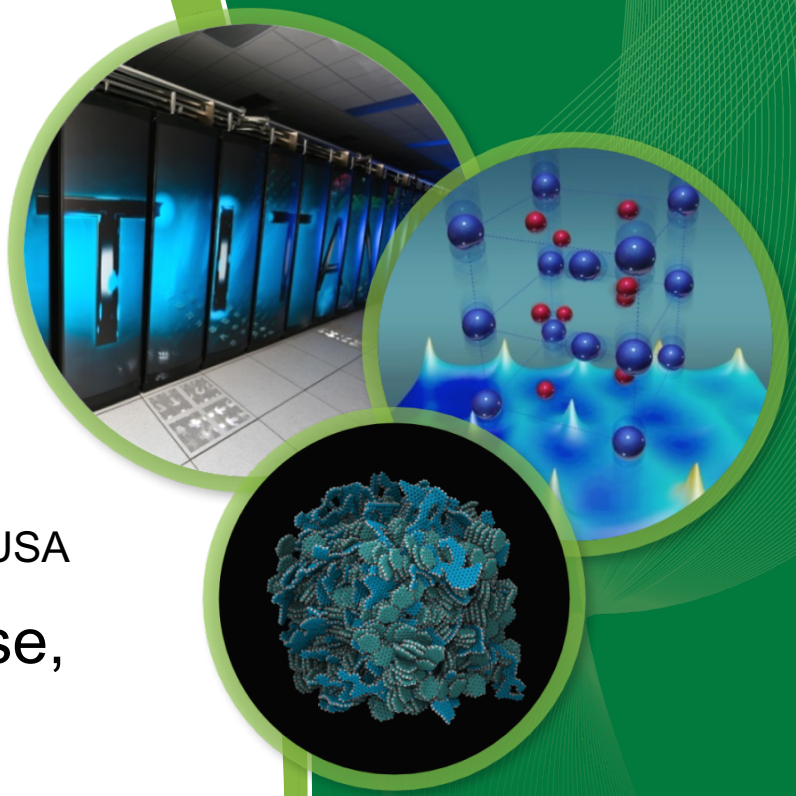
ORNL neutron cross section measurements for the US Nuclear Criticality Safety Program



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OAK RIDGE National Laboratory

Resonance region nuclear data work for NCSP

- Objective: Provide measured, evaluated resonance-region cross section data to address priority nuclear data needs for NCSP
- Vision: Address multiple nuclear data 5- and 10-year goals identified in the NCSP vision
- Final product: Rigorous ENDF/B resonance evaluations produced from cross section measurements (new/old) and analyses
- Last year's measurement work effort focused on vanadium, cerium and zirconium, which were differential nuclear data needs identified by NCSP Nuclear Data Advisory Group (NDAG)

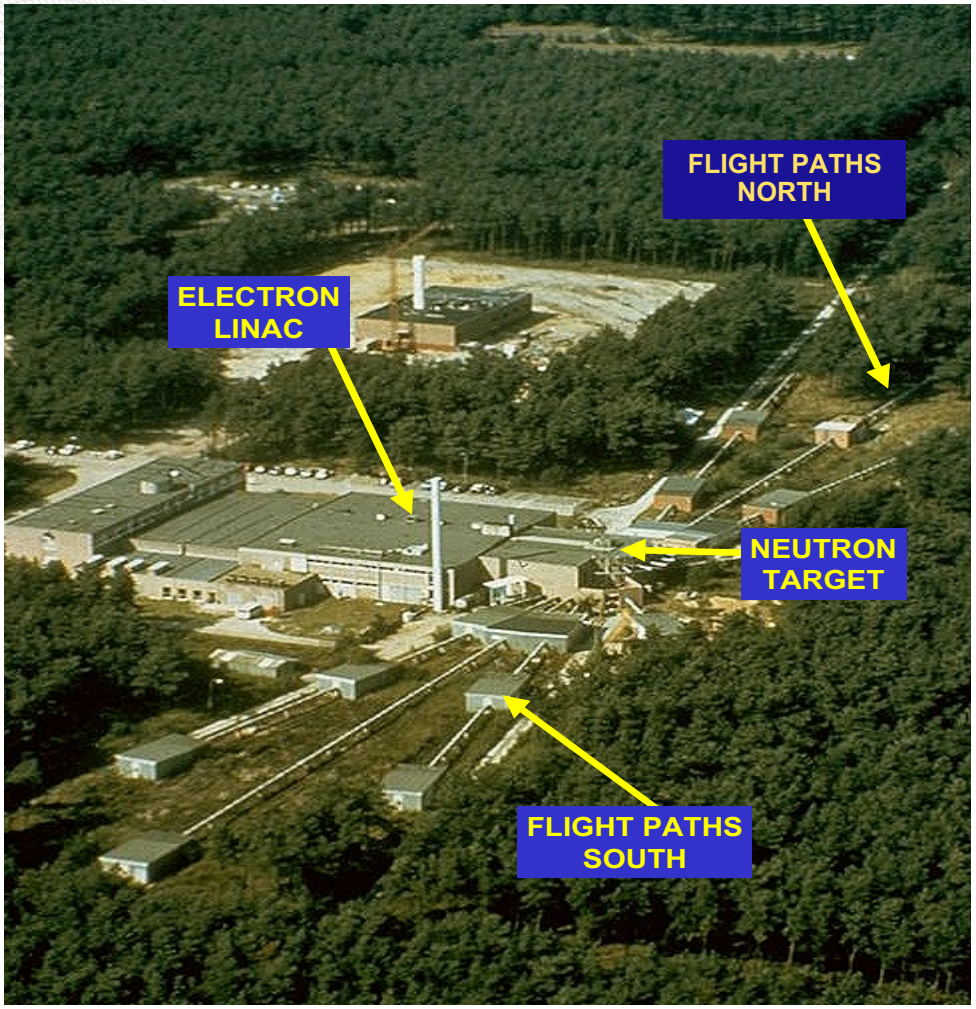
NCSP Five-Year Plan

Nuclear Data

Priority Needs */ Additional Needs		Thermal scattering (BeO, HF, D_2O, SiO_2, CH_2, C_2F_4, $C_5O_2H_8$, etc.), ^{239}Pu, Cr, ^{237}Np, Pb, ^{55}Mn, Ti, ^{240}Pu / ^{233}U, Th, Be, ^{51}V, Zr, F, K, Ca, Mo, Na, La								
Completed Evaluations (FY)		Minor Actinides (13), SiO_2 (12), ^{55}Mn (12), $^{180,128,183,184,186}W$ (14)								
	Materials	Pre FY2015	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	Post-FY2021
Measurements	Calcium (Ca)									
	Cerium (Ce)									
	Copper (Cu)									
	Iron (Fe)									
	Lucite ($C_5O_2H_8$)									
	Tantalum (Ta)									
	Strontium (Sr)									
	Tungsten (W)									
	Vanadium (V)									
	Zirconium (Zr)									
	Polyethylene (CH_2)	H_2O / CH_2								
	Materials	Pre FY2015	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	Post-FY2021
Complete Evaluations	Calcium (Ca)									
	Cerium (Ce)									
	Cobalt (Co)									
	Copper (Cu)									
	Dysprosium (Dy)									
	Gadolinium (Gd)									
	Iron (Fe)									
	Lead (Pb)									
	Nickel (Ni)									
	Oxygen (O)									
	Rhodium (Rh)									
	Plutonium-239									
	Tantalum (Ta)									
	Strontium (Sr)									
	Tungsten (W)									
	Uranium-235									
	Uranium-238									
	Vanadium (V)									
	Zirconium (Zr)									
	Hydrofluoric Acid									
	Lucite ($C_5O_2H_8$)									
	Polyethylene (CH_2)									
		ORNL		RPI		LANL		LLNL/NCSU		

- Requests for additional IE measurements: Ni, Mo, Cr (Fe-Cr alloys), Mn in intermediate energy range (VNIITF, NCERC).
- Request for measurements and evaluation of angular distributions at high energy for Cu.
- Continuing need for thermal scattering data.

*Note: work has been completed for some priority needs (e.g., ^{55}Mn, Ti, and Cr), and these isotopes/nuclides are maintained on the list for reference. Furthermore, the table represents the list of materials that can be addressed during the next five years under the current budget target. The additional priority needs will be addressed beyond the next five years.



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)
- The measurement stations have special equipment to perform the following:
  - Total cross section measurements
  - Partial cross section measurements

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

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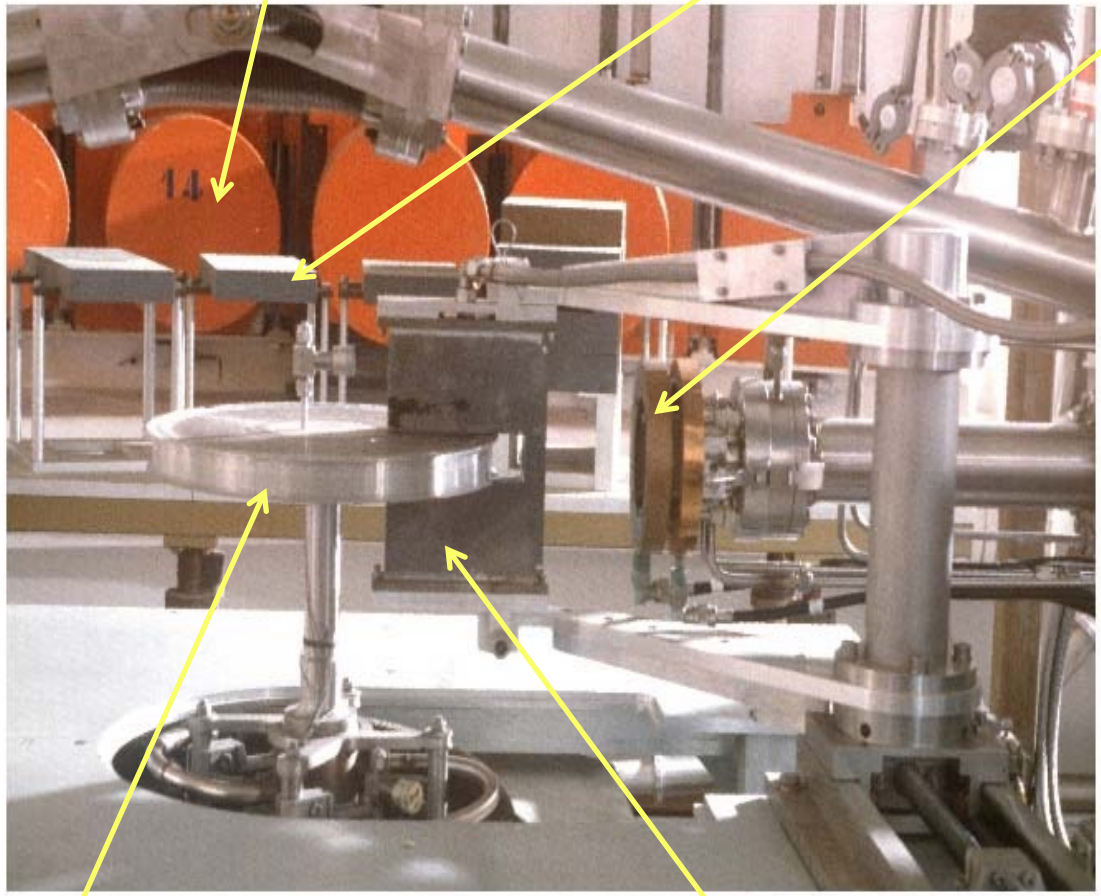
Neutron production



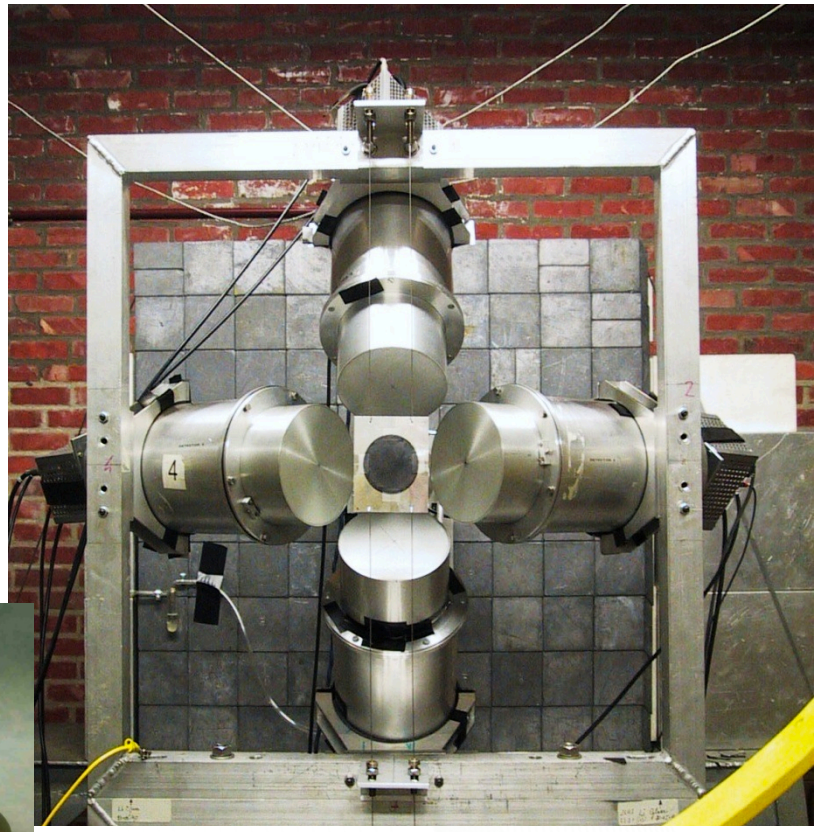
- e^- accelerated to $E_{e-,max} \approx 140$ MeV
- (e^-, γ) Bremsstrahlung in U-target (rotating and cooled with liquid Hg)
- (γ,n) , (γ ,f) in U-target
- Low energy neutrons by water moderator in Be-canning

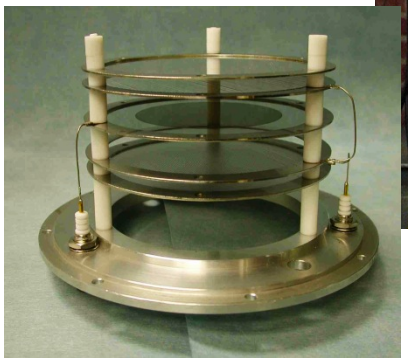
Capture cross section measurements at GELINA

Total energy detection principle

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

L = 10 m, 30 m, and 60 m

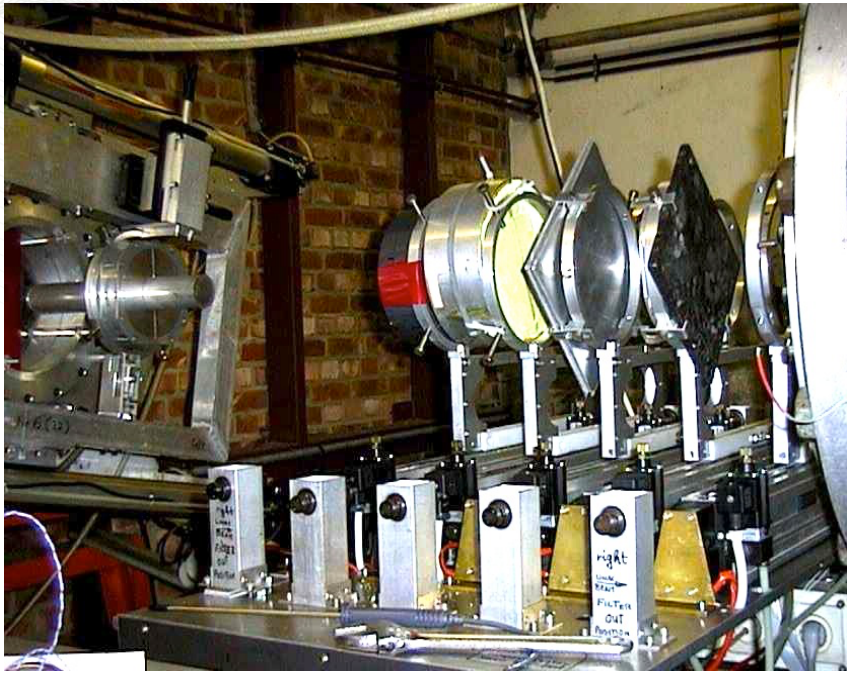




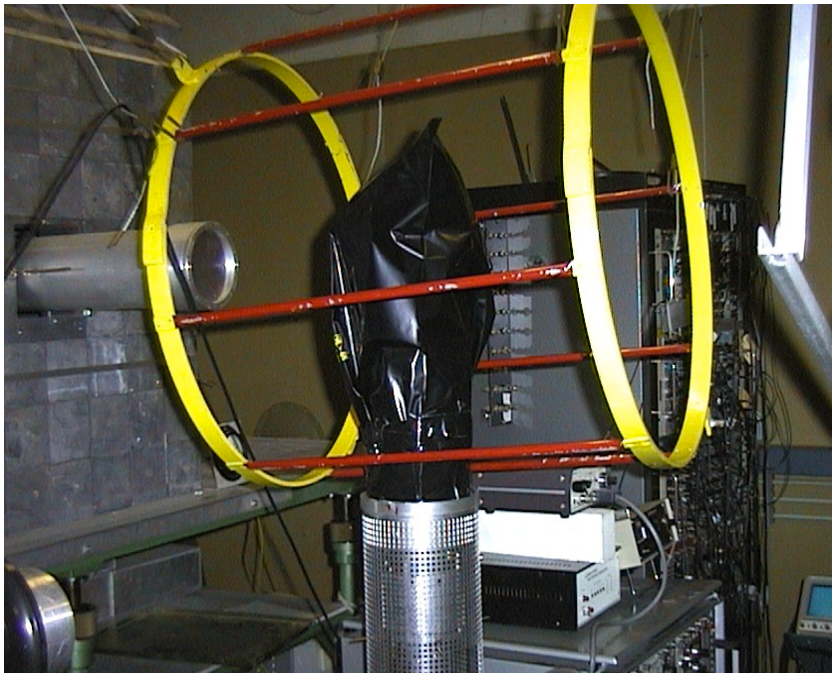
$$Y_{exp} = N\sigma_{\varphi}\frac{C_w - B_w}{C_{\varphi} - B_{\varphi}}$$

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

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

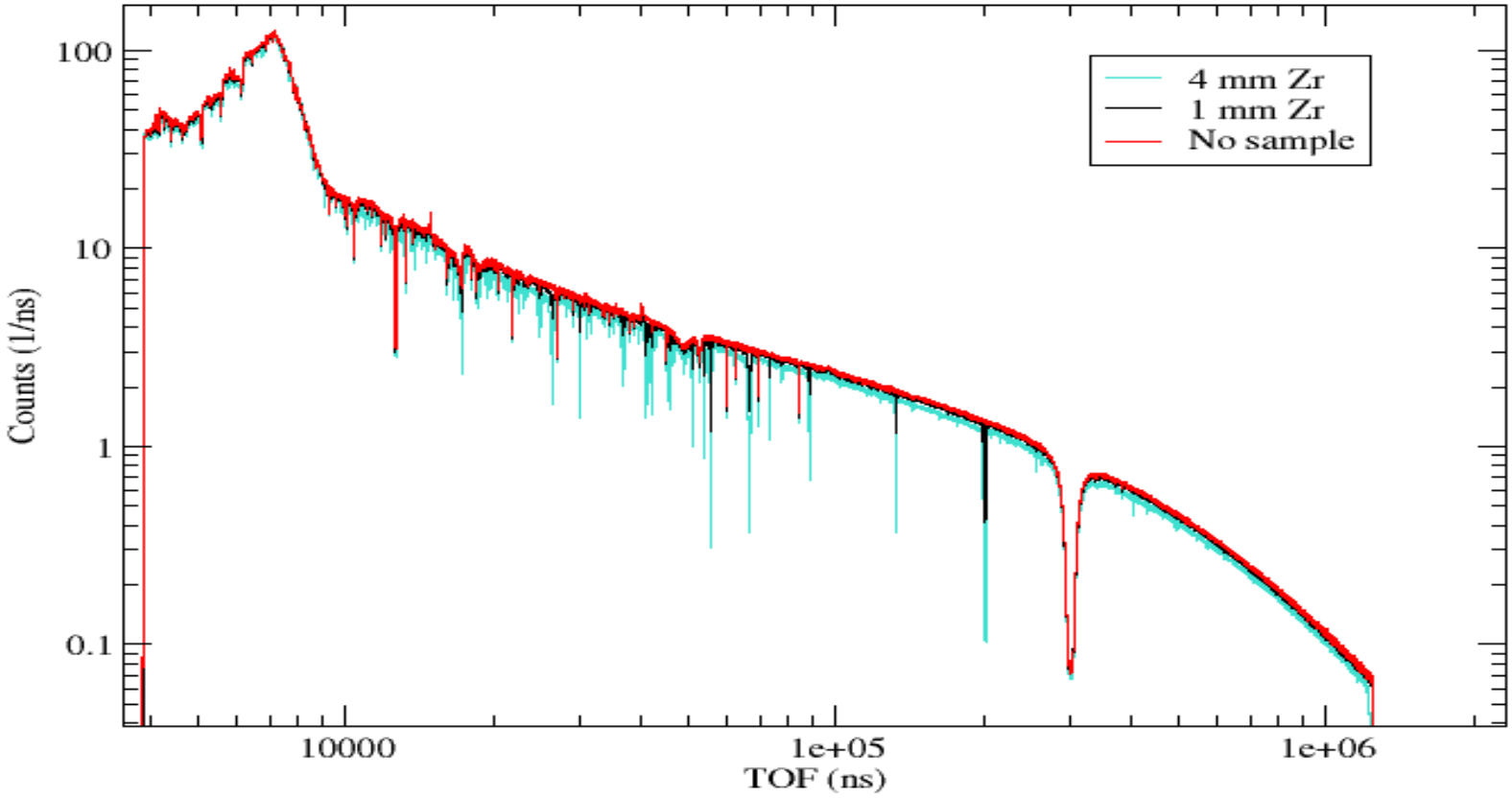
ORNL measurement activities for Zr

- Zr has 5 stable isotopes; at least 4 major isotopes should be measured
- Good high resolution 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
- The new DOE lease policy might present a problem, especially regarding no-RAD-added with the ^{93}Zr half-life of 1.5 E6a

ORNL measurement activities for Zr

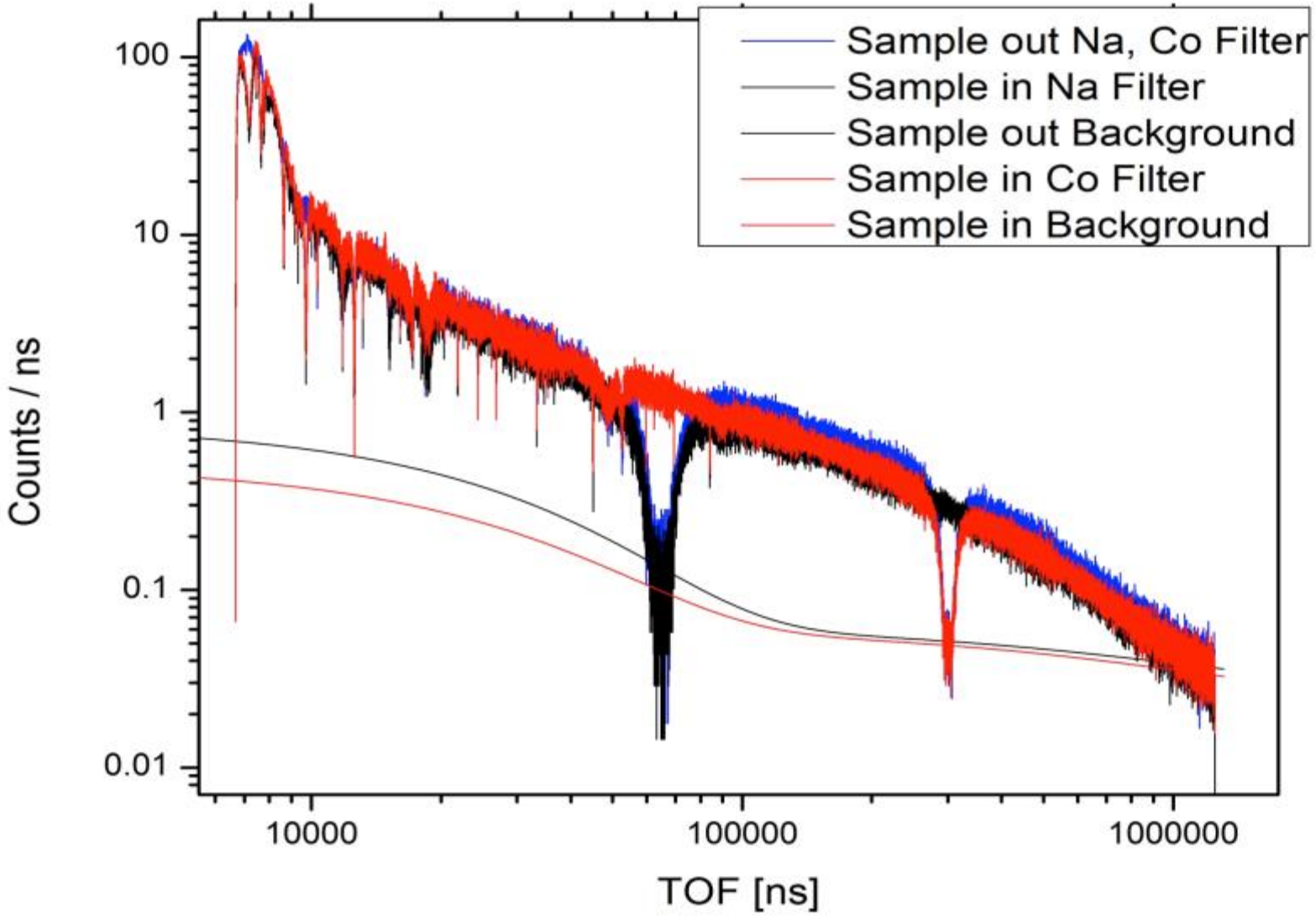
- The current ORNL approach is to start with natural Zr neutron capture and transmission using metallic samples of different thicknesses
- The combination of the natural sample capture data with the total cross section of the separated isotopes will help to obtain already parameters for the strong capture resonances
- A natural sample is always a good check for the performance of the resonance parameters obtained from the separated isotopes experiments

ORNL measurement activities for Zr

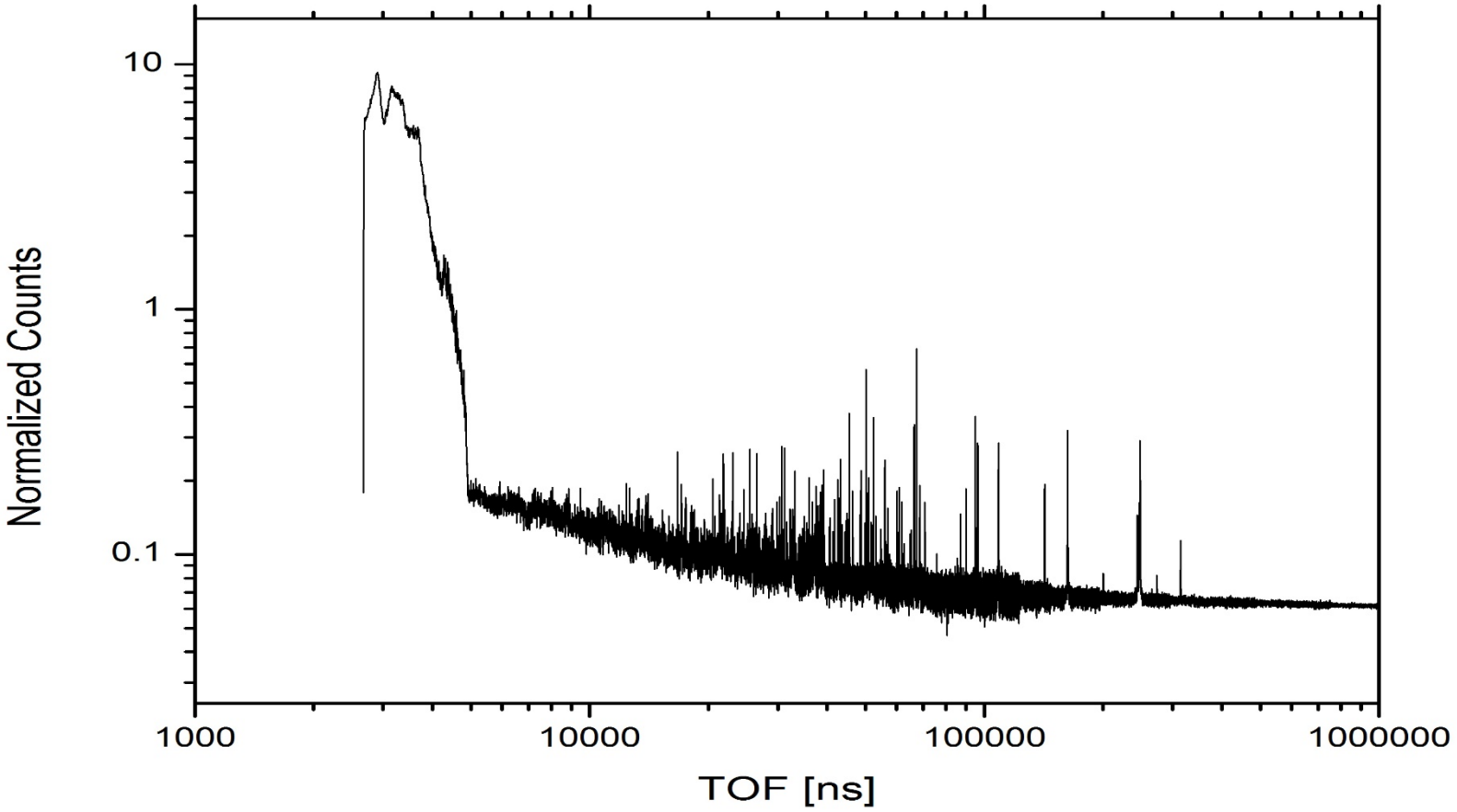


- Transmission experiments with different Zr samples are performed using the FP4, 50 m station
- Experiments are performed using different background filter combinations

Background determination in transmission using black resonance filters

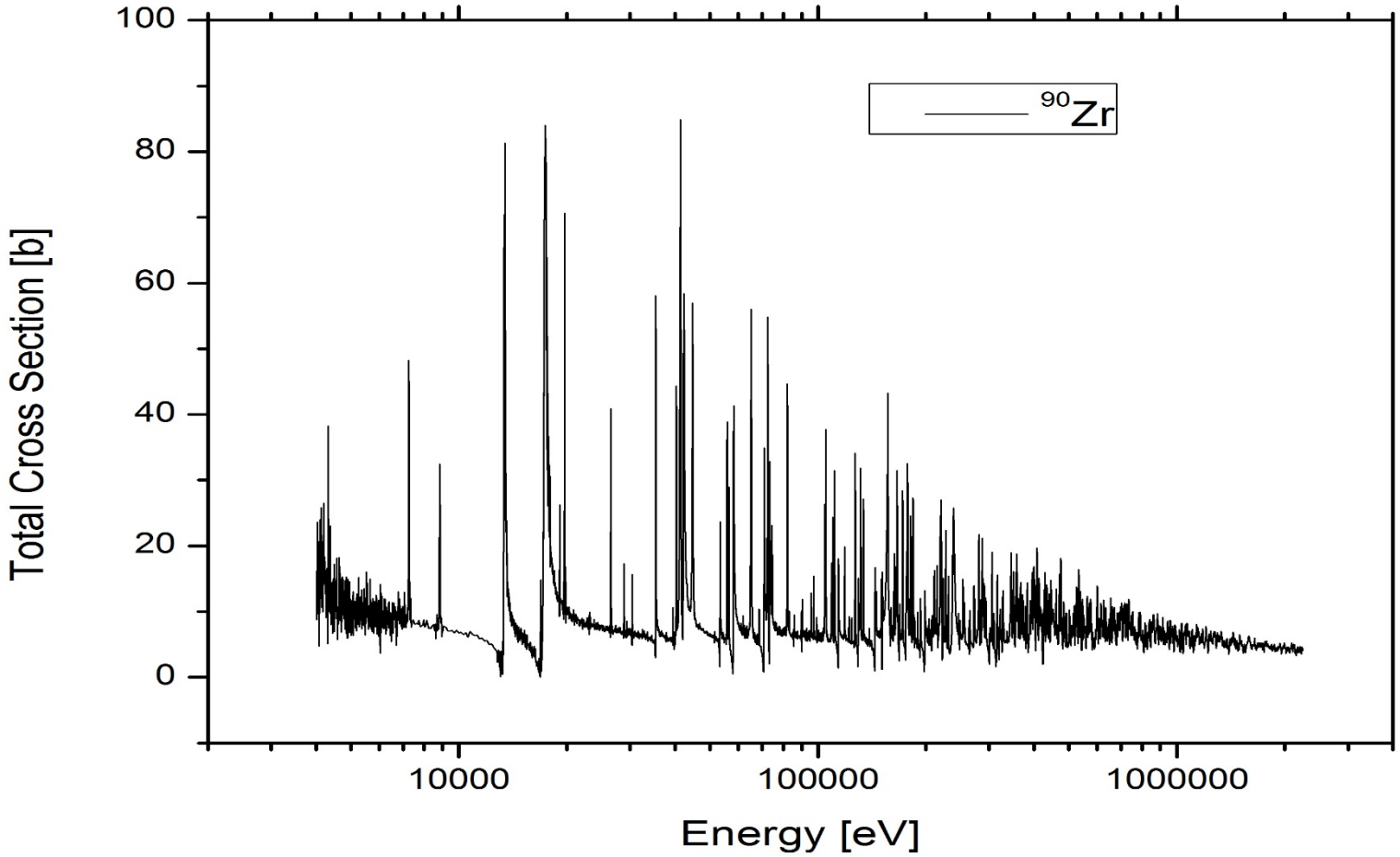


ORNL measurement activities for Zr (continued)



Neutron capture at FP14, 60 m

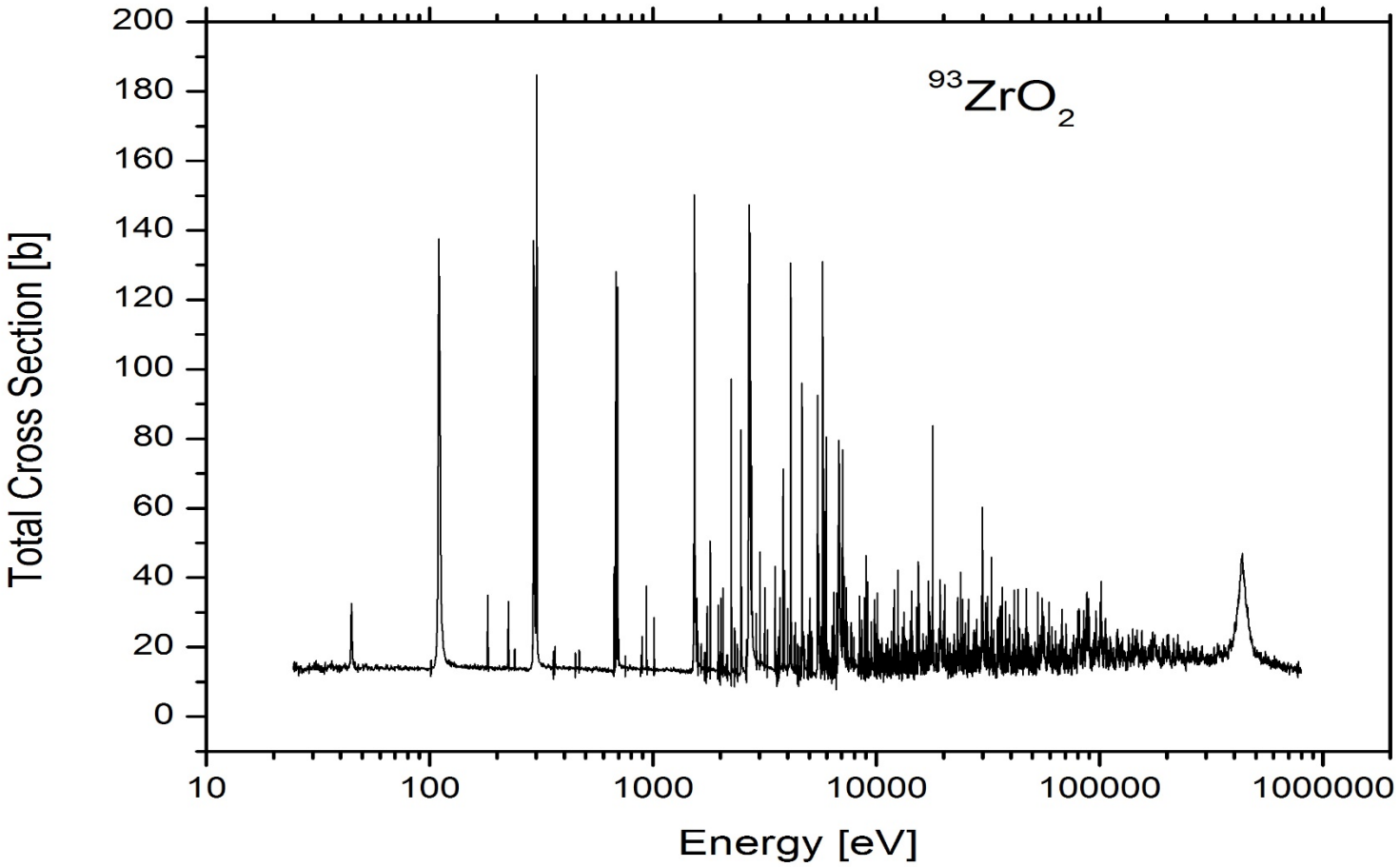
Old ORNL ^{90}Zr data



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

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

Old ORNL ^{93}Zr data



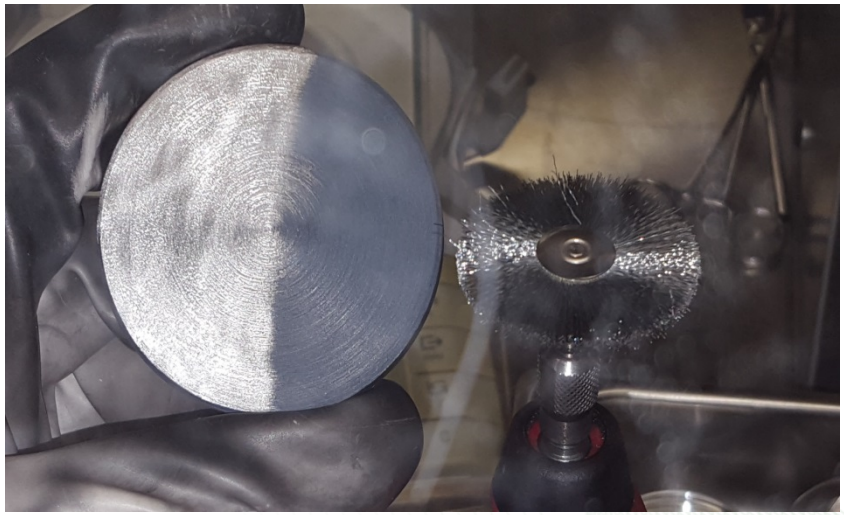
Total cross section of $^{93}ZrO_2$ resolved resonances well above 100 keV

ORNL measurement activities for lanthanum

- Natural La is 99.91% ^{139}La and 0.09% ^{138}La
- Measurements use metallic samples of different thickness
- Transmission experiments with different samples are performed using FP4, 50 m station
- Neutron capture experiments are performed at FP14, 60 m
- Experiments are made with different background filter combinations
- Capture and transmission experiments have been started

ORNL measurement activities for lanthanum

- La target delivered in oil
- Wiped free of mineral oil with ethanol and admitted into atmosphere glove box
- Shown with half the original oxide removed by steel wire brush



ORNL measurement activities for lanthanum

Status of NCSP experiments at EC-JRC Geel

	W	Cu	Ca	Ce	V	Zr
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 2014–2015	metallic disks 2015–2016	Nat Zr metallic disks ^{90,91,92,94}Zr 2016
Experiments GELINA	60m, 30m (n,γ) transmission	60m (n,γ)	60m (n,γ) transmission	Nat Ce 60m (n,γ) Nat Ce transmission ^{142}Ce sample problems	60m (n,γ) transmission	Nat Zr 60m (n,γ) + transmission started ^{90,91,92,94}Zr sample problems
Data sorting	finished 60m + transmission	finished 60m	finished 60m transmission	finished for thin and thick sample	finished for thin and thick sample	
Reduced to cross section	X-section, transmission	X-section	X-section transmission 0.6, 1.0, 5 cm samples	2mm X-section 2mm transmission 10mm transmission	thin X-section 0.35 and 2mm transmission	
Data testing	Data ready for evaluation	Data ready for evaluation	Data ready for evaluation	In progress	In progress	
Analysis and evaluation	Finalized and submitted to NNDC	Finalized and submitted to NNDC	Finalized and submitted to NNDC	Started		

People Involved in the Experiments

- Peter Schillebeeckx, EC-JRC Geel
- Carlos Paradela, EC-JRC Geel
- Stefan Kopecky, EC-JRC Geel
- Peter Siegler, EC-JRC Geel
- Ruud Wynats, EC-JRC Geel
- Clint Ausmus, ORNL

People Involved in the Evaluations

- Marco Pigni, ORNL
- Vlad Sobes, ORNL