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Abstract. Transmission measurements have been performed at the time-of-flight facility GELINA to determine neutron resonance parameters for ^{103}Rh. The measurements have been carried out at a 50 m transmission station at a moderated neutron beam using a Li-glass scintillator with the accelerator operating at 50 Hz. This report provides the experimental details required to deliver the data to the EXFOR data library which is maintained by the Nuclear Data Section of the IAEA and the Nuclear Energy Agency of the OECD. The experimental conditions and data reduction procedures are described. In addition, the full covariance information based on the AGS concept is given, such that nuclear reaction model parameters together with their covariances can be derived in a least squares adjustment to the data.

1 Introduction

To study the resonance structure of neutron induced reaction cross sections, neutron spectroscopic measurements are required, which determine with a high accuracy the energy of the neutron that interacts with the material under investigation. To cover a broad energy range such measurements are best carried out with a pulsed white neutron source, which is optimized for time-of-flight (TOF) measurements [1].

The TOF-facility GELINA [2][3] has been designed and built for high-resolution cross section measurements in the resonance region. It is a multi-user facility, providing a white neutron source with a neutron energy range from 10 meV to 20 MeV. Up to 10 experiments can be performed simultaneously at measurement stations located between 10 m and 400 m from the neutron production target. The electron linear accelerator provides a pulsed electron beam with a maximum energy of 150 MeV, a maximum peak current of 10 A and a repetition rate ranging from 50 Hz to 800 Hz. A compression magnet reduces the width of the electron pulses to about 2 ns [4]. The electron beam hits a mercury-cooled uranium target producing Bremsstrahlung and subsequently neutrons via photonuclear reactions

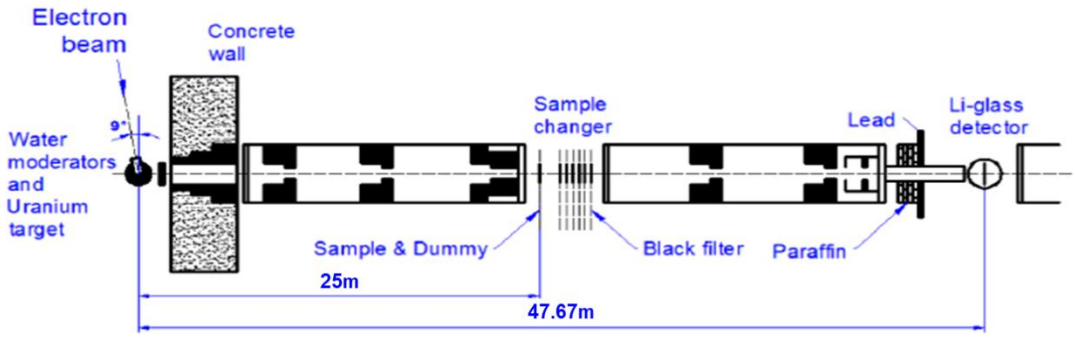
[5]. Two water-filled beryllium containers mounted above and below the neutron production target are used to moderate the neutrons. By applying different neutron beam collimation conditions, experiments can use either a fast or a moderated neutron spectrum. The neutron production rate is monitored by BF_3 proportional counters which are mounted in the ceiling of the target hall. The output of the monitors is used to normalize the time-of-flight spectra to the same neutron intensity. The measurement stations are equipped with air conditioning to reduce electronic drifts in the detection chains due to temperature changes.

This report describes the results obtained for transmission measurements carried out at GELINA with a ^{103}Rh metallic sample. To reduce bias effects due to e.g. dead time and background, the measurement and data reduction procedures recommended in Ref. [1]. have been followed. The main objective of this report is to provide the information that is required to extract resonance parameters for ^{103}Rh in a least squares adjustment to the data using e.g. the resonance shape analysis code REFIT [6]. In the description of the data the recommendations resulting from a consultant's meeting organized by the Nuclear Data Section of the IAEA (NDS/IAEA) have been followed [7].

2 Experimental conditions

The transmission experiments were performed at the 50 m measurement station of flight path 4 with the accelerator operating at 50 Hz. The moderated neutron spectrum was used. A shadow bar made of Cu and Pb was placed close to the uranium target to reduce the intensity of the γ-ray flash and the fast neutron component. The flight path forms an angle of 9° with the direction normal to the facet of the moderator viewing the flight path. The samples and detector were placed in an acclimatized room to keep them at a constant temperature of 21 °C. Figure 1 shows a schematic view of the experimental set-up.

Figure 1. Schematic representation of the transmission set-up at the 50 m transmission station of GELINA.



The partially thermalized neutrons scattered from the moderators were collimated into the flight path through an evacuated aluminium pipe of 50 cm diameter with annular collimators, consisting of borated wax, copper and lead. A combination of Li-carbonate plus resin, Pb and Cu collimators was used to reduce the neutron beam to a diameter of 45 mm at the sample position [8]. The impact of the γ-ray flash was reduced by a 16 mm Pb filter. The sample was placed at approximately 24 m distance from the neutron source. The neutron beam passing through the sample and filters was further collimated and detected by a 6.35 mm thick and 152.4 mm diameter NE912 Li-glass scintillator enriched in ^{6}Li. The scintillator was connected through a boron-free quartz window to a 127 mm EMI 9823 KQB photomultiplier (PMT). The detector was placed at about 47.67 m from the neutron target, the beam diameter at this position being about 90 mm. Close to the target hall exit, a 1.5 mm Cd overlap filter was placed to absorb slow neutrons from a previous burst. Permanent Na, Co and Ag black resonance filters were used to continuously monitor the background at 2850 eV, 132 eV and 5.2 eV, respectively, and to account for the impact of the sample on the background [1].

The TOF of the detected neutron was derived from the time difference between the stop signal T_s, obtained from the anode impulse of the PMT, and the start signal T_0, given at each electron burst. This time difference was processed with a multi-hit fast time coder with a 1 ns time resolution. The TOF and the pulse height of each detected event were recorded in list mode using a multi-parameter data acquisition system developed at the EC-JRC [9]. Each measurement was subdivided in different cycles. Only cycles for which the ratio between the total counts in the transmission detector and in the neutron monitor deviated by less than 1 % with respect to the average ratio of the previous and the following cycles were selected. The dead time of the detection chain t_d = 3510 (10) ns was derived from a spectrum of the time-interval between successive events. The uncertainties due to dead time corrections in the region of interest are very small and can be neglected.

The measurement was performed with a ^{103}Rh metallic sample. Its main characteristics are reported in Table 1. The areal density was derived from a measurement of the weight and the area with an uncertainty better than 0.1 %. The mass was determined by substitution weighing with a microbalance from Mettler Toledo. The area was determined by an optical surface inspection with a microscope system from Mitutoyo [10].

Table 1. Characteristics of the sample used for the transmission measurement at FP4-50m. The areal density n_d was calculated by using the experimentally determined mass and area.

ID	Thickness /mm	Mass/g	Area/mm2	Areal Density (at/b)
1	0.15	4.6356 (2)	2505.286 (2)	1.0817 (3) x 10^{-3}

3 Data reduction

The AGS code [11][12], developed at the EC-JRC, was used to derive the experimental transmission from the TOF-spectra. The code is based on a compact formalism to propagate all uncertainties starting from uncorrelated uncertainties due to counting statistics.

3.1 Experimental transmission

The experimental transmission T_{exp} as a function of TOF was obtained from the ratio of a sample-in measurement C_{in} and a sample-out measurement C_{out}, both corrected for their background contributions B_{in} and B_{out}, respectively:

$$T_{exp} = N\frac{C_{in} - KB_{in}}{C_{out} - KB_{out}}, \tag{3.1}$$

The TOF spectra (C_{in}, C_{out}, B_{in}, B_{out}) were corrected for losses due to the dead time in the detector and electronics chain. All spectra were normalized to the same TOF-bin width structure and neutron beam intensity. The latter was derived from the response of the BF_3 beam monitors. To avoid systematic effects due to slow variations of both the beam intensity and detector efficiency as a function of time, data were taken by alternating sample-in and sample-out measurements in cycles of about 500 seconds. Such a procedure reduces the uncertainty on the normalization to the beam intensity to less than 0.25 %. This uncertainty was evaluated from the ratios of counts in the ^{6}Li transmission detector and in the flux monitors. To account for this uncertainty the factor N= 1.0000 (25) was introduced in Eq. (3.1). The background as a function of TOF was approximated by an analytic expression applying the black resonance technique [1]. The factor K = 1.00 (3) in Eq. (3.1) was introduced to account for systematic effects due to the background model. Its uncertainty was derived from a statistical analysis of the difference between the observed black resonance dips and the estimated background [13]. This uncertainty is only valid for measurements with at least two fixed black resonance filters in the beam [1].

The time-of-flight (t) of a neutron creating a signal in the neutron detector was determined by the time difference between the start signal (T_0) and the stop signal (T_s):

$$t = (T_s - T_0) + t_0, \tag{3.2}$$

with t_0 a time-offset which was determined by a measurement of the γ-ray flash. The flight path distance L = 47.67 (1) m, i.e. the distance between the centre of the moderator viewing the flight path and the front face of the detector, was derived previously from results of transmission measurements using uranium standard references.

3.2 Background correction

The background as a function of TOF was parametrized by an analytical expression consisting of a constant and two exponentials:

$$B(t) = b_0 + b_1 e^{-\lambda_1 t} + b_2 e^{-\lambda_2 t} \tag{3.3}$$

The parameter b_0 is the time independent contribution. The first exponential is due to the detection of 2.2 MeV γ-rays resulting from neutron capture in hydrogen present in the moderator. The second exponential originates predominantly from neutrons scattered inside the detector station. Because of the presence of the 1.5 mm Cd filter in this measurement, the background contribution due to the slow neutrons from previous accelerator cycles can be neglected. The time dependence of the background was derived from the results of the measurement with the 0.15 mm thick Rh sample and verified with measurements using a 3 mm thick Au sample. The dead time corrected sample-in TOF-spectrum together with the background contributions resulting from the measurement with the ^{103}Rh sample and Na, Co and Ag black resonance filters is shown in Figure 2.

Figure 2. TOF spectrum with the 0.15 mm thick ^{103}Rh sample (C_{in}) in the beam at 50 Hz together with the total background (B_{in}) and its different components.

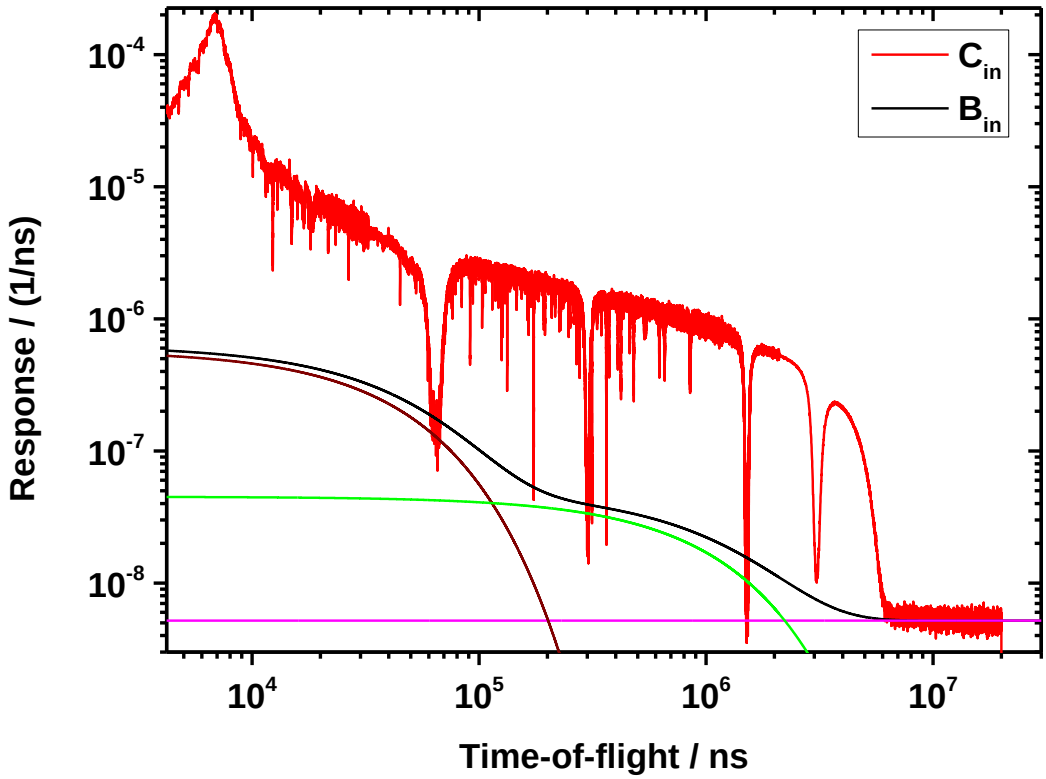


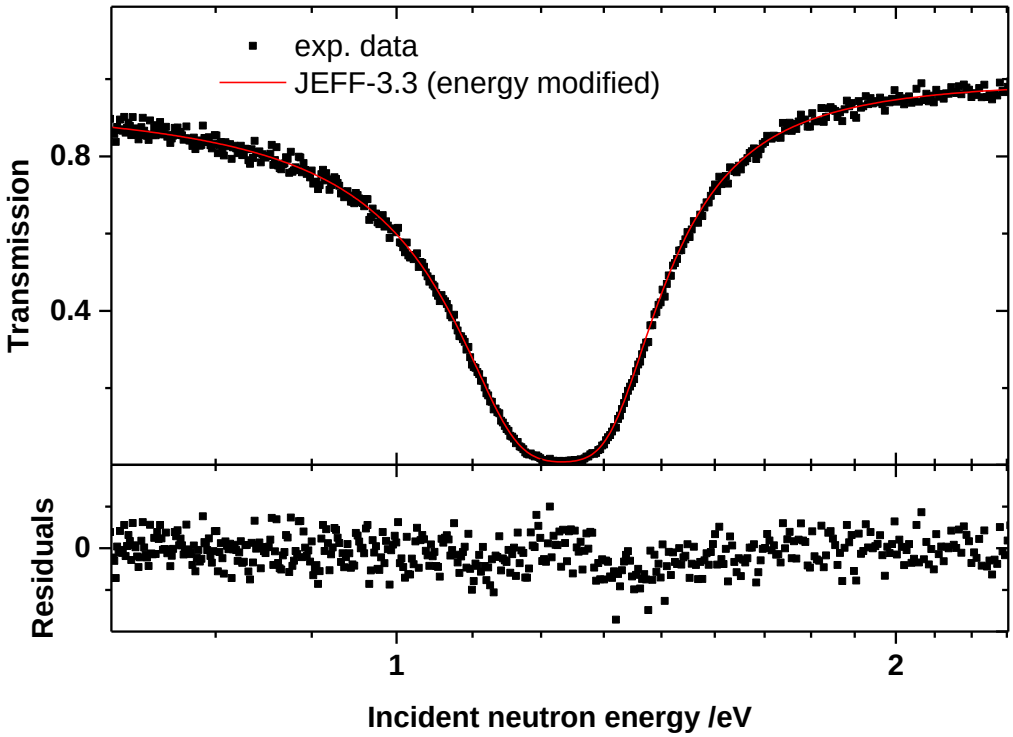
Table 2. Parameters for the analytical expressions of the background correction for the sample-in and sample-out measurements for the rhodium sample of 0.15 mm measured at a 50 Hz linac frequency. Parameter uncertainties are smaller than reported digits.

ID	$b_0/10^{-9}$ ns^{-1}	$b_1/10^{-7}$ ns^{-1}	$\lambda_1/10^{-5}$ ns^{-1}	$b_2/10^{-8}$ ns^{-1}	$\lambda_2/10^{-7}$ ns^{-1}
B_{in}	5.19	5.79	-2.34	4.50	-9.72
B_{out}	5.19	5.72	-2.34	4.77	-9.72

4 Results

The AGS code [11][12] was used to derive the experimental transmission and propagate both the correlated and uncorrelated uncertainties. The code is based on a compact formalism to propagate all uncertainties starting from uncorrelated uncertainties due to counting statistics. It stores the full covariance information after each operation in a concise, vectorized way. The AGS formalism results in a substantial reduction of data storage volume and provides a convenient structure to verify the various sources of uncertainties through each step of the data reduction process. The concept is recommended by the NDS/IAEA [7] to prepare the experimental observables, including their full covariance information, for storage into the EXFOR data library [14][15].

Figure 3. Experimental transmission as a function of time-of-flight resulting from measurements with the 0.15 mm thick ^{103}Rh sample at 50 Hz in the energy region 0.7-3 eV compared with the transmission spectrum calculated with REFIT by using resonance parameters provided in JEFF-3.3 evaluation.



The experimental transmission resulting from the measurements with the 0.15 mm thick metallic sample is shown in Figure 3, and compared with the transmission calculated with the resonance parameters in the JEFF-3.3 evaluation library. The format in which the numerical data will be stored in the EXFOR data library is illustrated in the Appendix. The data include the full covariance information based on the AGS concept. The total uncertainty and the uncertainty due to uncorrelated components are reported, together with the contributions due to the normalization and background subtraction. Applying the AGS concept the covariance matrix V of the experimental transmission can be calculated by:

$$V = U_u + S(\eta)S(\eta)^T, \tag{4.1}$$

where U_u is a diagonal matrix containing the contribution of all uncorrelated uncertainty components. The matrix S contains the contribution of the components $\eta = \{N, K_{in}, K_{out}\}$ creating correlated components. The uncertainty due to the dead time correction can be neglected. The experimental details, which are required to perform a resonance analysis on the data, are summarized in the Appendix.

Acknowledgements

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Appendix

A. SUMMARY OF EXPERIMENTAL DETAILS

A. 1 Experiment description

1. Main Reference		[a]
2. Facility	GELINA	[b]
3. Neutron production		
Neutron production beam	Electron	
Nominal average beam energy	100 MeV	
Nominal average current	50 μA	
Repetition rate (pulses per second)	50 Hz	
Pulse width	2 ns	
Primary neutron production target	Mercury cooled depleted uranium	
Target nominal neutron production intensity	3.4 x10^{13} s^{-1}	
4. Moderator		
Primary neutron source position in moderator	Above and below uranium target	
Moderator material	2 water filled Be-containers around U-target	
Moderator dimensions (internal)	2 x (14.6 cm x 21 cm x 3.9 cm)	
Density (moderator material)	1 g/cm^3	
Temperature (K)	Room temperature	
Moderator-room decoupler (Cd, B, …)	None	
5. Other experimental details		
Measurement type	Transmission	
Method (total energy, total absorption, …)	Good transmission geometry	[c][d]
Flight Path length (m) (moderator centre-detector front face)	L = 47.67 (1) m	
Flight path direction	9° with respect to normal of the moderator face viewing the flight path	
Neutron beam dimensions at sample position	45 mm in diameter	
Neutron beam profile	-	
Overlap suppression	1.5 mm Cd overlap filter	
Other fixed beam filters	Na, Co, Ag, Pb	
6. Detector		
Type	Scintillator	
Material	Li-glass	
Surface Dimensions	152.4 mm diameter	
Thickness (cm)	6.35 mm	
Detector(s) position relative to neutron beam	In the beam	
Detector(s) solid angle	-	
Sample		
7. Type (metal, powder, liquid, crystal)	Metal	
Chemical composition	^{103}Rh (100 at %)	
Sample composition (at/b)	1.0817 (3) x 10^{-3} at/b	
Temperature	21 ℃	
Sample mass (g)	4.6356 (2) g	
Geometrical shape (cylinder, sphere, …)	Square plate	

Surface dimension	2505.286 (2) mm^2	
Nominal thickness (mm)	0.15 mm	
Containment description	None	
Data Reduction Procedure		[d][e]
8. Dead time correction	Done (< factor 1.2)	
Background subtraction	Black resonance technique	
Flux determination (reference reaction, …)	-	
Normalization	1.0000 (25)	
Detector efficiency	-	
Self-shielding	-	
Time-of-flight binning	Zone length bin width 8192 4 ns 10240 16 ns 16384 32 ns 8192 32 ns 6144 32 ns 6144 64 ns 2048 256 ns 3072 4096 ns 3072 4096 ns 2048 16384 ns	
Response function		
9. Initial pulse	Normal distribution, FWHM = 2 ns	
Target / moderator assembly	Numerical distribution from MC simulations	[f][g]
Detector	Analytical function defined in REFIT manual	[h]

B. Data format

Column	Content	Unit	Comment
1	Energy	eV	Relativistic relation using a fixed flight path length (L = 47.67 m)
2	t_l	ns	
3	t_h	ns	
4	Y_{exp}		Transmission
5	Total uncertainty		
6	Uncorrelated unc.		Uncorrelated uncertainty due to counting statistics
7	AGS-vector (K)		Background model uncertainty (u_K/K=3 %)
8	AGS-vector (N)		Normalization (u_N/N = 0.25 %)

Comments from the authors:

– The AGS concept was used to derive the experimental transmission

$$T_{exp} = N \frac{C_{in} - KB_{in}}{C_{out} - KB_{out}},$$

and to propagate the uncertainties, both the uncorrelated due to counting statistics and the uncertainty due to the normalization and the background contributions.

– The quoted uncertainties are standard uncertainties at 1 standard deviation

B.1 DATA (ID 1)

E/ eV	t_l / ns	t_h / ns	Y_{exp}	u_t	u_u	AGS K	N
0.49954	4874240	4878336	0.8795	0.0311	0.0310	-0.000187	0.00220
0.50038	4870144	4874240	0.8812	0.0308	0.0307	-0.000180	0.00220
…	…	…	…	…	…	…	…
0.99981	3444736	3448832	0.6031	0.0133	0.0132	-0.000240	0.00151
1.00219	3440640	3444736	0.6149	0.0136	0.0136	-0.000240	0.00153
…	…	…	…	…	…	…	…
2.99939	1989888	1990144	1.0224	0.0602	0.0601	0.000037	0.00256
3.00016	1989632	1989888	1.0085	0.0583	0.0582	0.000026	0.00252

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