

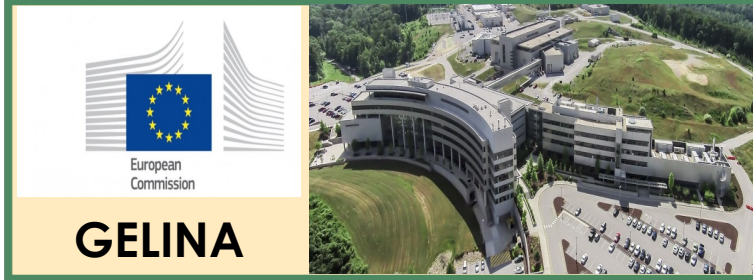
# ORNL Neutron Cross Section Measurements of Zr-isotopes ---NCSP Task ND-1 + ND-3

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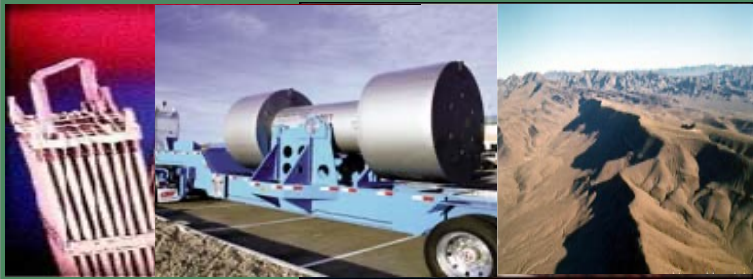
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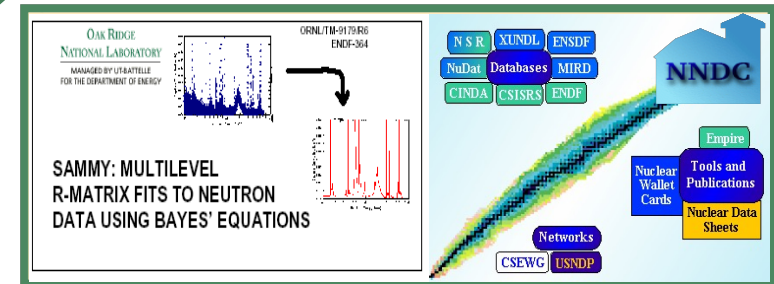
## Basic Science Cross Section



## Applications



## Cross Section Evaluations



ORNL ND  
Support  
for NCSP  
Applications

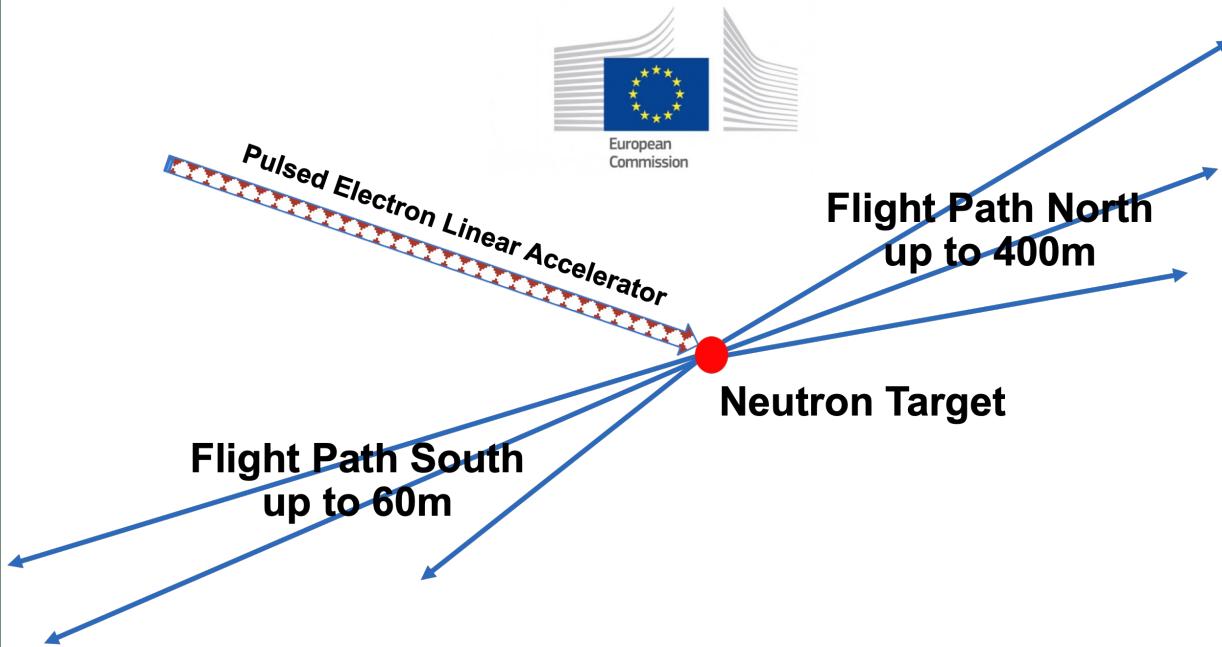
## Integral Experiments



## Computational Modeling and Processing



ND testing and adjustments



Pulse width	: 1 ns
Frequency	: 40–800 Hz
Average current	: 4.7–75 $\mu$ A
Neutron intensity	: $1.6 \cdot 10^{12}$ – $2.5 \cdot 10^{13}$ n/s

# 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

# Neutron production



- $e^-$  accelerated to  $E_{e^-, \max} \approx 140 \text{ MeV}$
- $(e^-, \gamma)$  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
- **NCSP-Y12 build a new neutron production target for GELINA**

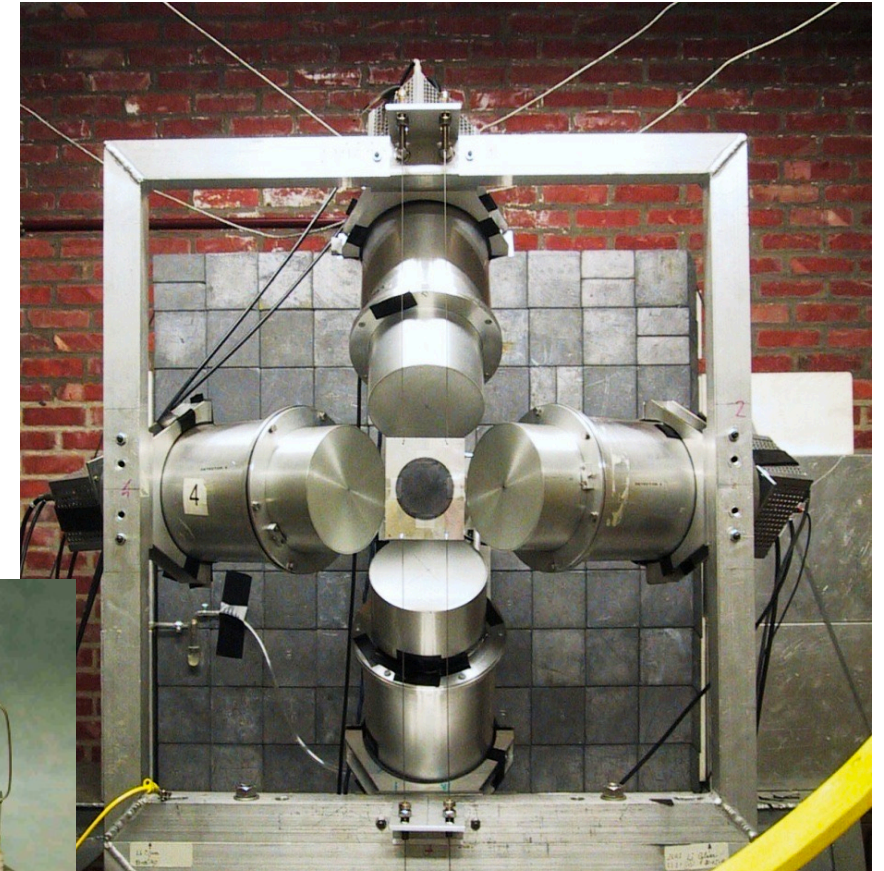
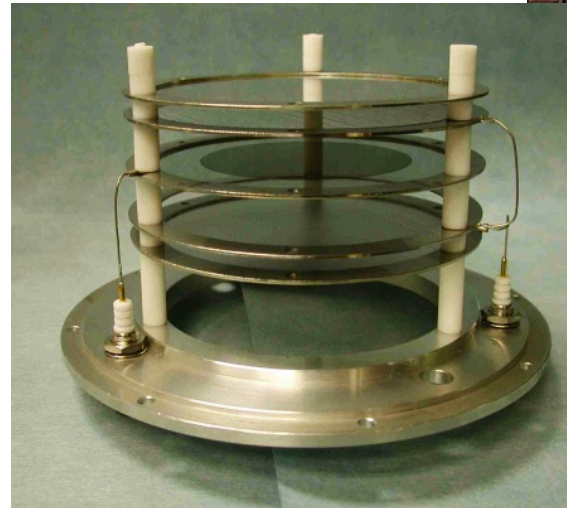
# Capture cross section measurements at GELINA

## Total energy detection principle

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

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

L = 10 m, 30 m, and 60 m



# Total cross section/transmission measurements

Sample and background filters

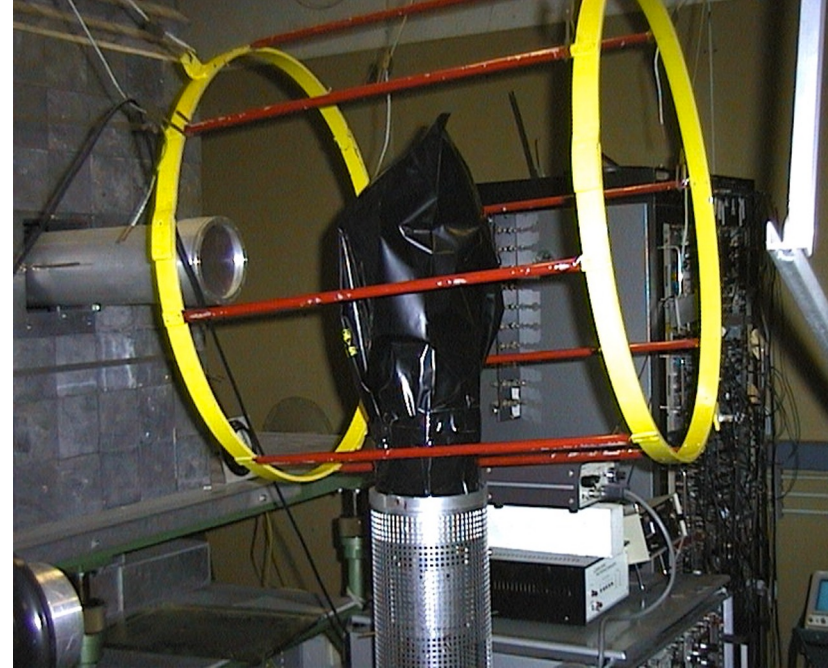


Detector stations

Moderated: L = 30 m, 50 m (100 m, 200 m)

Fast: L = 400 m

Detector



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

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

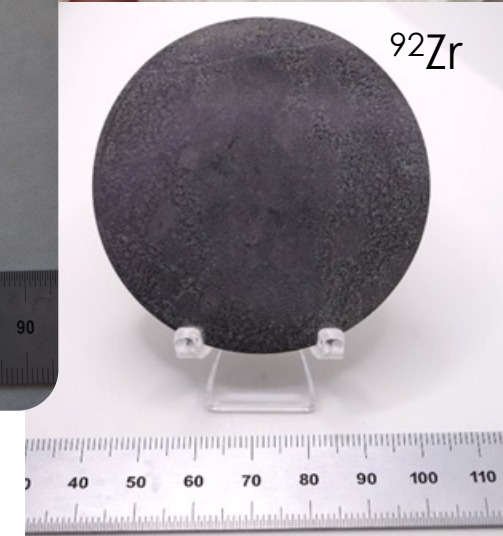
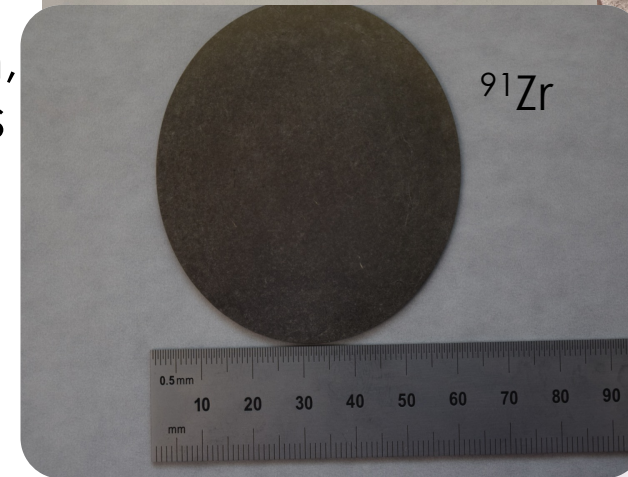
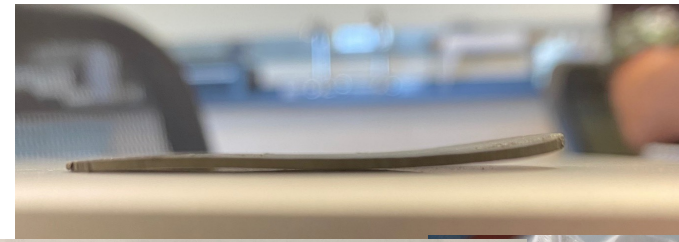
$$T = \frac{C_{in}}{C_{out}} \cong e^{-n\sigma_{tot}}$$

# Isotopic Zr Campaign (ORNL-ND1)

- Goal: improve accuracy of evaluated cross sections for  $^{90,91,92,94}\text{Zr}$ ; at least the 4 major isotopes should be measured.
- Good high-resolution Oak Ridge National Laboratory (ORNL) transmission (total cross section) data for separated isotopes are available; data were retrieved from the Jack Harvey archive of ORELA experiments. Experiments were performed in the seventies using metallic samples at 80 and 200m FP length.
- Therefore, only neutron capture experiments must be performed using isotopically enriched samples
- Transmission and  $(n,\gamma)$  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

# $^{90,91,92}\text{Zr}$ 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 sometimes not very uniform and warped, but for capture experiments, this is not a real problem
- However, transmission samples should be uniform, but with our good ORELA transmission data, this is not an issue
- But the nonuniform transmission data could be used to test analysis program data correction procedures; the results can be compared to existing ORELA transmission data

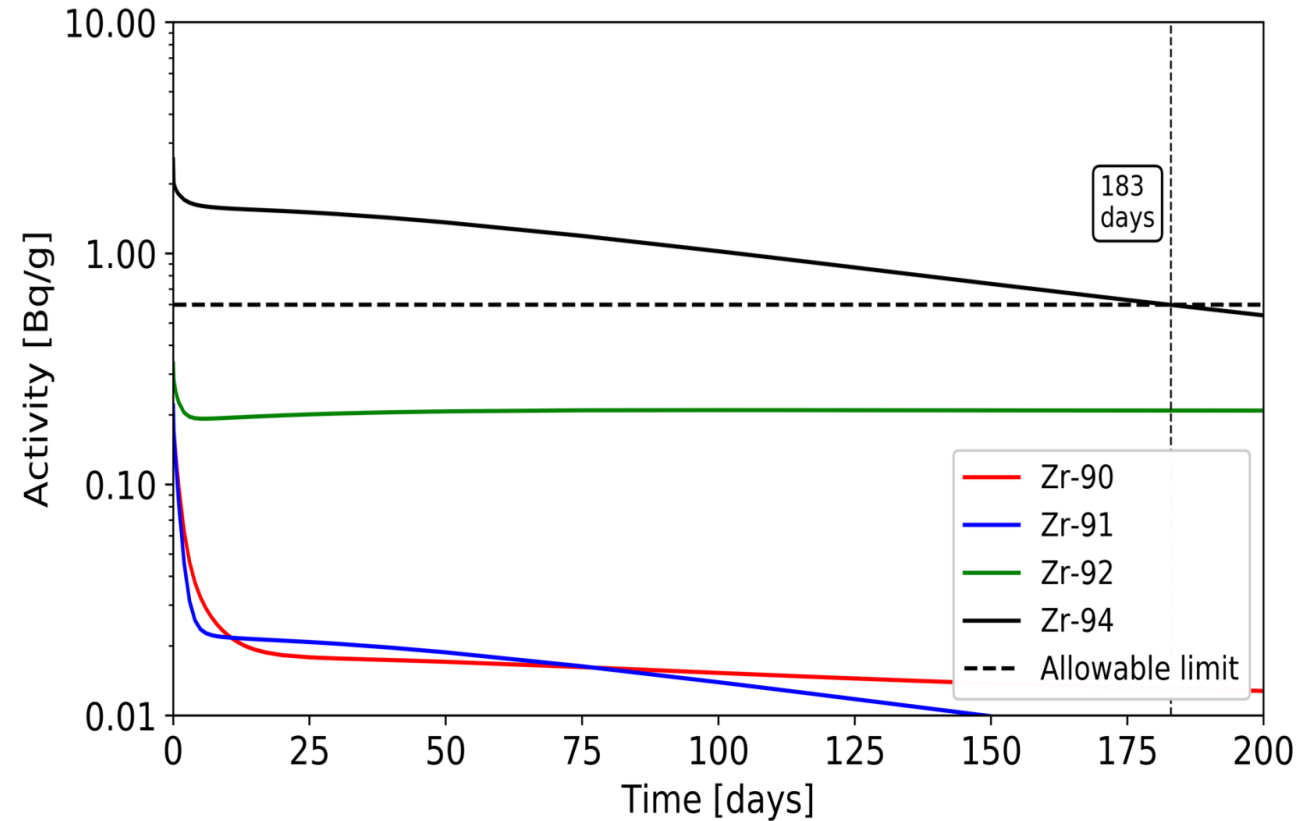




# Zr-92,94 Isotope Leasing (ORNL-ND3)

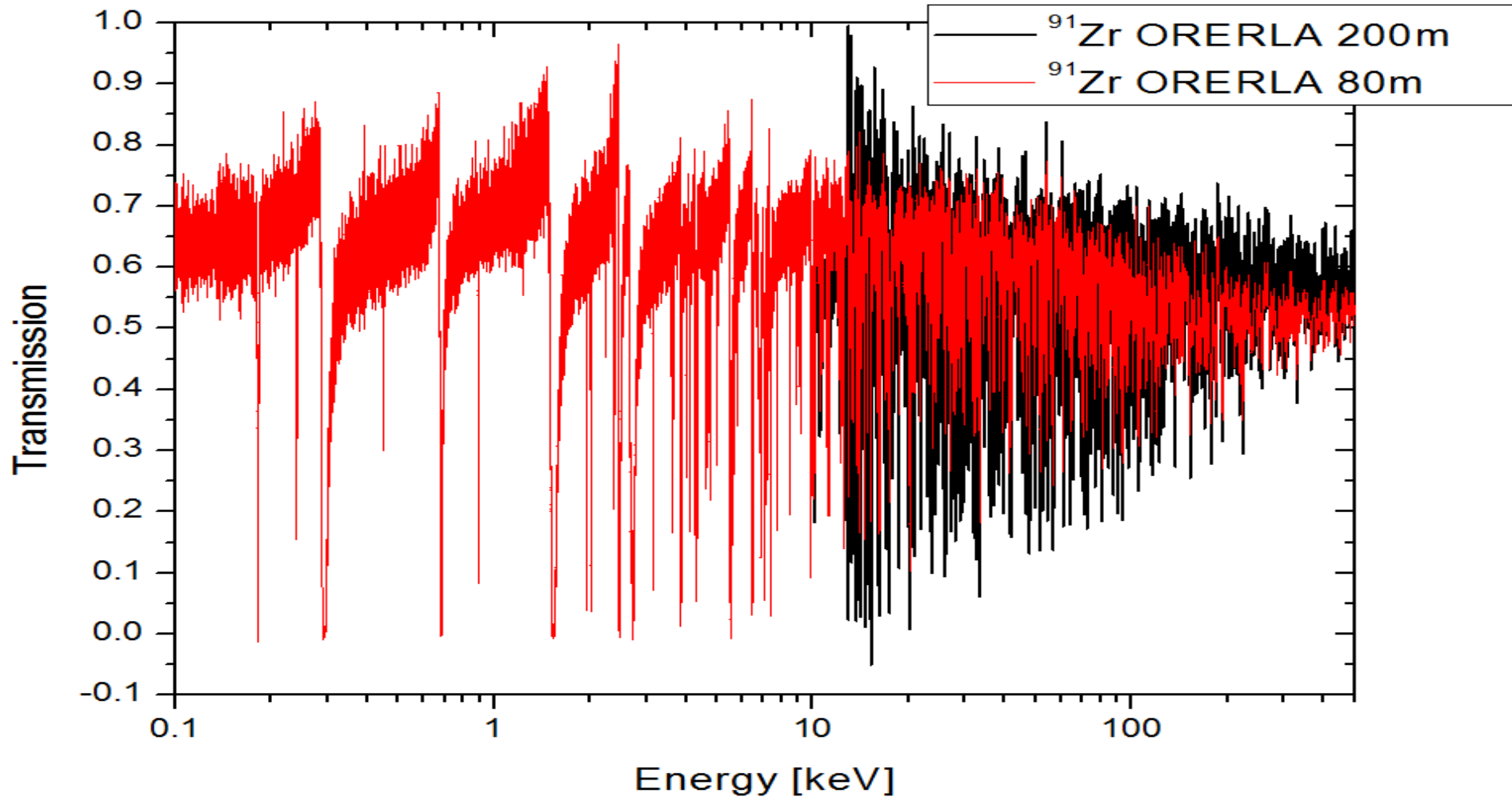
- Zr-92 Sample delivered to JRC March 2023

- Metallic Zr
- Enrichment: 95%
- $n = 0.00363$  at/b
- FP: 60 m
- $C_6D_6$  capture system
- Sample thickness: 0.88mm



- Zr-94 Sample lease approved by DOE; sample is in production

# Old ORNL $^{91}\text{Zr}$ data



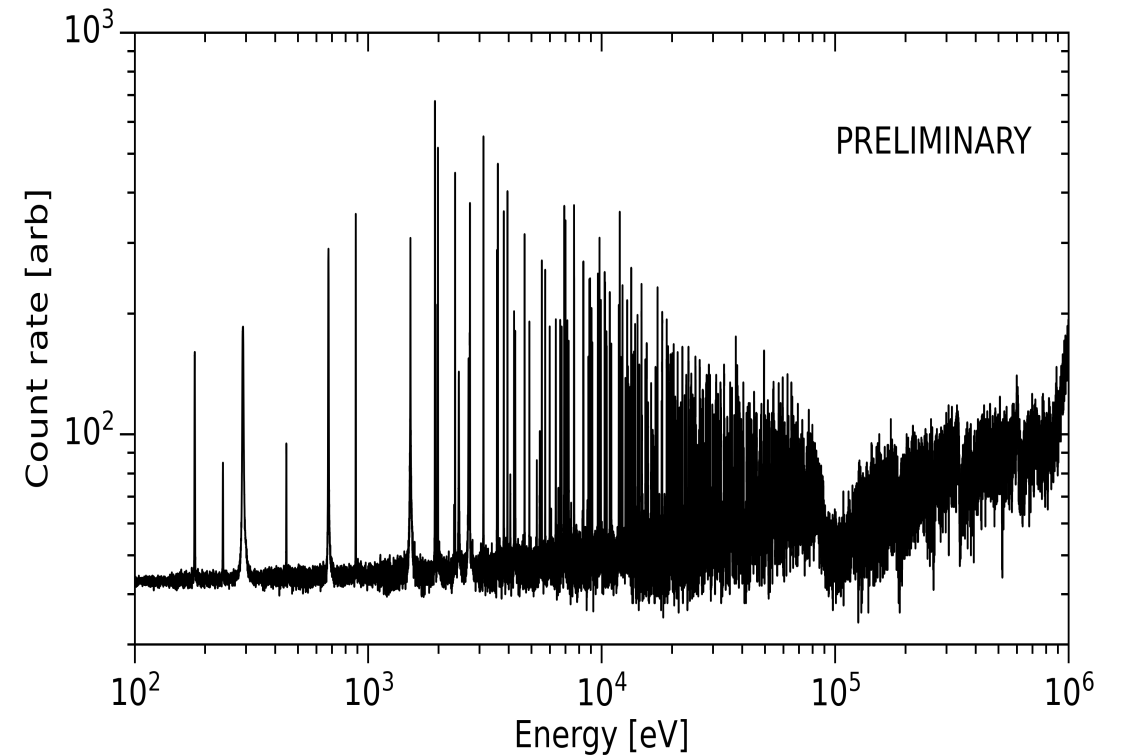
Resonance structure is visible above 100 keV, factor 5 more than previous evaluations. 80m data obtained using a  $^6\text{Li}$ -detector, 200m with NE110- detector

# ORNL measurement activities for Zr at JRC-Geel

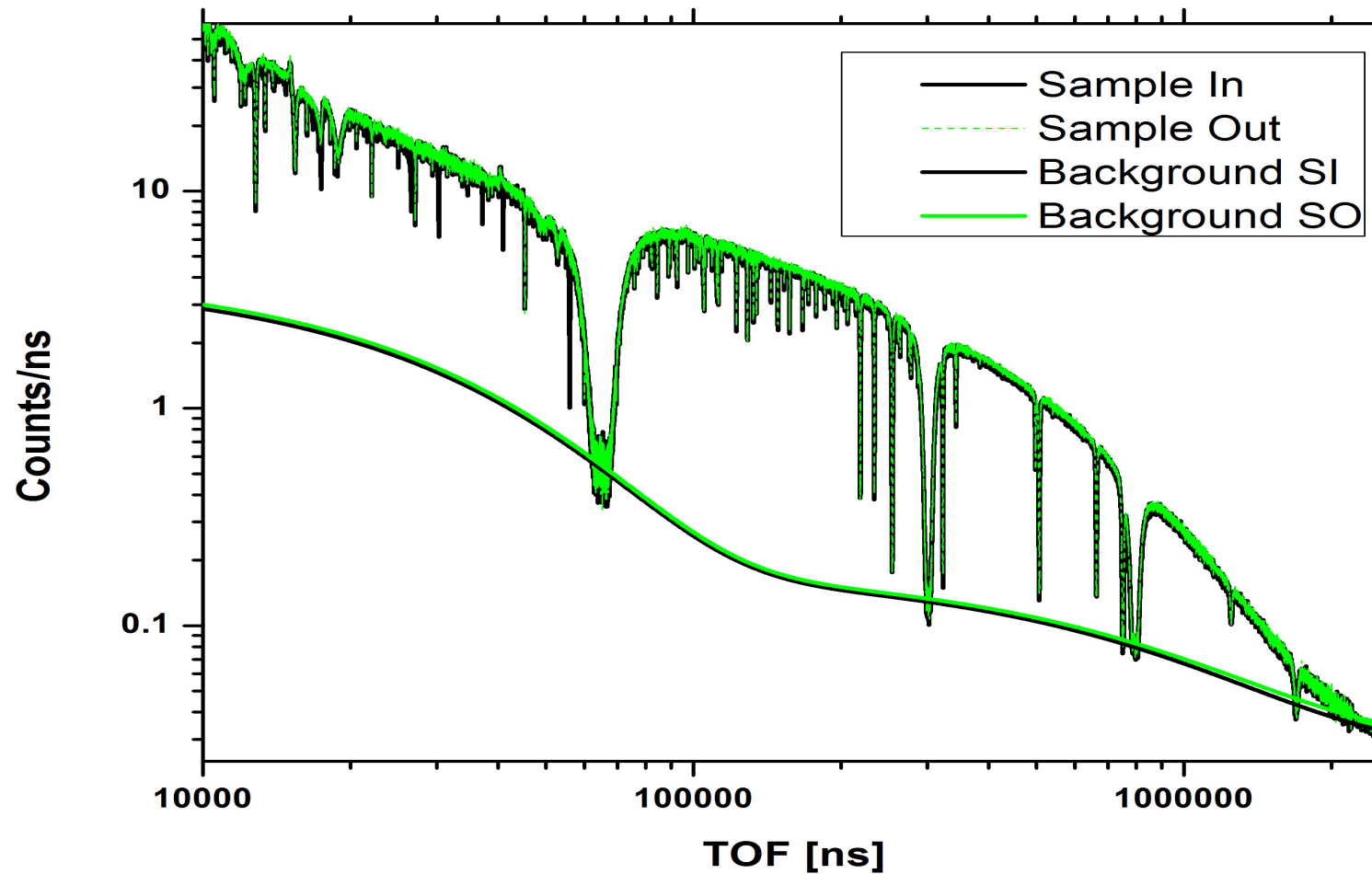
- No **Zr-92** experiments performed before the summer break in 2023 due to budget constraints to operate GELINA and performance issue of the GELINA electron gun.
- After start up in late summer the RF window cracked, no replacement is available and new windows need adapter to fit on old klystrons.
- Ordered parts in fall 2023 and repair is expected to finish in spring 2024.
  
- Data sorting and reduction for transmission Zr-91 experiments
- Data sorting for Zr-91 capture experiments, problems with flux monitor

# Zr-91 capture data

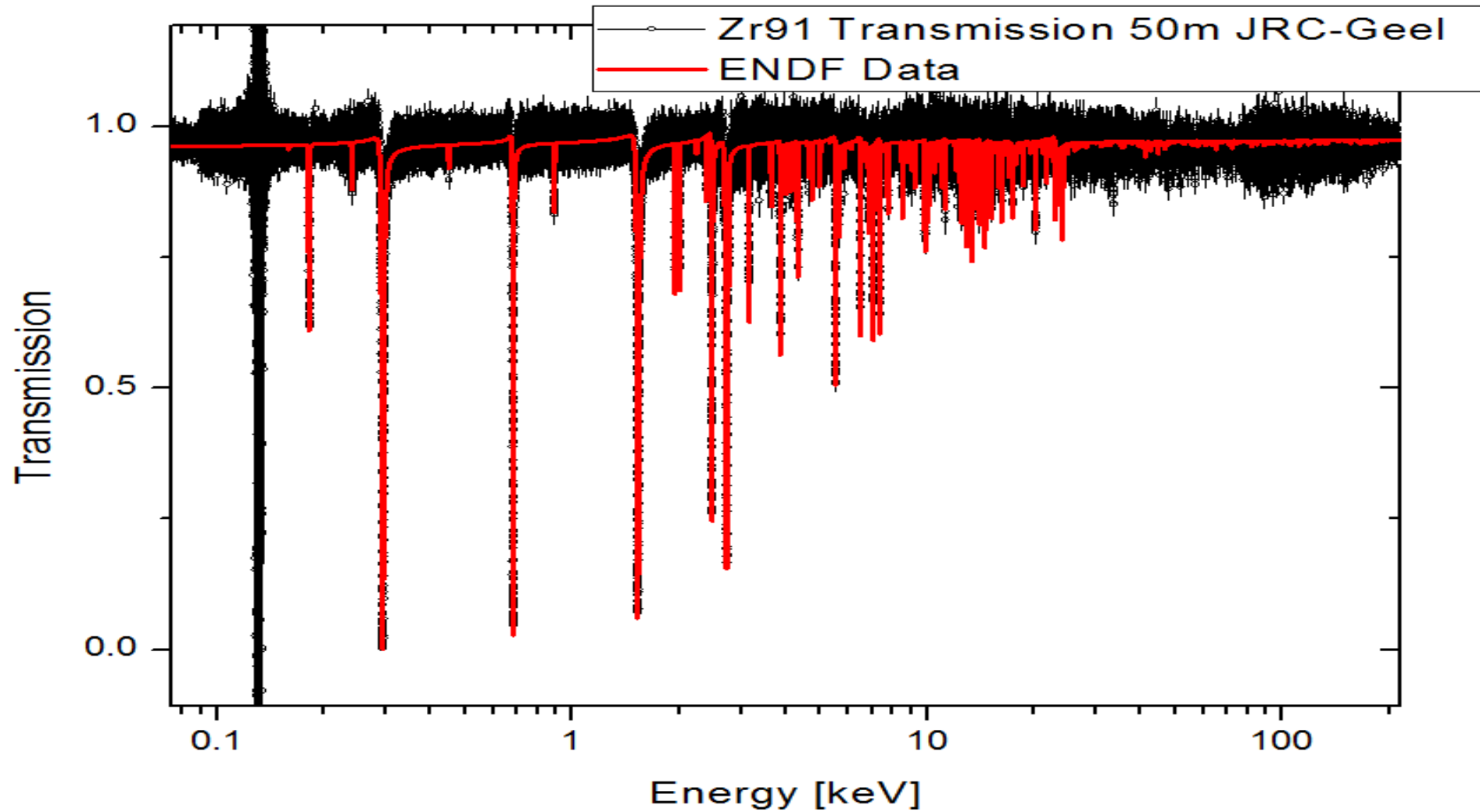
- During the capture experiment the n-flux monitor malfunctioned
- Part of the flux data was salvaged. This data was compared to a flux spectrum from previous Zr experiments
- It was determined the shape of the flux spectrum from Zr90 and Zr91 runs did not change. The Zr90 flux and can be used for the Zr91 data reduction.



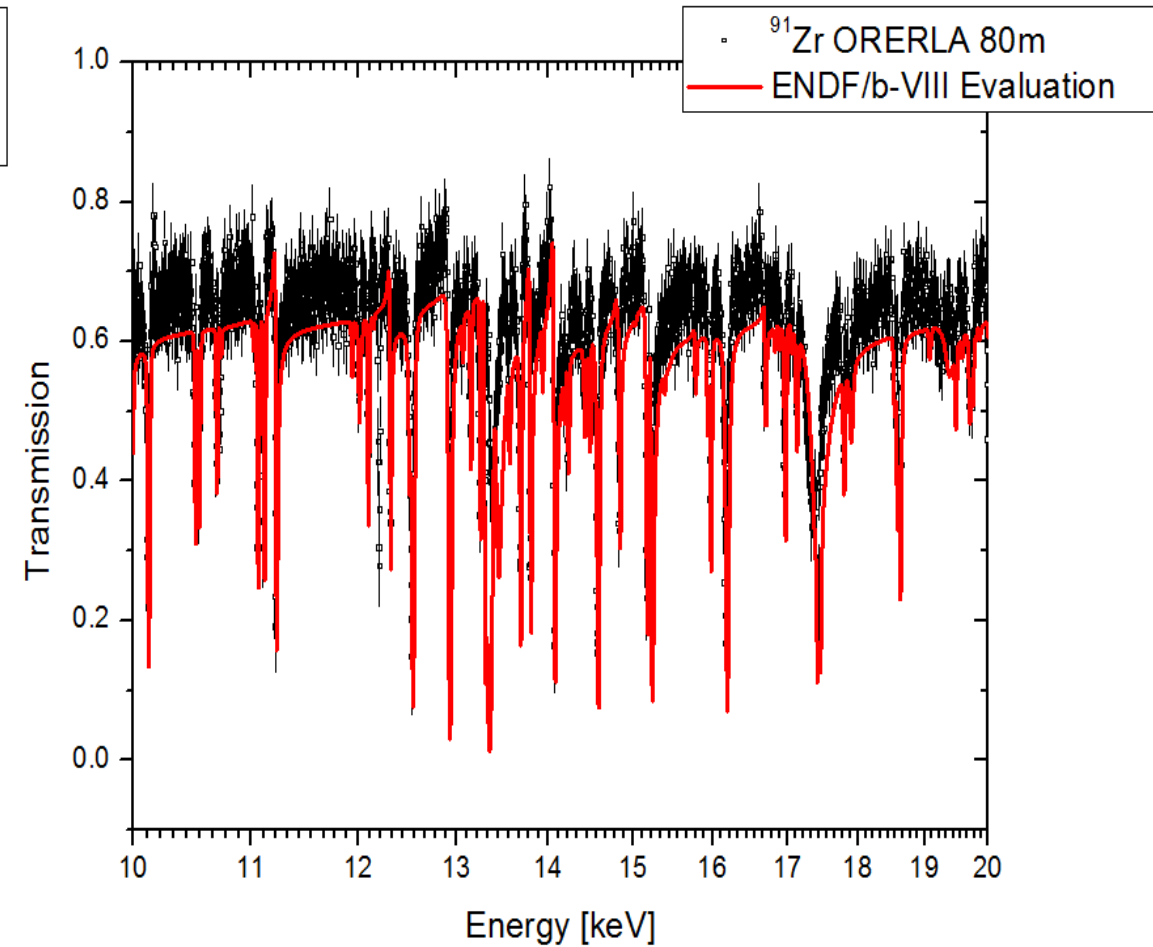
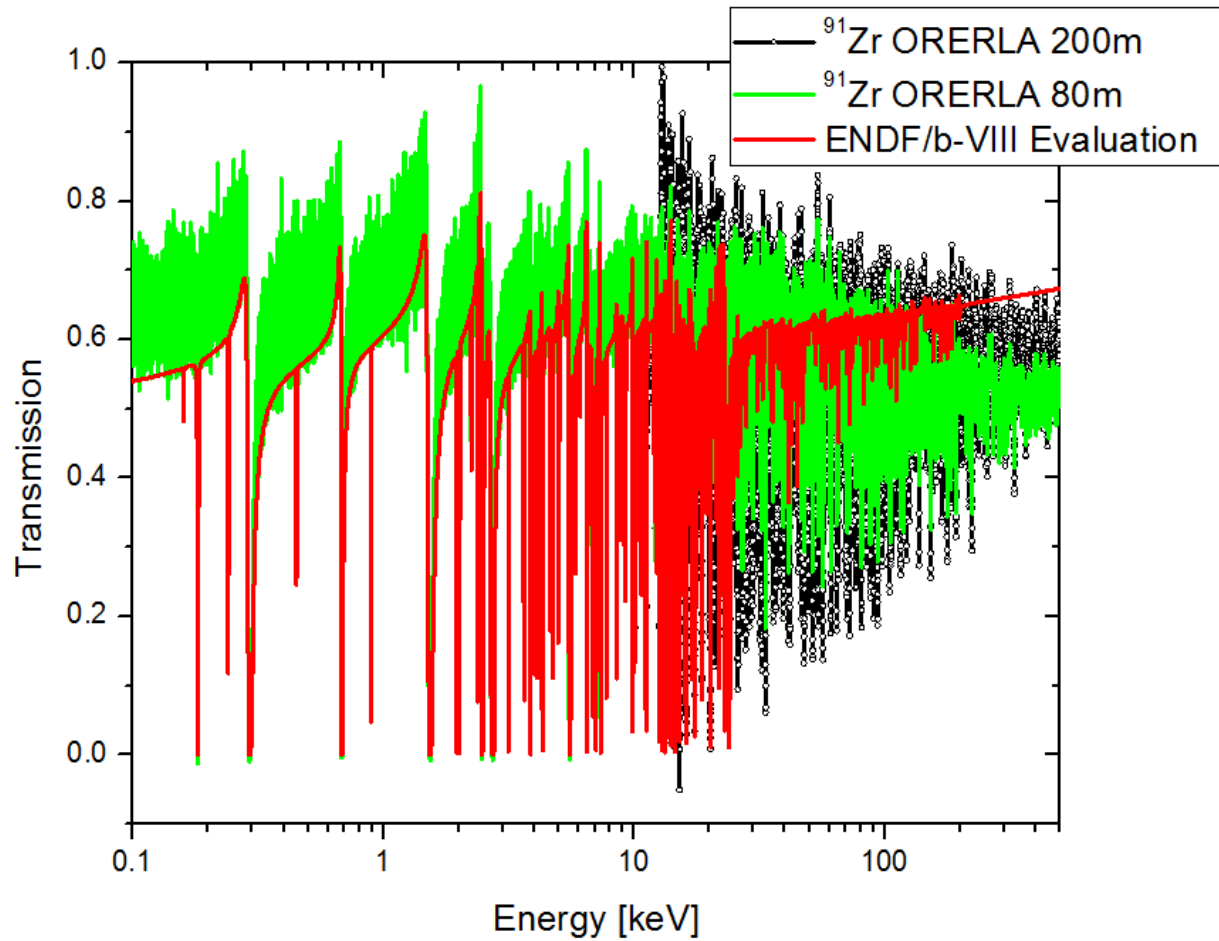
# Background determination in transmission using black resonance filters



# $^{91}\text{Zr}$ transmission compared to ENDF



# ORELA $^{91}\text{Zr}$ transmission compared to ENDF



# Status of NCSP experiments at EC-JRC Geel

	W	Cu	Ca	Ce	V	Zr	La
<b>Sample</b>	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 <sup>90,91,92,94</sup> Zr 2016–2017 2021–20	Nat La metallic disks  2017–2018
<b>Experiments GELINA</b>	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, <sup>142</sup> Ce experiments completed	60 m (n,γ) transmission	Nat Zr 60 m (n,γ) + transmission <sup>90,91</sup> Zr transmission and (n,γ) data	60 m (n,γ) transmission
<b>Data sorting</b>	Finished 60 m + transmission	Finished 60 m	Finished 60 m transmission	Finished for thin and thick sample, <sup>142</sup> Ce data sorting finalized	Finished for thin and thick sample	Finished for thin and thick natural sample, <sup>90</sup> Zr (n,γ)+ transmission, <sup>91</sup> Zr transmission + n,γ)	Finalized
<b>Reduced to cross section</b>	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 <sup>142</sup> Ce data	Thin X-section 0.35 and 2 mm, transmission	<sup>90</sup> Zr transmission + (n,γ) <sup>91</sup> Zr transmission	X-section, transmission
<b>Data testing</b>	Data ready for evaluation	Data ready for evaluation	Data ready for evaluation	Data ready for evaluation	Data ready for evaluation	In progress	Data ready for evaluation
<b>Analysis and evaluation</b>	Finalized and submitted to National Nuclear Data Center	Finalized and submitted to National Nuclear Data Center	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 RPI PhD Student	In progress



## People supporting JRC experiments and evaluations

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