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Description of GELINA data to be stored in the EXFOR data base

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Results of time-of-flight transmission measurements for ^{nat}V at a 50 m station of GELINA

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Contents

Abstract

Transmission measurements have been performed at the time-of-flight facility GELINA to determine neutron resonance parameters for ^{51}V. 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 800 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 International Atomic Energy Agency (NDS/IAEA) and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (NEA/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 to 400 m from the neutron production target. The electron linear accelerator provides a pulsed electron beam with a maximum energy of 150 MeV, a peak current of up to 100 A and a repetition rate ranging from 50 Hz to 800 Hz. A compression magnet reduces the width of the electron pulses down to about 1 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.

In recent years, several experiments have been performed at the GELINA facility in support to criticality safety programme. These new cross section measurements were motivated due to the concerns about data deficiencies in some existing cross-section evaluations from libraries such as ENDF/B, JEFF or JENDL for nuclear criticality calculations [6]. One of the investigated materials was vanadium (V), which is a key structural element. Recent data testing for ICSBEP critical benchmarks involving vanadium resulted in an overprediction of the experiment eigenvalue. The integral data testing is based on the JENDL-4.0 evaluation and does not have covariance data. Also, the ENDF/B-VII.1 and JENDL-4.0 resonance evaluations are based on the parameters (up to 100 keV) represented by the multi-level Breit-Wigner (MLBW) formalism. As a result, the MLBW resonance evaluation does not account for the resonance-resonance interference effects. New differential measurements and the corresponding resonance evaluation are needed to accurately predict the neutron resonances and to provide detailed resonance parameters and covariance data.

In this report results of transmission measurements carried out at GELINA with natural vanadium (^{nat}V) metallic samples are described. 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 ^{51}V in a least squares adjustment to the data. In the description of the data the recommendations resulting from a consultant's meeting organized by the Nuclear Data Section of the 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 800 Hz and an average beam current of about 60 µA. This flight path forms an angle of 9° with respect to the normal of the moderator surface facing the flight path. 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 sample and detector were placed in a climatised room to keep them at a constant temperature of 20 °C. A schematic view of the experimental set-up is shown in Figure 1. The experimental conditions, including the facility, the sample, the detector characteristics and the type of background and overlap filters used in the experiment, are specified in Appendix A.

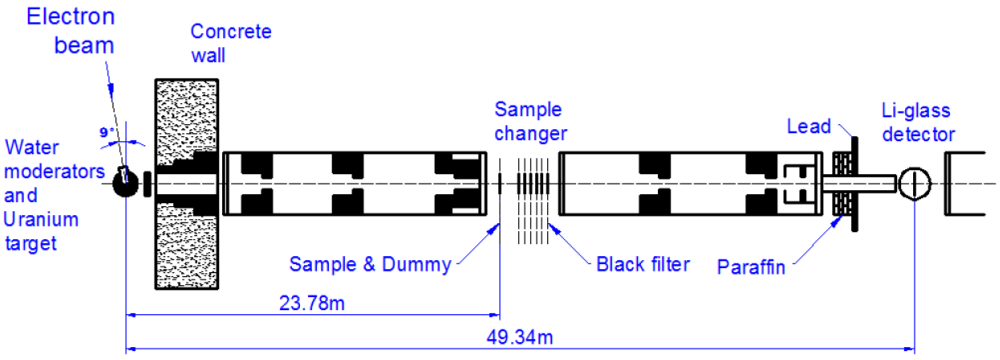

Figure 1 Schematic representation of the transmission set-up at the 50 m transmission station of GELINA.

The partially thermalized neutrons scattered from the moderators were collimated into the flight path through evacuated aluminum pipes 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. Close to the target hall exit, a ^{10}B overlap filter was placed to absorb slow neutrons from a previous burst. The impact of the γ-ray flash was reduced by a 16 mm Pb filter. The samples were placed at 25 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.

The output signals of the detector were connected to conventional analog electronics. The anode pulse of the PMT was fed into a constant fraction discriminator to create a fast logic signal which defines the time the neutron has been detected. The signal of the 9th dynode was shaped by a spectroscopic amplifier to determine the energy deposited by the ^{6}Li(n,t)α reaction in the detector. A module was included to produce a fixed dead time in the whole electronics chain directly after the detection of an event. This dead time t_d = 3305 (10) ns was continuously monitored by recording the time interval between successive pulses. The time-of-flight (TOF) of the detected neutron was determined by the time difference between the start signal (T_0), given at each electron burst, and the stop signal (T_s) derived from the anode pulse of the PMT. This time

difference was measured with a multi-hit fast time coder with a 1 ns time resolution. The TOF and pulse height of a detected event were recorded in list mode using a multi-parameter data acquisition system developed at the JRC-Geel [8]. Each measurement was subdivided in cycles alternating different configurations with and without sample and filters in beam. Only cycles for which the ratio between the total counts in the transmission detector and in the neutron beam monitor deviated by less than 1% from the average value were selected.

All measurements were performed with two natural vanadium metallic discs of 0.35 and 2 mm thicknesses, separately or combined, providing data for three different areal densities. The main characteristics of the samples are reported in Table 1. The areal density of the natural samples was derived from a measurement of the weight and the area with an uncertainty better than 0.1 %. The area was determined by an optical surface inspection with a microscope system from Mitutoyo [9]. The areal density of the measurement with both samples in the beam was obtained from the addition of the corresponding areal densities of each sample.

ID	Thickness (mm)	Mass (g)	Area (mm^2)	Areal Density (at/b)
1	0.35	10.503 ± 0.010	5031.37 ± 0.09	(2.468 ± 0.002) x 10^{-3}
2	2.0	68.812 ± 0.010	5074.64 ± 0.09	(16.030 ± 0.002) x 10^{-3}

Table 1 Characteristics of the vanadium samples used for the experiments at GELINA. Each areal density was calculated by using the experimentally determined mass and area.

3 Data reduction

The AGS code [10], 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.

The experimental transmission T_{exp} as a function of the time-of-flight was obtained from the ratio of the counts of a sample-in measurement C_{in} and a sample-out measurement C_{out}, after subtraction of the background contributions B_{in} and B_{out}, respectively [1]:

$$T_{\exp}(t_m) = N\frac{C_{in}(t_m) - K_{in}B_{in}(t_m)}{C_{out}(t_m) - K_{out}B_{out}(t_m)} \quad , \qquad (1)$$

where t_m denotes the measured time-of-flight. The TOF-spectra C_{in} and C_{out} in Eq. 1 were corrected for losses due to the dead time in the detector and the electronics chain. All spectra were normalized to the same TOF-bin width structure and to the neutron beam intensity. The latter was derived from the response of the BF_3 beam monitors. To avoid systematic uncertainties due to slow variations of both the beam intensity and the detector efficiency as a function of time, data were taken by alternating sample-in and sample-out measurements in cycles of about 600 seconds each. Such a procedure reduces the uncertainty on the normalization to the beam intensity to less than 0.25 % [1]. This uncertainty was evaluated from the ratios of the counts in the ^{6}Li transmission detector and in the flux monitors. To account for this uncertainty the factor N = 1.0000 ± 0.0025 was introduced in Eq. 1. Finally, the K factors introduce a correlated uncertainty component accounting for systematic effects due to the background model.

The time-of-flight t_m 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):

$$t_m = (T_s - T_0) + t_o \quad , \quad (2)$$

with t_o a time offset which was determined by a measurement of the γ-ray flash. The flight path distance L = 47.669 (0.004) m, i.e. the distance between the centre of the moderator and the front face of the detector, was derived previously from the result of transmission measurements on ^{238}U using as reference the 6.673 ± 0.001 eV resonance reported by Derrien et al.[11].

The background as a function of TOF is described by using an analytical expression consisting of a constant and three exponentials [1]:

$$B(t_m) = b_0 + b_1 e^{-\lambda_1 t_m} + b_2 e^{-\lambda_2 t_m} + b_3 e^{-\lambda_3 (t_m + \tau_o)} \quad . \quad (3)$$

The time independent contribution b_0 can be estimated from measurements when the accelerator is not in operation. The first exponential accounts for the contribution due to the detection of 2.2 MeV γ-rays resulting from neutron capture in hydrogen that is present in the moderator. The second exponential originates predominantly from neutrons scattered inside the detector station. The last time-dependent component is due to the detection of slow neutrons from previous accelerator cycles. This overlap component and the independent term b_0 were obtained by extrapolating the TOF spectra at the end of the cycle and it was approximated by an exponential, with τ_o related to the operating frequency of the accelerator (i.e τ_o = 1.25 ms for 800 Hz).

The rest of the background contributions were determined by using the black resonance technique. The parameters of the two first exponentials in Eq. [3] were obtained from least squares fits to saturated resonance dips observed in the TOF-spectra resulting from measurements with black resonance filters. The λ_1 and λ_2 parameters were derived from

dedicated measurements with Cu, Na, Co and W black resonance filters in the beam [12] and kept as fixed for all the vanadium measurements. The contribution from each exponential, described by the b_1 and b_2 parameters, were continuously monitored by alternating short cycles with Na and Co black resonance filters in the beam during the experiment.

For this measurement, two different approaches were considered. In the first one, the Na filter was kept fixed in the beam in order to account for the dependence of the background level on the presence of the sample [1], while the relative contribution of the first (γ-rays) and the second (scattered neutrons) components (b_1/b_2) is set to the value obtained for the cycles with Na and Co filters in the beam. It is assumed that the effect of the Co filter in the relative contribution of the two background components is negligible. This is the more accurate way of estimating the background contribution during the experiment but with the drawback of losing information in the energy region around the Na black resonance. A model uncertainty of 3% was already derived in Ref. [12] from a statistical analysis between the estimated background and the observed background in the black resonance dips. In addition, because the same procedure has been followed to obtain B_{in} and B_{out}, K_{in} and K_{out} become the same factor K and the experimental transmission is expressed as:

$$T_{\exp}(t_m) = N\frac{C_{in}(t_m) - KB_{in}(t_m)}{C_{out}(t_m) - KB_{out}(t_m)} \quad , \quad (4)$$

the factor K = 1.0000 ± 0.0025 being introduced to account for systematic effects due to the background model.

In the second approach, no permanent black resonance filter was included in the experiment in order to access the whole energy range. For the thickest vanadium sample, the resonance at 4.1 keV could be used as black resonance. Therefore, this resonance was used to determine the background level for the sample-in measurements in a way similar to the measurement with the fixed Na filter. Moreover, it was also used to estimate the effect of the presence of the Na and Co black resonance filters in the background level. An increment of the background level of around 13% was observed when removing the filters, which was used for the determination of B_{out}. In the case of the thin vanadium sample, the same increment in the background level has been considered to determine B_{in} and B_{out} from the background obtained from the corresponding cycles with Na and Co filters in the beam. An uncertainty of 5% was derived for this procedure in previous experiments.

The dead time corrected TOF-spectra together with the background contributions resulting from the measurements with the 2 mm and the 0.35 mm thick ^{nat}V samples are shown in Figure 2 and Figure 3, respectively. In addition, the fitting parameters describing the background contributions for all the cases studied are provided in Table 2, Table 3 and Table 4.

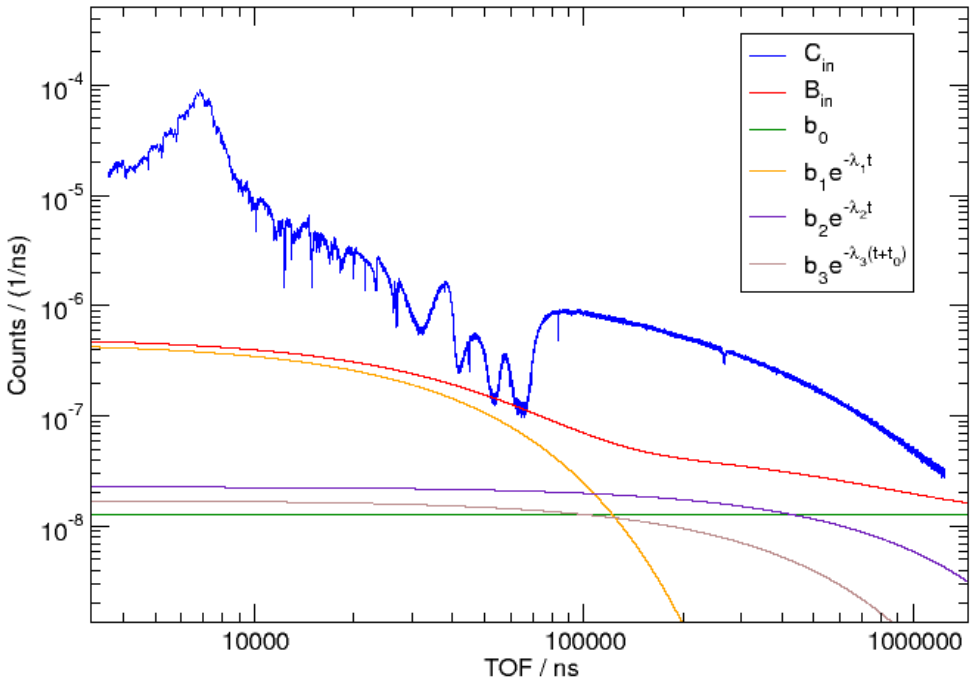

Figure 2 TOF spectrum obtained with a fixed Na filter and the thick vanadium sample (C_{in}) in the beam together with the total background (B_{in}) and its different components.

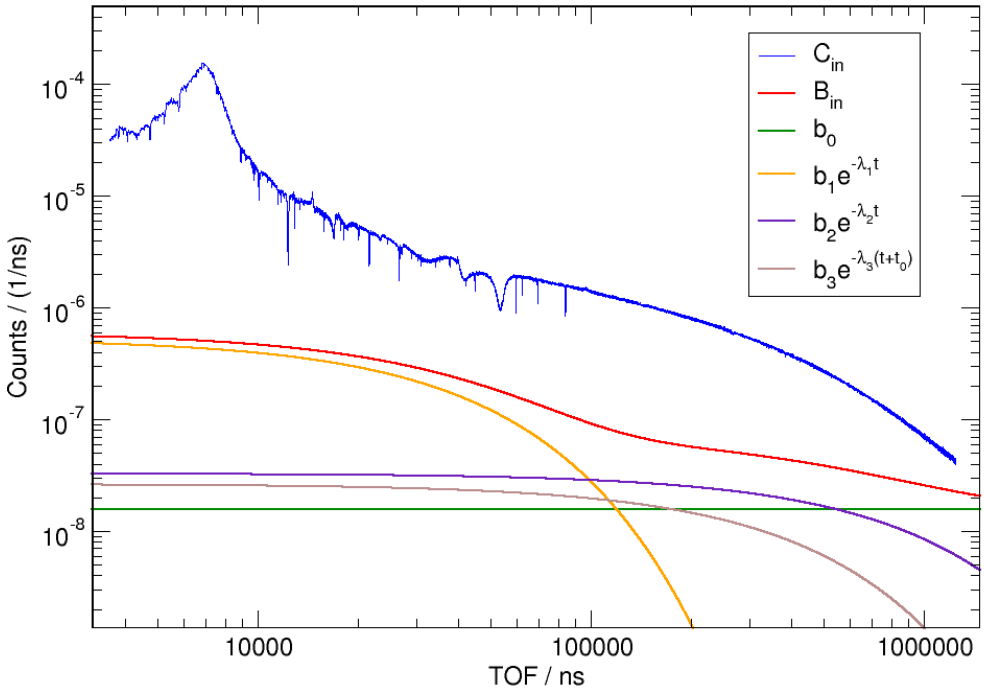

Figure 3 TOF spectrum obtained with the thin vanadium sample (C_{in}) in the beam together with the total background (B_{in}) and its different components. No fixed black resonance filters were present.

Fix filt.	ID	$b_0/10^{-8}$ ns	$b_1/10^{-7}$ ns	$\lambda_1/10^{-5}$ ns	$b_2/10^{-7}$ ns	$\lambda_2/10^{-6}$ ns	$b_3/10^{-7}$ ns	$\lambda_3/10^{-6}$ ns
Φ	C_{in}	1.58	5.28	2.94	0.327	1.35	10.5	2.95
Φ	C_{out}	1.59	5.56	2.94	0.333	1.35	10.7	2.95
Na	C_{in}	1.16	4.77	2.94	0.219	1.35	6.79	2.95
Na	C_{out}	1.29	4.89	2.94	0.217	1.35	6.88	2.95

Table 2 Parameters for the analytical expressions of the background correction for the sample-in and sample-out measurements for the vanadium sample of 0.35 mm thickness.

Fix filt.	ID	$b_0/10^{-8}$ ns	$b_1/10^{-7}$ ns	$\lambda_1/10^{-5}$ ns	$b_2/10^{-7}$ ns	$\lambda_2/10^{-6}$ ns	$b_3/10^{-7}$ ns	$\lambda_3/10^{-6}$ ns
Φ	C_{in}	1.57	5.39	2.94	0.310	1.35	9.91	2.95
Φ	C_{out}	1.70	6.09	2.94	0.355	1.35	10.9	2.95
Na	C_{in}	1.29	4.64	2.94	0.228	1.35	6.81	2.95
Na	C_{out}	1.43	5.17	2.94	0.261	1.35	7.39	2.95

Table 3 Parameters for the analytical expressions of the background correction for the sample-in and sample-out measurements for the vanadium sample of 2 mm thickness.

Fix filt.	ID	$b_0/10^{-8}$ ns	$b_1/10^{-7}$ ns	$\lambda_1/10^{-5}$ ns	$b_2/10^{-7}$ ns	$\lambda_2/10^{-6}$ ns	$b_3/10^{-7}$ ns	$\lambda_3/10^{-6}$ ns
Φ	C_{in}	1.50	5.21	2.94	0.288	1.35	8.17	2.95
Φ	C_{out}	1.59	5.56	2.94	0.333	1.35	10.7	2.95
Na	C_{in}	1.39	4.73	2.94	0.262	1.35	7.61	2.95
Na	C_{out}	1.53	5.36	2.94	0.319	1.35	8.40	2.95

Table 4 Parameters for the analytical expressions of the background correction for the sample-in and sample-out measurements with both vanadium samples.

4 Results

In this work, experimental transmission has been obtained for three different thicknesses of natural vanadium samples. For each thickness, transmission measurements were performed both with a permanent Na filter for background estimation and without any permanent black resonance filter. Figure 4 shows the result obtained for the 2 mm thickness sample without any permanent filter, compared to the theoretical transmission calculated using ENDF/B-VII.0 evaluation.

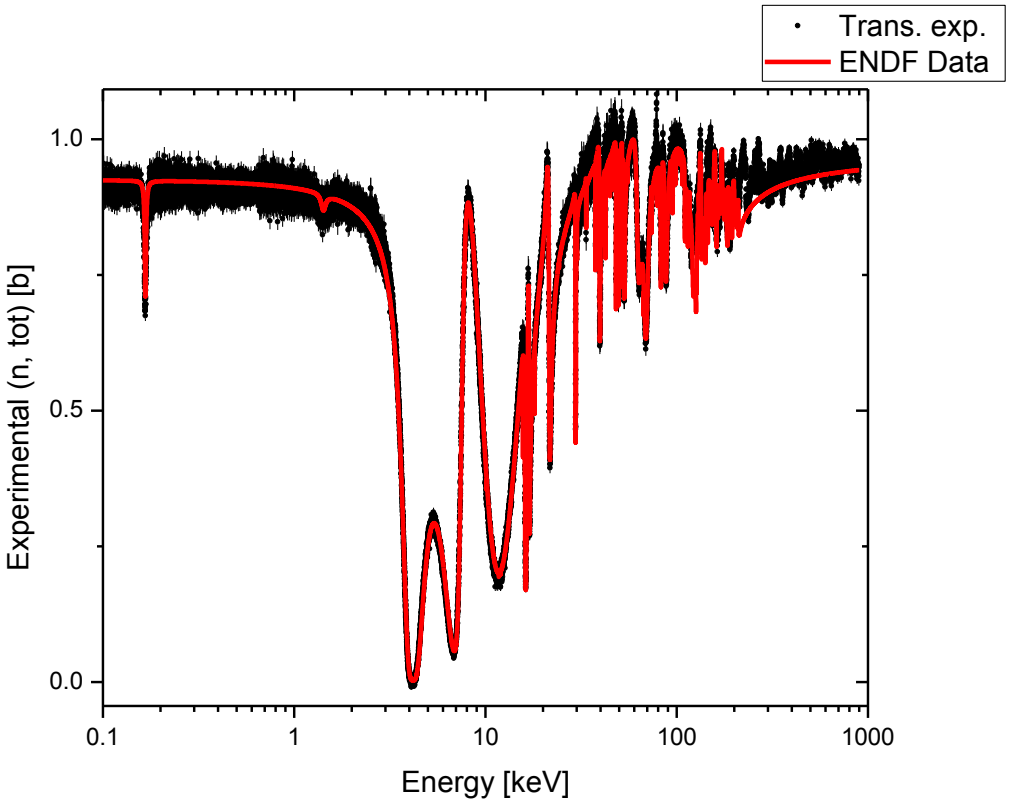

Figure 4 Experimental transmission obtained with the thick vanadium sample compared with the theoretical transmission using ENDF/B-VII.0 evaluated files.

To derive the experimental transmission and propagate both the correlated and uncorrelated uncertainties the AGS code was used [10]. 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 use of the AGS concept is recommended by the Nuclear Data Section of the IAEA [7] to prepare the experimental observables, including their full covariance information, for storage into the EXFOR data library [13][14].

The format in which the numerical data will be stored in the EXFOR data library is illustrated in Appendix B. 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 described in Ref. [10], 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 Appendix A.

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Appendix

A. SUMMARY OF EXPERIMENTAL DETAILS

A. 1 Experiment description (ID 1)

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)	800 Hz	
	Pulse width	2 ns FWHM	
	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 = 47.669 (4) 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	^{10}B overlap filter (8x10^{-3} at/b)	
	Other fixed beam filters	Na, Pb (16 mm)	
6.	**Detector**		
	Type	Scintillator (NE905)	
	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	-	
7.	**Samples**		
	Type (metal, powder, liquid, crystal)	Metal	
	Chemical composition	^{nat}V (100 at %)	
	Sample composition (at/b)	^{nat}V (2.468 ± 0.002) x 10^{-3} and ^{nat}V (16.030 ± 0.002) x 10^{-3}	
	Temperature	22°C	
	Sample mass (g)	(10.503 ± 0.01) and (68.812 ± 0.01)	

	Geometrical shape (cylinder, sphere, …)	cylinder	
	Surface dimension (mm^2)	(5031.37 ± 0.09) and (5074.64 ± 0.09)	
	Nominal thickness (mm)	0.35 and 2	
	Containment description	None	
	Additional comment	99.75 at % ^{51}V, 0.25 at % ^{50}V	
8.	**Data Reduction Procedure**		[d],[e]
	Dead time correction	Done (< factor 1.2)	
	Background subtraction	Black resonance technique	
	Flux determination (reference reaction, …)	-	
	Normalization	1.000 ± 0.0025	
	Detector efficiency	-	
	Self-shielding	-	
	Time-of-flight binning	Zone length bin width 10240 2 ns 4096 4 ns 4096 8 ns 4096 16 ns 5096 32 ns 4096 64 ns 6144 128 ns	
9.	**Response function**		
	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]

A. 2 Experiment description (ID 2)

1.	**Main Reference**		[a]
2.	**Facility**	GELINA	[b]
3.	**Neutron production**		
	Neutron production beam	Electron	
	Nominal average beam energy	100 MeV	
	Nominal average current	65 µA	
	Repetition rate (pulses per second)	800 Hz	
	Pulse width	2 ns FWHM	
	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 = 47.669(4) 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	^{10}B overlap filter (8x10^{-3} at/b)	
	Other fixed beam filters	Pb (16 mm)	
6.	**Detector**		
	Type	Scintillator (NE905)	
	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	-	
7.	**Sample**		
	Type (metal, powder, liquid, crystal)	Metal	
	Chemical composition	^{nat}V (100 at %)	
	Sample composition (at/b)	^{nat}V (2.468 ± 0.002) x 10^{-3} and ^{nat}V (16.030 ± 0.002) x 10^{-3}	
	Temperature	22°C	
	Sample mass (g)	(10.503 ± 0.01) and (68.812 ± 0.01)	
	Geometrical shape (cylinder, sphere, …)	cylinder	
	Surface dimension (mm^2)	(5031.37 ± 0.09) and (5074.64 ± 0.09)	
	Nominal thickness (mm)	0.35 and 2mm	
	Containment description	None	
	Additional comment	99.75 at % ^{51}V, 0.25 at % ^{50}V	
8.	**Data Reduction Procedure**		[d],[e]
	Dead time correction	Done (< factor 1.2)	
	Background subtraction	Black resonance technique	
	Flux determination (reference reaction, …)	-	
	Normalization	1.000 ± 0.0025	
	Detector efficiency	-	
	Self-shielding	-	
	Time-of-flight binning	Zone length / bin width: 10240 / 2 ns 4096 / 4 ns 4096 / 8 ns 4096 / 16 ns 5096 / 32 ns 4096 / 64 ns 6144 / 128 ns	
9.	**Response function**		
	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 = 47.699 m)
2	t_{low}	ns	
3	t_{high}	ns	
4	T_{exp}		Transmission
5	Total Uncertainty		
6	Uncorrelated uncertainty		Uncorrelated uncertainty due to counting statistics
7	AGS-vector (K)		Background model
8	AGS-vector (N)		Normalization (u_N/N = 0.25 %)

Comments from the authors:

- The AGS concept was used to derive the experimental transmission and to propagate the uncertainties, both the uncorrelated uncertainty due to counting statistics and the uncertainty due to the normalization and the background contributions.

- In the cases that both background contributions, B_{in} *and* B_{out}, were determined following the same procedure, the experimental transmission is expressed as:

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

In the cases that the background contributions were determined by using different methods, the experimental transmission is expressed as:

$$T_{exp} = N\frac{C_{in} - K_{in}B_{in}}{C_{out} - K_{out}B_{out}}.$$

The uncertainty for the background model using a permanent black resonance was estimated to be 3 %, whereas the uncertainty for the background model without a permanent black resonance was estimated to be 5 %.

- The quoted uncertainties are standard uncertainties at 1 standard deviation.

B.1 DATA (ID 1, S1)

					AGS		
E/ eV	**t_l / ns**	**t_h / ns**	**Y_{exp}**	**u_t**	**u_u**	**K**	**N**
949784.1	3538	3540	0.97857	0.02705	0.02536	-0.00065	0.00245
948709.9	3540	3542	0.97895	0.02958	0.02802	-0.00065	0.00245
…							
40908.2	53880	53888	0.40983	0.03211	0.03153	-0.00102	0.00102
40896.1	53888	53896	0.42047	0.03173	0.03050	-0.00099	0.00105
…							
100.166	344320	344384	0.95601	0.03063	0.03054	-0.00013	0.00239
100.129	344384	344444	0.96470	0.03072	0.03062	-0.00009	0.00241

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