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NEUTRON TOTAL AND CAPTURE CROSS SECTION MEASUREMENTS AND RESONANCE PARAMETER ANALYSIS OF TUNGSTEN FROM 0.01 to 200 eV

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Neutron Total and Capture Cross Section Measurements and Resonance Parameter Analysis of Tungsten from 0.01 to 200 eV

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Abstract

Natural tungsten metal has been measured using neutron time-of-flight spectroscopy at the Rensselaer Polytechnic Institute (RPI) Gaerttner LINAC Laboratory to improve the tungsten resonance parameters. Three separate types of measurements were performed; transmission, capture and self-indication. Previous measurements did not employ all three experimental types and used less sophisticated analysis methods. It is our conclusion that the current work improves on the published tungsten data base and reduces the resonance parameter uncertainties.

Introduction

The present work deals with the measurement of tungsten metal samples using three different methods and performs a simultaneous analysis for determining the resonance parameters. A set of capture and transmission measurements was performed for the neutron energy range of 0.01 eV to 20 eV, while another set of capture, transmission and self-indication measurements was made for the neutron energy range of 2 to 200 eV.

Experimental Description

The Gaerttner LINAC Laboratory has two neutron targets (see Figure 1) and three detection stations for time-of-flight measurements. The Enhanced Thermal Target (ETT) neutron source consists of a tantalum photoneutron target, graphite reflector and a polyethylene moderator optimized for the production of thermal neutrons.[1] This neutron source was used in both capture and transmission measurements for measurements from 0.01 to 20 eV. The Bounce Target (BT) also consists of a tantalum photoneutron target but with only a polyethylene moderator optimized for the epi-thermal neutron energy range of 1 eV to 10 keV.[2] The BT was used in capture, transmission and self-indication measurements.

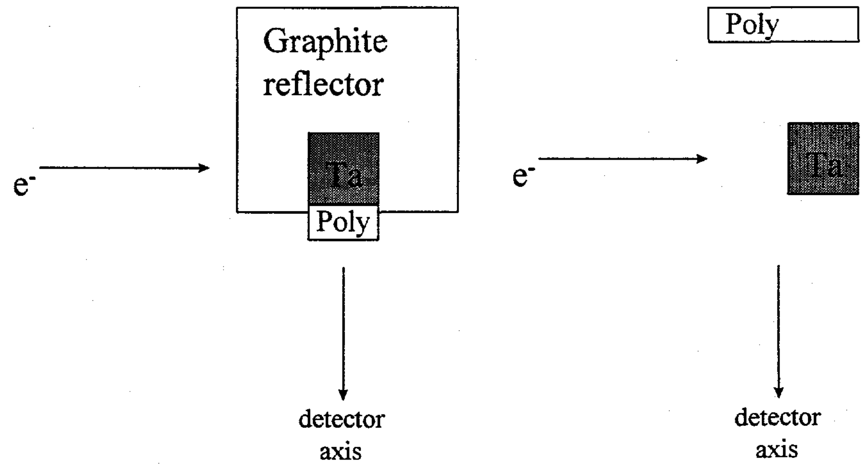

Figure 1 - Top view of the Enhanced Thermal Target (left) and Bounce Target (right) not to scale.

A 15 meter flight path and a 25 meter flight path for transmission measurements were used with Li-glass neutron detectors.[3] Thermal transmission measurements were performed at the 15m station, while epi-thermal measurements were made at the 25m station.

A 16-segment NaI multiplicity detector was employed to perform capture and self-indication measurements.[4,5,6] The detector is located at the end of a 25m flight path and was used for both capture and self-indication measurements using the BT. An additional measurement was performed in capture using the ETT in order to determine the thermal capture cross section of tungsten and complement the thermal transmission measurement.

Sample Description

A total of twelve natural tungsten metal samples, 99.95% elemental tungsten, was measured for all three experiments. The mass of each individual sample was determined using a Fisher Scientific chain balance with an accuracy of 0.1 mg. All sample diameters are 1.985 $\pm$ 0.005 inches. The thickness ranged from 0.3 mil to 200 mil, where 1 mil = 0.001 inch = 0.00254 cm.

Data Analysis and Results

A total of approximately 300 hours of data was collected for all experiments. The data sets were put through a rigorous statistical analysis for consistency of collection and for determining anomalous data sets to be removed from further analysis. The data were then background corrected and reduced to transmission or capture yields and analyzed using the least squares, multi-level R-matrix code REFIT[7] to obtain a single set of resonance parameters from all three types of measurement. REFIT was used because of its ability to simultaneously fit all three types of experiment as well as its multiple scattering calculation capability. First individual and then simultaneous analysis of all three experimental data types were performed for the neutron energy range of 0.01 eV to 200 eV. A sample of the results of a simultaneous fit to all three data types is shown in figures 2, 3 and 4. These three figures show the capture, transmission and self-indication data plotted with their REFIT fits using the final RPI resonance parameters for the 18 and 21 eV tungsten resonances . The final RPI total and capture cross sections are shown in figures 5 through 8 along with the ENDF/B-VI evaluated cross sections.[8] The thermal region results are shown in figure 9 along with the measurements of Havens et al.[9] and Schmunk et al.[10] This work identifies numerous tungsten resonances with energy values shifted from ENDF/B-VI (see Table 1). Differences in the thermal region, below 2 eV, are present as well. The total and capture cross sections determined at 0.0253 eV from the present measurements are 21.71 $\pm$ 0.12 barns and 18.17 $\pm$ 0.14 barns, respectively. The corresponding ENDF/B-VI cross sections are 23.17 and 18.19 barns. The resonance integral for natural tungsten using the RPI parameters is 347 barns, about 3.5 % lower then the ENDF/B-VI value of 360 barns.

A consistent single set of RPI parameters obtained using data from three different types of measurement fitted simultaneously improves the accuracy of the tungsten resonance parameters. The final RPI parameters are given in Table 1 along with the ENDF/B-VI and Mughabghab[11] resonance parameters. Also shown in Table 1 are the spins of the resonances, the isotope to which the resonance belongs, and the statistical uncertainties of the parameters from the REFIT analysis (inside brackets). In several cases for resonance fitting, the radiation width could not be resolved and therefore was fixed to the ENDF/B-VI value. These instances are shown in Table 1 as those RPI values that have no uncertainty assigned to them. The resonance parameters varied for this fit cover the energy range of 0.01 eV to 200 eV. The neutron width of the negative energy resonance, belonging to the ^{182}W isotope, at -100 eV was also varied to adjust the fit to the thermal region.

The multiplicity, i.e. number of photons per neutron capture, was obtained in both capture and self-indication, and was utilized to verify the spin states of the tungsten resonances. During a capture measurement, sixteen spectra, ranging from multiplictity 1 to 16, are recorded for each sample.[5] An example of multiplicity spectra for multiplicity one through eight is plotted in Figure 10 for the 7.6 eV resonance in ^{183}W with a 0.3 mil thick sample. This figure shows that the multiplicity peaks at 3 and then decreases with increasing multiplicity. Beyond multiplicity 8, the counts in each spectrum are few and are, therefore, not included in this figure. Similar multiplicity information assists in identifying the spin as J=1 for the 101.3 eV resonance in ^{183}W, rather than J=0 assigned in ENDF/B-VI.

It is our conclusion that the present tungsten measurements from thermal to 200 eV for transmission, capture and self-indication are an improvement over the previous measurements that were evaluated for the ENDF/B-VI parameters. The ENDF/B-VI parameters are based on measurements dating back to the 1960s and earlier (see Figure 9).[9,10] In particular, the ENDF/B-VI thermal resonance parameters were based on a capture-only measurement performed in 1966.

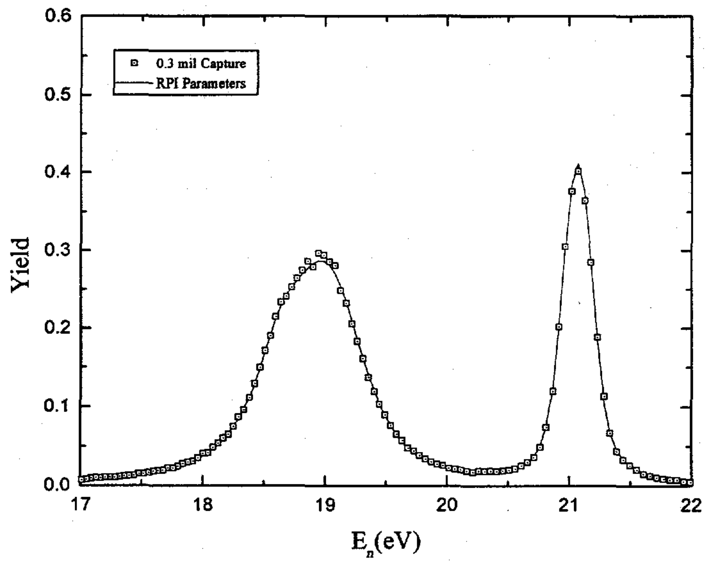

Figure 2 - Tungsten capture yield data for a 0.3 mil thick sample and fit simultaneously using capture, transmission and self-indication data.

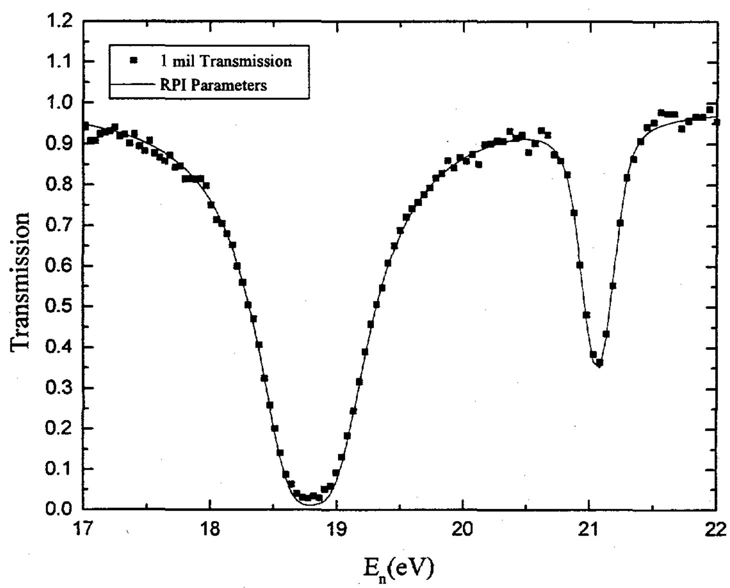

Figure 3 - Tungsten transmission data for a 1 mil thick sample and fit simultaneously using capture, transmission and self-indication data.

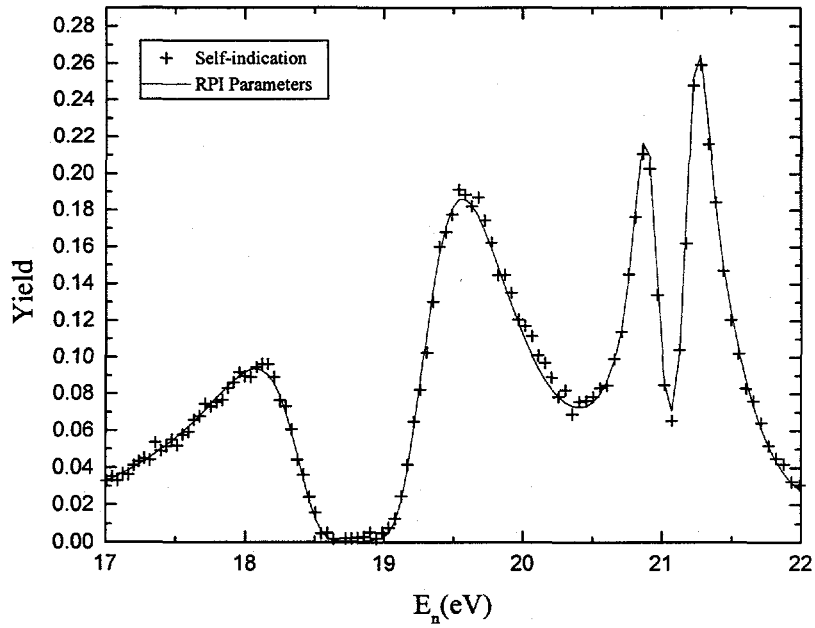

Figure 4 - Tungsten self-indication yield data for a 2 mil transmission sample and a 5 mil capture sample and fit simultaneously using capture, transmission and self-indication data.

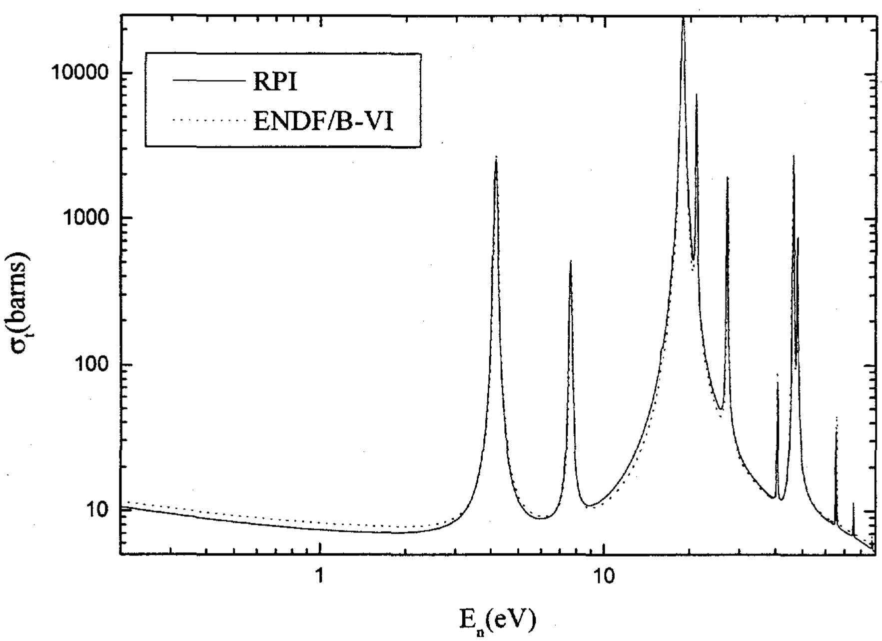

Figure 5 - The RPI and ENDF/B-VI total cross section for tungsten broadened to 300 K for the neutron energy range of 0.01 to 90 eV.

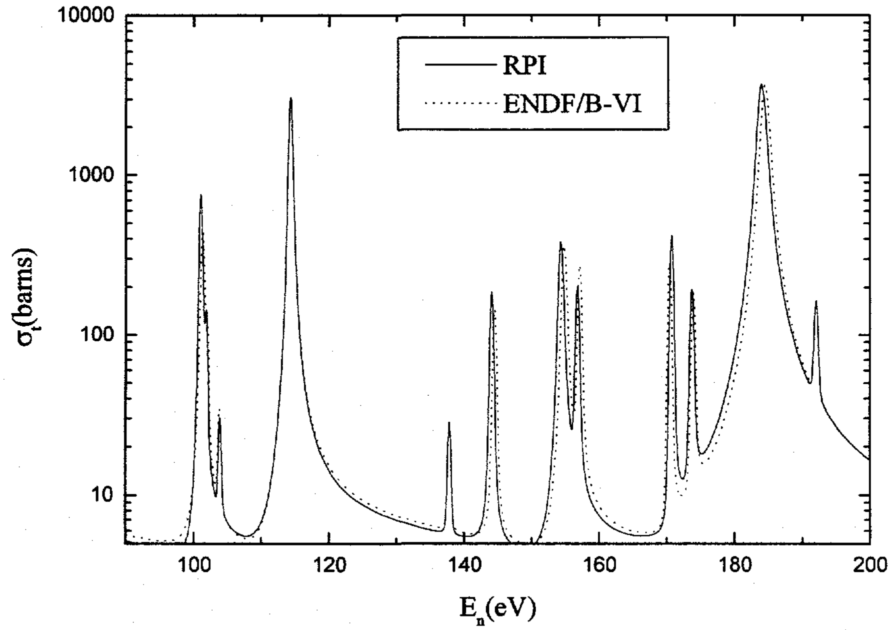

Figure 6 - The RPI and ENDF/B-VI total cross section for tungsten broadened to 300 K for the neutron energy range of 90 to 200 eV.

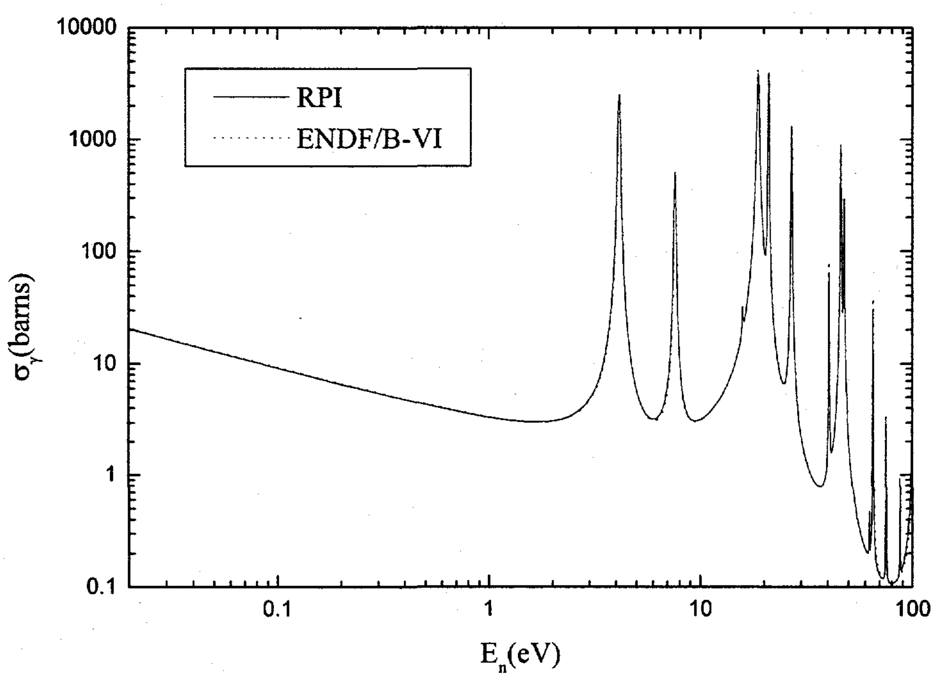

Figure 7 - The RPI and ENDF/B-VI capture cross section for tungsten broadened to 300 K for the neutron energy range of 0.01 to 100 eV.

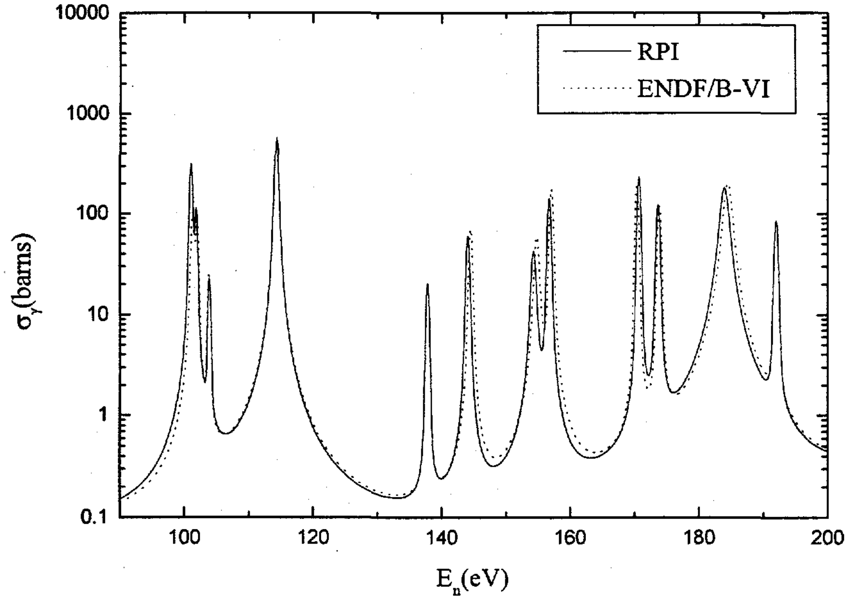

Figure 8 - The RPI and ENDF/B-VI capture cross section for tungsten broadened to 300K for the neutron energy range of 90 to 200 eV.

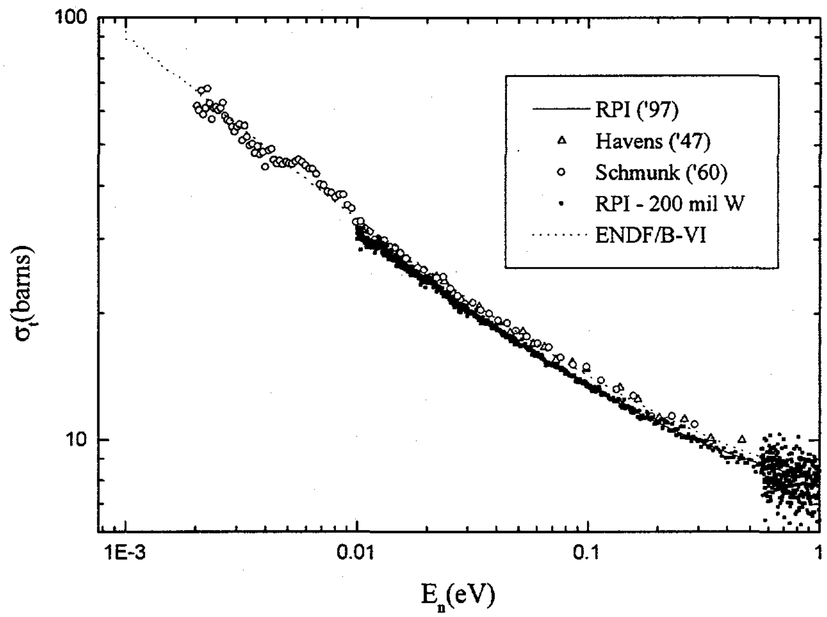

Figure 9 - The RPI total cross section plotted with the 200 mil tungsten sample data, the ENDF/B-VI total cross section and the data sets from Havens and Schmunk used for the ENDF evaluation.

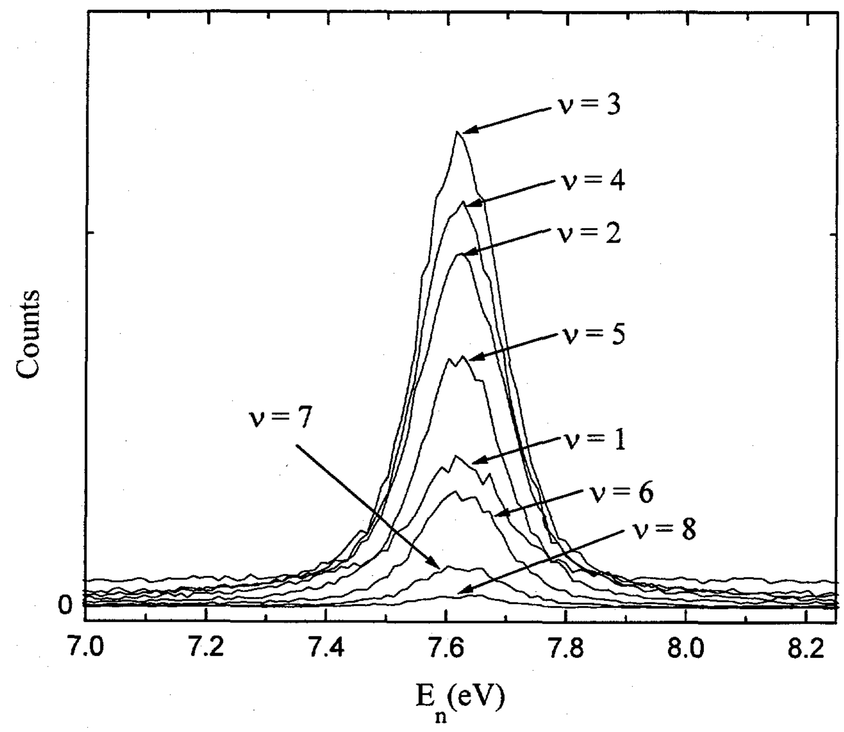

Figure 10 - Capture multiplicity(ν) spectrum for 0.3 mil W near 7.6 eV.

ENDF/B-VI			Mughabghab			RPI			
E_n (eV)	Γ_γ (meV)	Γ_n (meV)	E_n (eV)	Γ_γ (meV)	Γ_n (meV)	E_n (eV)	Γ_γ (meV)	Γ_n (meV)	Isotope
-100	63	2360	-94	64	193.91	-100	63	1613 [12.2]	182
4.16	50	1.47	4.155 [0.005]	48 [3]	1.47 [0.03]	4.1407 [0.0004]	52.41 [0.181]	1.420 [0.004]	182
7.65	70	1.75	7.63 [0.03]	77 [3]	1.47 [0.16]	7.6198 [0.0004]	80.27 [0.34]	1.753 [0.004]	183 J=1
18.81	49	280	18.83 [0.30]	43.8 [1.4]	300 [15]	18.8114 [0.0009]	44.63 [0.11]	315.6 [0.37]	186
21.10	62	38	21.06 [0.03]	65 [6]	39 [1]	21.0637 [0.0007]	51.06 [0.20]	39.92 [0.11]	182
27.13	77	42	27.05 [0.03]	77 [6]	42	27.0319 [0.0006]	80.93 [0.54]	41.23 [0.20]	183 J=1
40.6	68	2.5	40.68 [0.03]	68 [30]	1.73	40.651 [0.002]	75.23 [2.46]	2.001 [0.019]	183 J=1
46.08	69	154	46.24 [0.07]	77 [8]	140	46.237 [0.009]	71.46 [0.22]	157.2 [0.51]	183 J=1
47.8	78	115	47.8 [0.04]	78 [10]	108	47.864 [0.009]	72.90 [0.45]	115.8 [0.75]	183 J=0
65.50	103	2.50	65.34 [0.03]	78 [21]	1.93 [0.33]	65.289 [0.005]	90.98 [5.178]	1.752 [0.019]	183 J=1
101.3	65	240	101.1 [0.1]	65 [30]	130 [10]	101.049 [0.002]	69.75 [0.44]	107.0 [0.86]	183 J=1
102.0	68	3.2	101.69 [0.1]	57 [5]	3.6 [0.3]	101.842 [0.002]	68	3.941 [0.028]	184
103.8	66	3	103.90 [0.12]	65 [30]	2.6 [0.4]	103.855 [0.003]	66	2.814 [0.027]	183 J=1
114.3	61	270	114.4 [0.1]	60 [3]	270 [10]	114.303 [0.004]	56.81 [0.25]	265.4 [1.00]	182
137.8	75	10.8	138.0 [0.1]	75 [20]	2.8 [0.47]	137.795 [0.010]	75	12.21 [0.15]	183 J=1
144.5	90	95	144.2 [0.1]	90 [20]	96 [10]	144.048 [0.005]	56.85 [0.56]	130.1 [2.69]	183 J=0
154.8	75	405	154.4 [0.1]	75 [8]	432 [40]	154.310 [0.005]	49.98 [0.39]	424.7 [4.49]	183 J=0
157.1	120	67	157.0 [0.7]	120 [30]	53.33 [3.33]	156.781 [0.003]	120	47.09 [0.32]	183 J=1
170.4	64	25	170.7 [0.1]	65 [17]	27 [3]	170.708 [0.002]	46.44 [5.16]	37.41 [0.33]	186
173.9	90	47	173.8 [0.1]	90 [30]	52.67 [3.33]	173.687 [0.003]	90	49.80 [0.42]	183 J=1
184.5	63	1100	184.17 [0.14]	57 [5]	1100 [50]	184.055 [0.006]	57.93 [0.19]	1161 [3.8]	184
192	70	35	192.1	70 [30]	35.33 [4]	192.035 [0.020]	70	36.68 [0.36]	183 J=1

Table 1 - Final RPI resonance parameters along with ENDF/B-VI and Mughabghab. The statistical uncertainties from the REFIT analysis are shown the brackets.

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