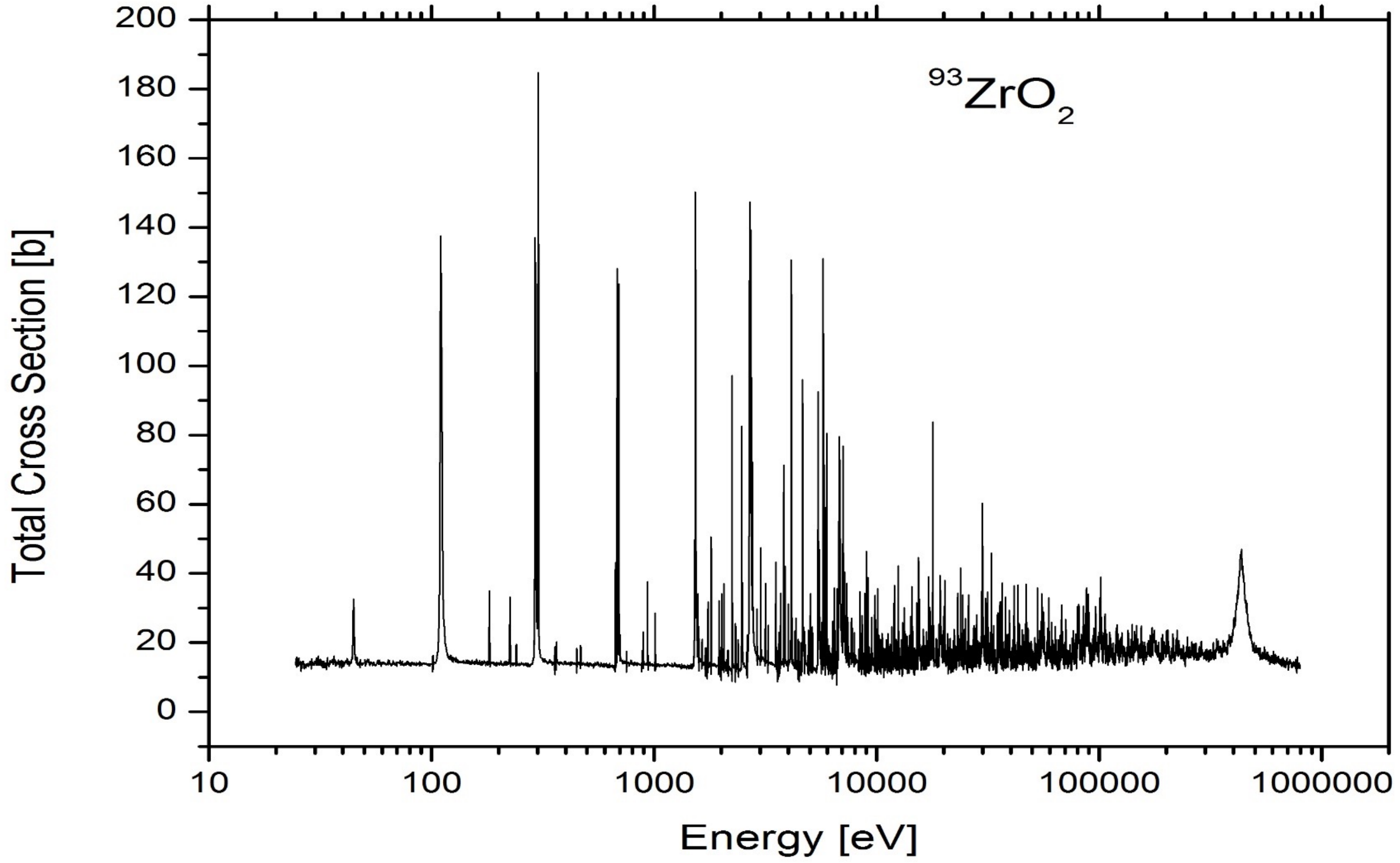
Old ORNL ^{90}Zr data



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

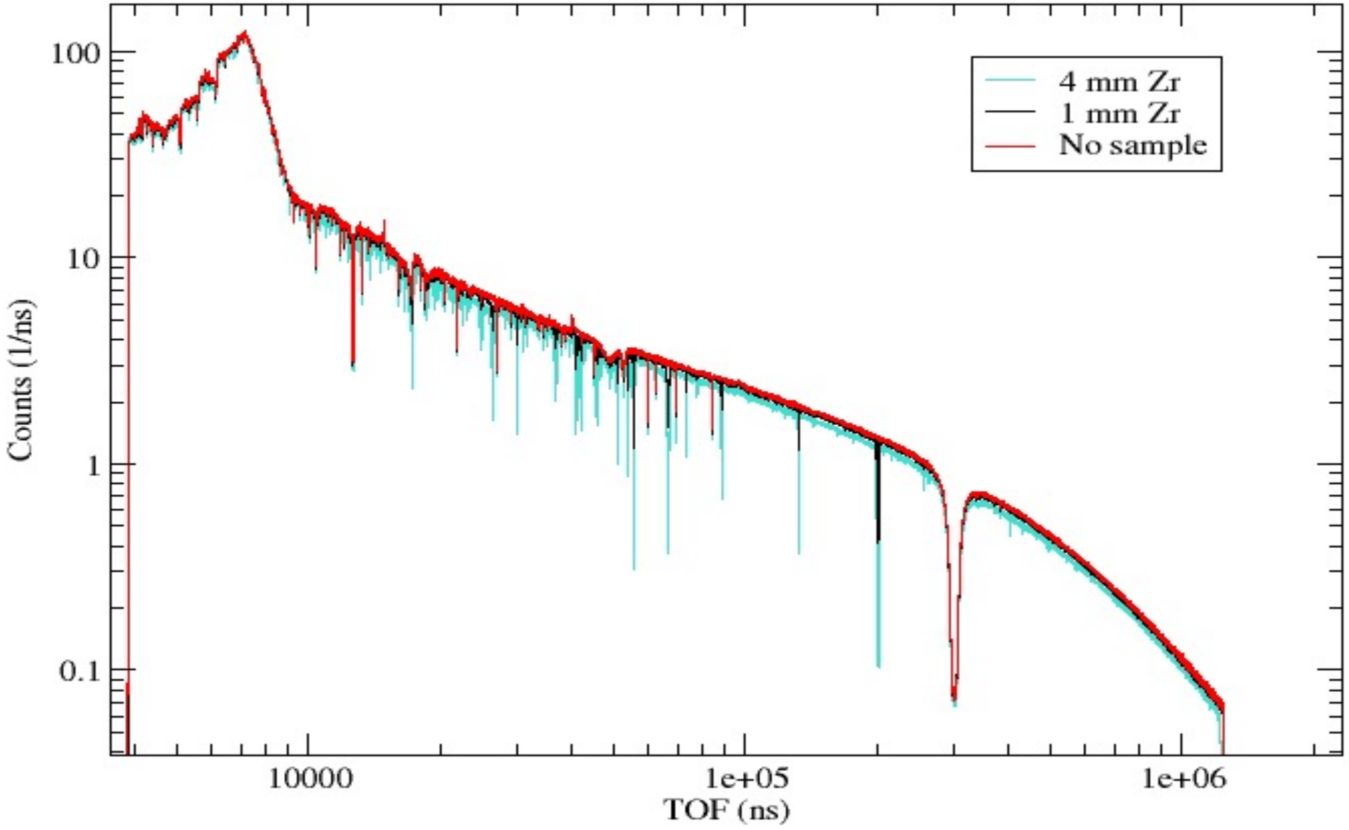
Resolved resonances are visible above 1 MeV by a factor of 3 more than previous experiments

Old ORNL ^{93}Zr data



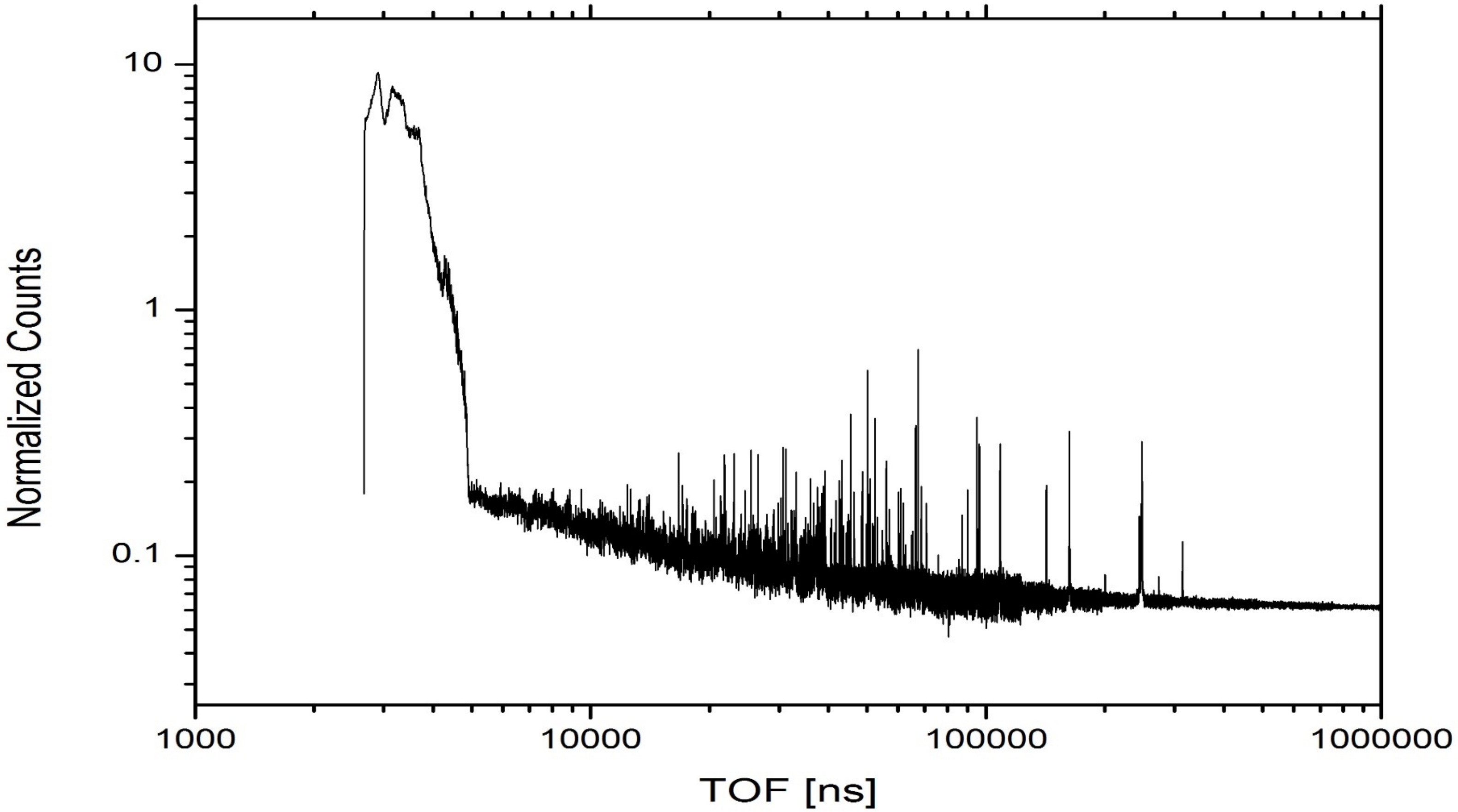
Total cross section of $^{93}ZrO_2$ resolved resonances well above 100 keV

ORNL measurement activities for Zr



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

ORNL measurement activities for Zr (continued)



Neutron capture at FP14, 60 m

^{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 a real problem
- Transmission samples should be uniform, but with good ORELA transmission data, this is not an issue
- However, the nonuniform transmission data could be used to test analysis program data correction procedures; the results can be compared to existing ORELA transmission data

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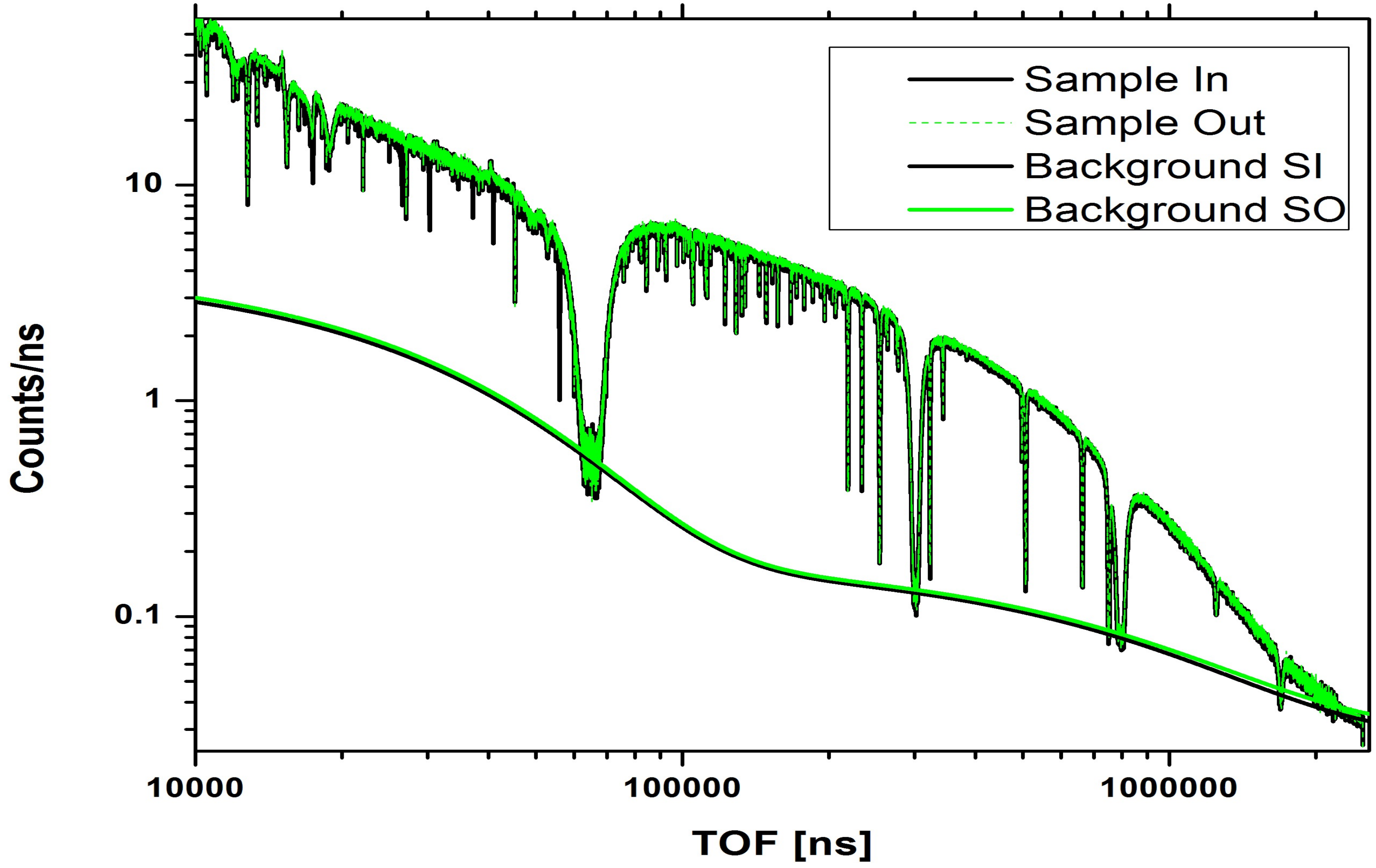
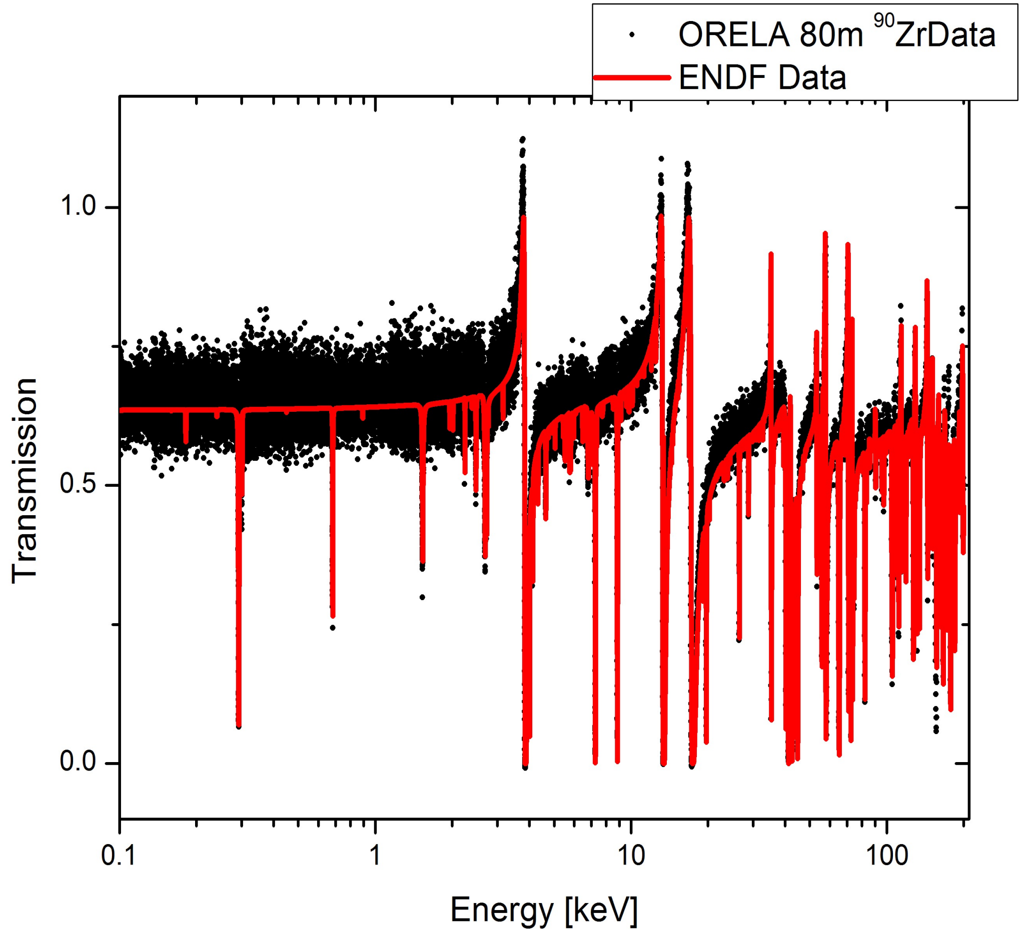
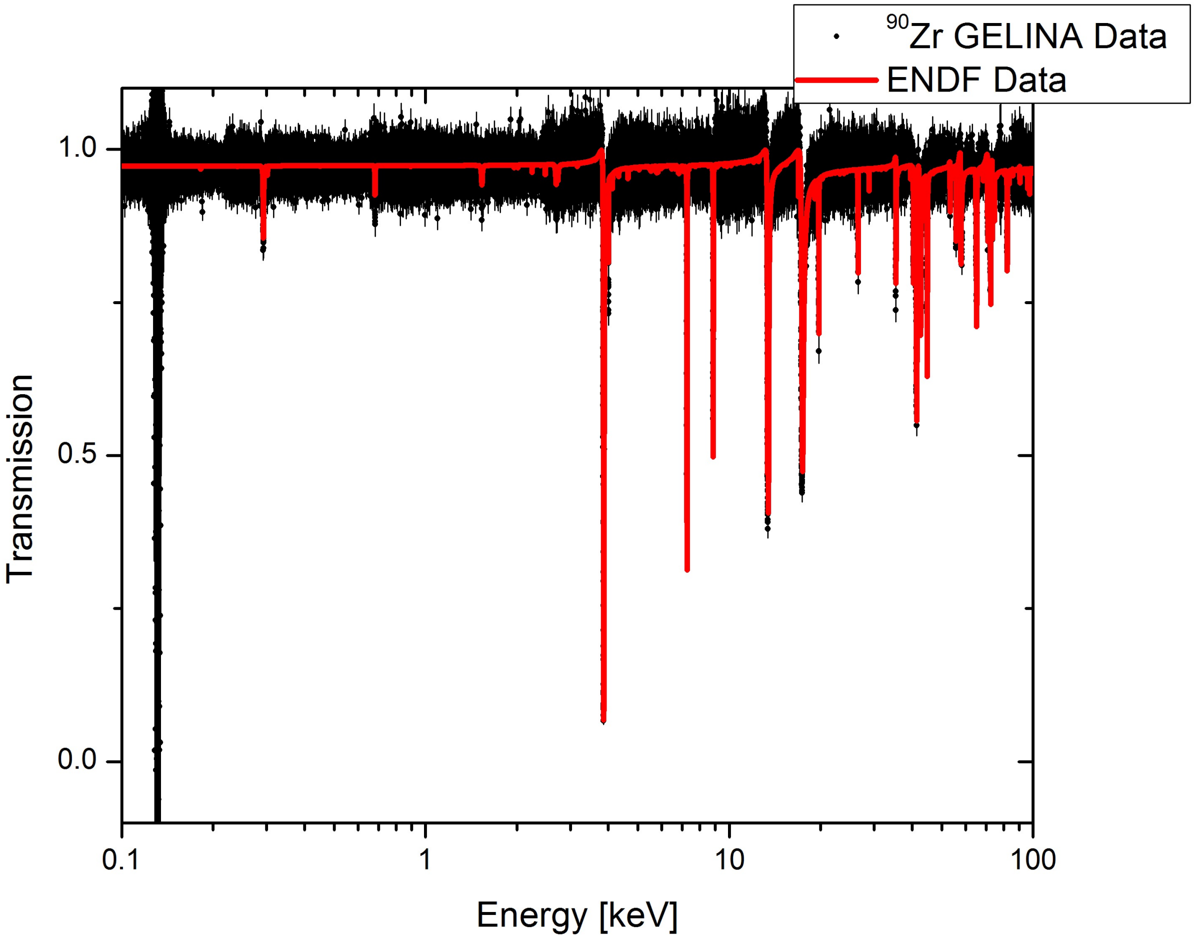
Background determination in transmission using black resonance filters

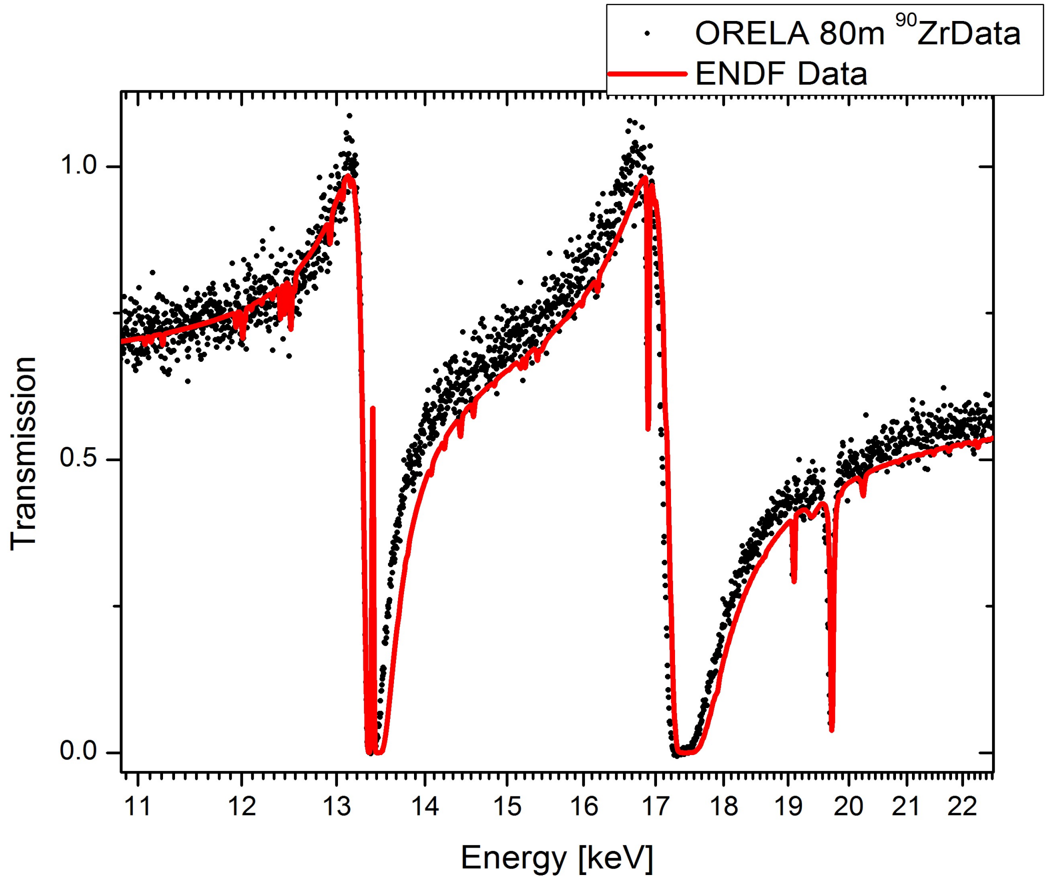


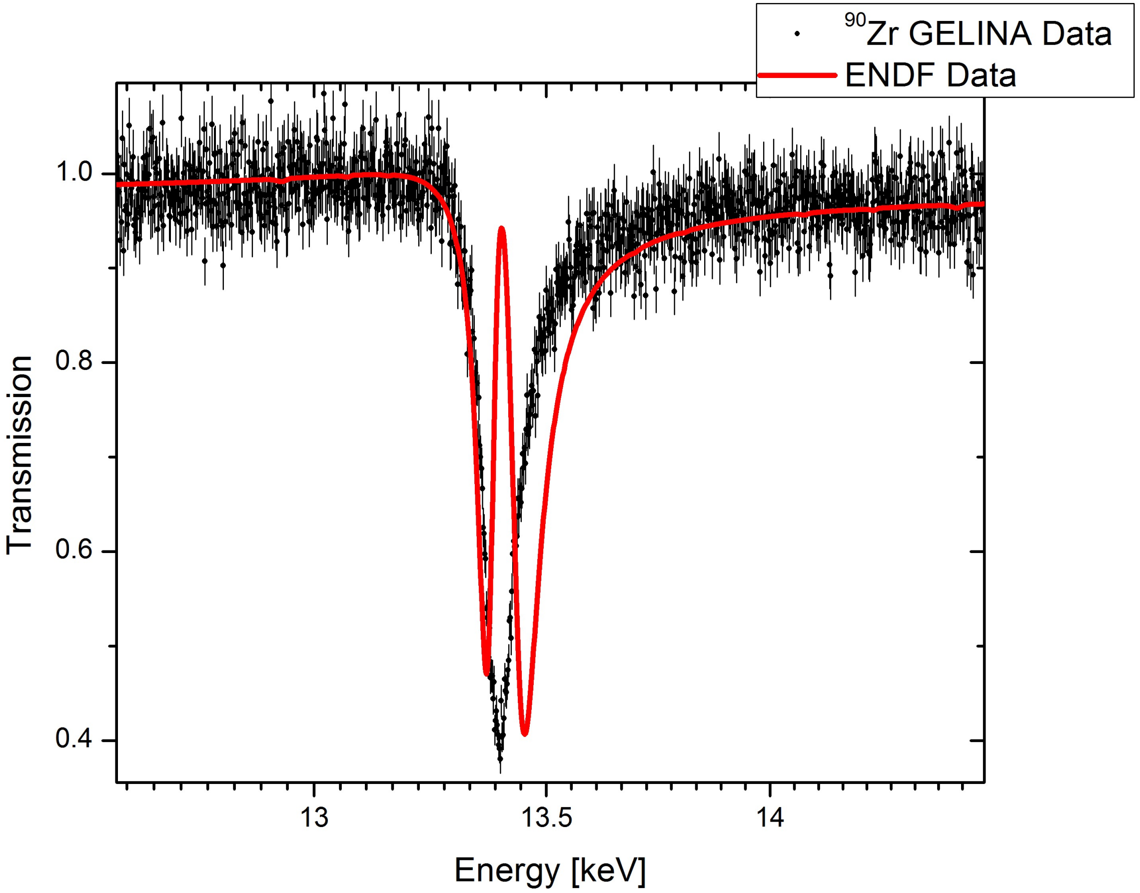
^{90}Zr transmission compared to ENDF





^{90}Zr transmission compared to ENDF





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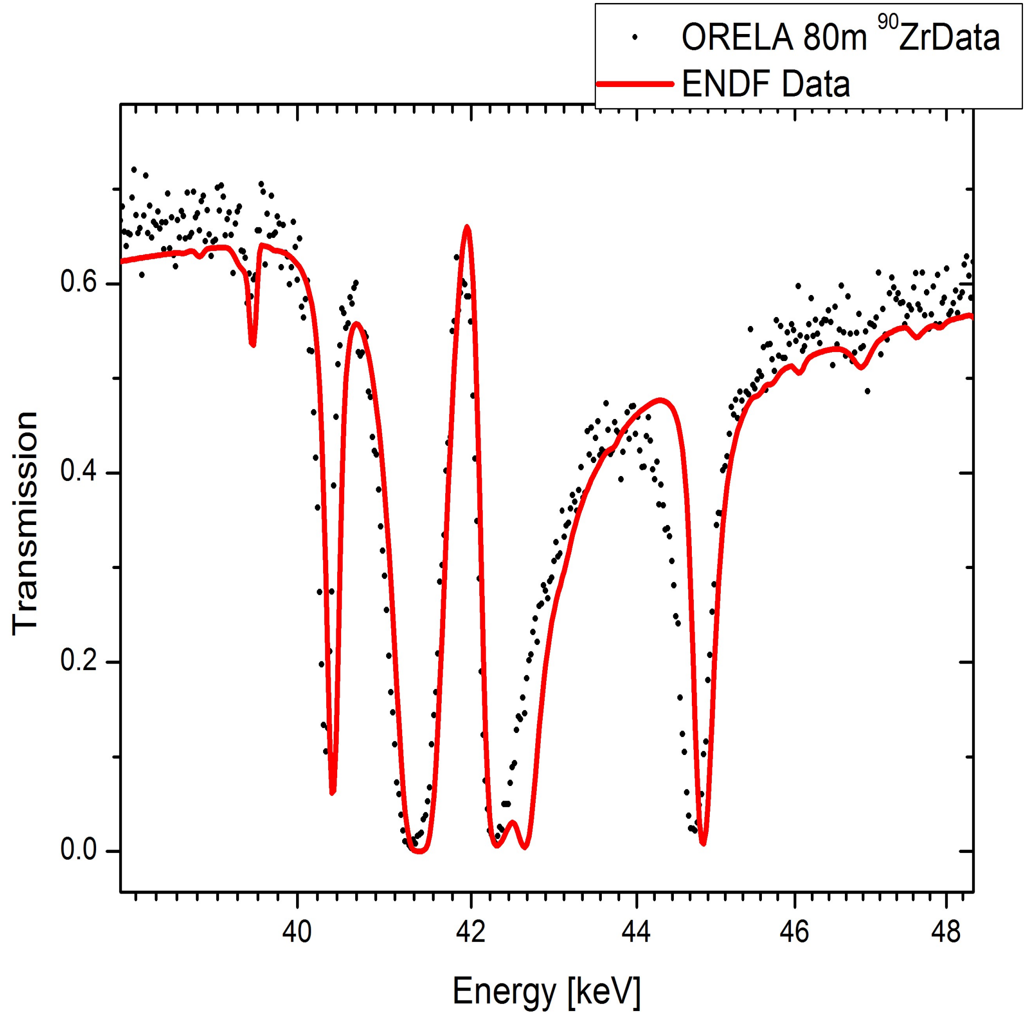
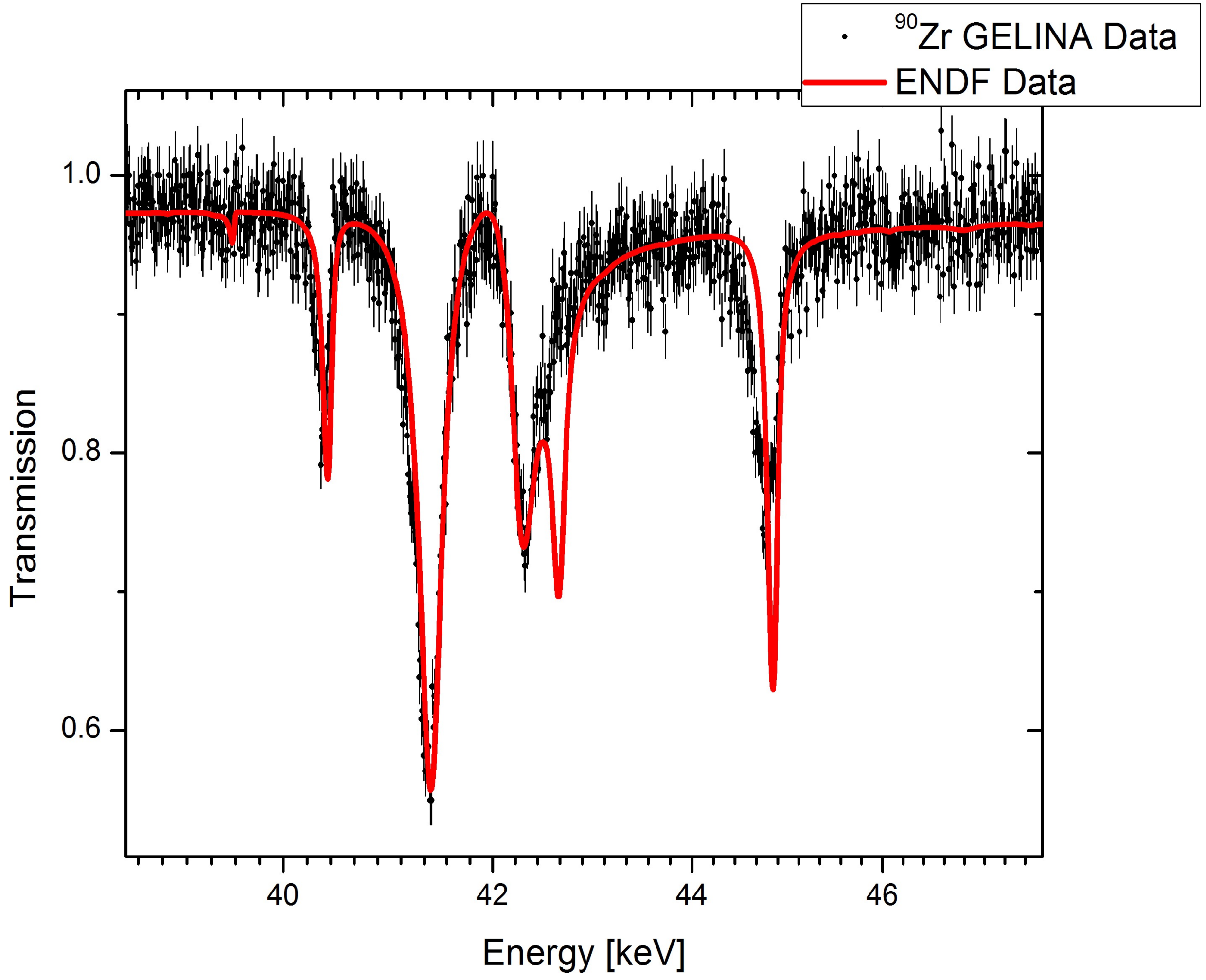
^{90}Zr transmission compared to ENDF





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 ^{90}Zr transmission and (n,γ) data in FY2021	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, ^{90}Zr transmission	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	^{90}Zr transmission	X-section, transmission
Data testing	Data ready for evaluation	Data ready for evaluation	Data ready for evaluation	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 Final stages	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
- Jan Heyse, EC-JRC Geel
- Ruud Wynats, EC-JRC Geel
- Clint Ausmus, Mike Zach, ORNL
- Marco Pigni, ORNL
- Chris Chapman, ORNL
- Jordan McDonnell, ORNL
- Jesse Brown, ORNL

Acknowledgments

This work was supported by the DOE Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the US Department of Energy

Additionally, this work was also supported by JRC-Geel and the European Union