Measurement of the Ta(n,γ) cross-section at EAR1

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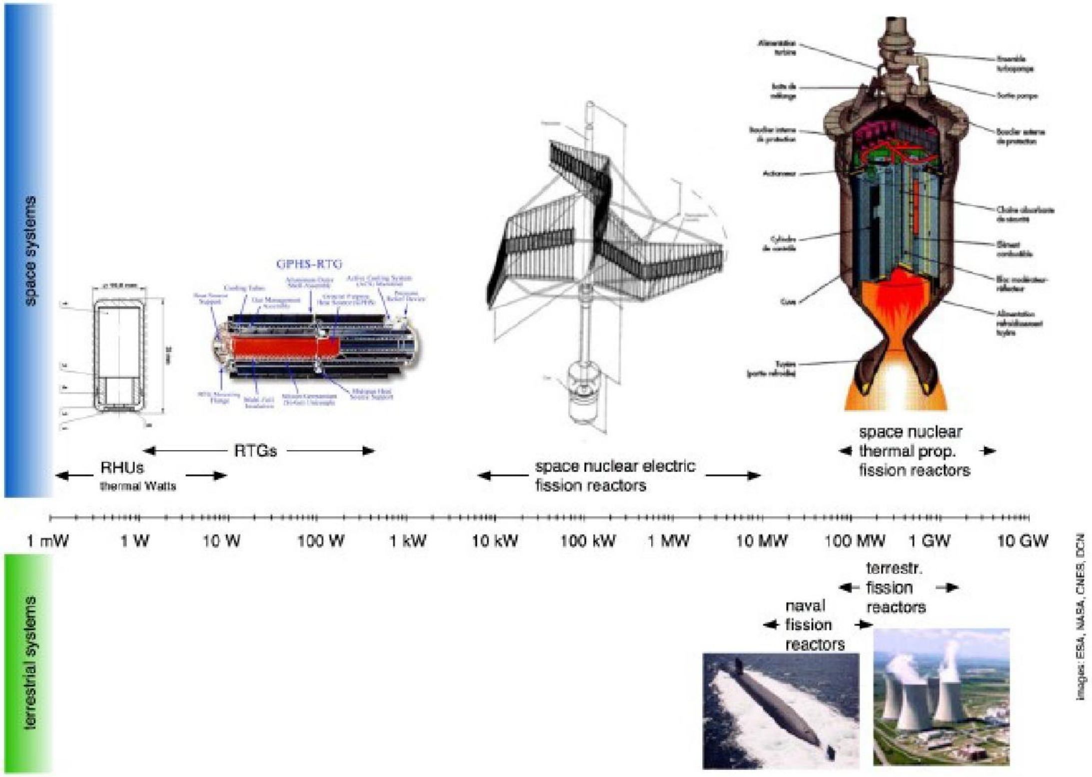
Outline of the presentation

- Introduction and motivation
- Previous measurements and evaluations of Ta
- Ta measurement at n_TOF EAR1
- Beam time request

Reactors for space

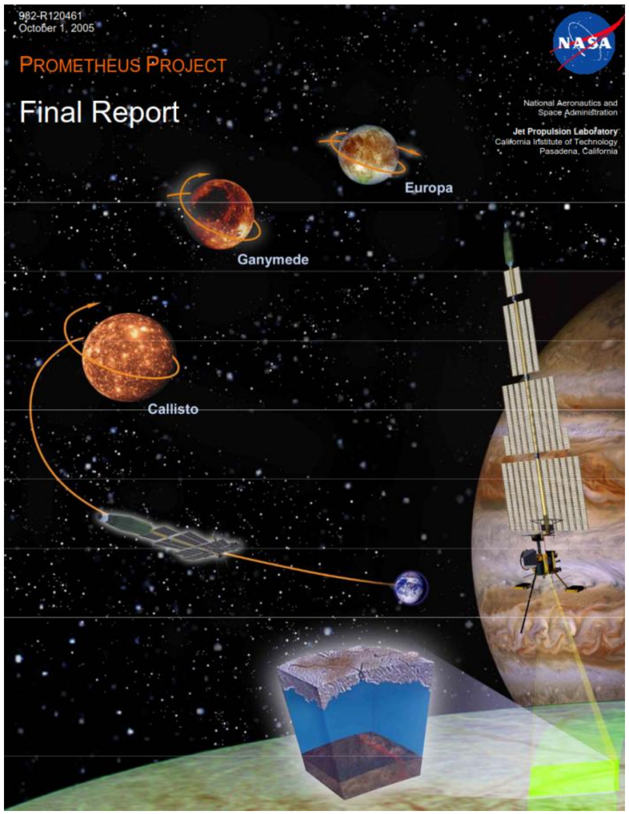
The absence of hydrocarbon power sources in space and the limitations of batteries have led to the development of photovoltaic and nuclear devices.



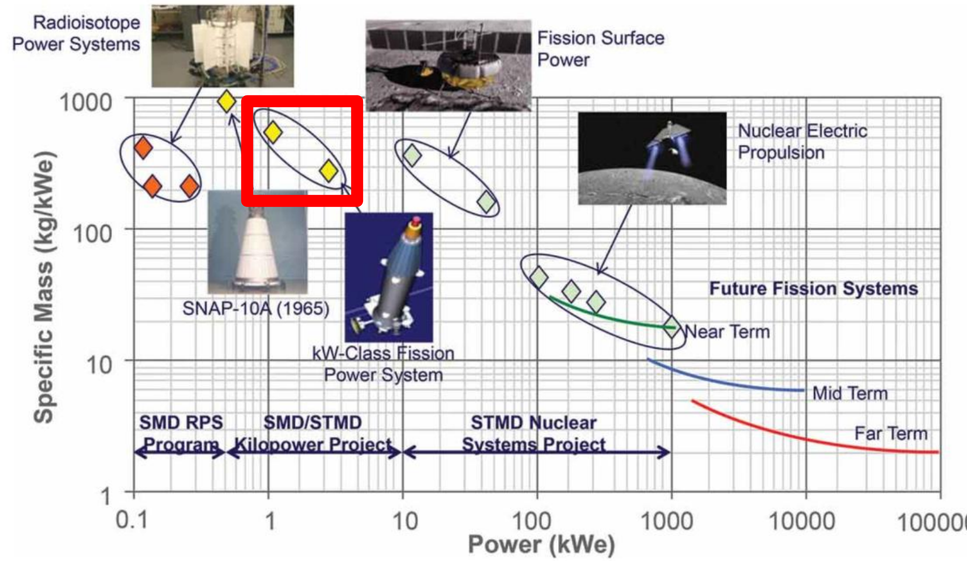
For space missions to Jupiter and beyond and surface missions on Mars nuclear devices are the most suitable option. When spacecrafts require more than 100 kW for power, nuclear reactors are much more cost-effective than RPS.

The NASA projects

The Prometheus project



The Kilopower project



nance map.[1] SMD is the NASA Science Mission Directorate; STMD is the NASA Space Technology Mission Directorate.

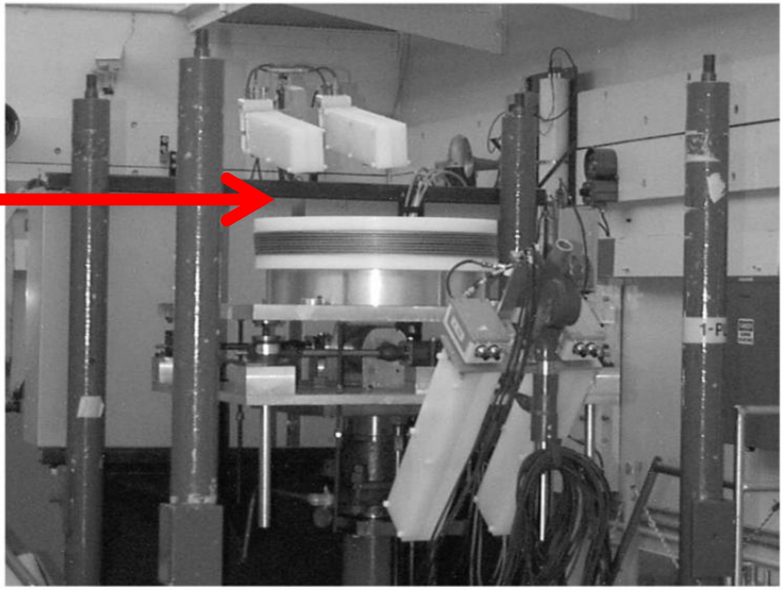
Fig. 9. LANL and NASA engineers lowering the top of the vacuum chamber over the Stirling engines.

The Krusty experiment has already test a 1kW fission power system on earth.

Refractory metals and critical experiments

Refractory metals are needed for the space nuclear reactors that operate at high temperatures. The available materials are Mo, W, Rh, and **Ta**.

Critical experiments in refractory materials were done as part of the Prometheus Project.



Uncertainty	Energy spectrum in the experiment			Mass differences in percentage
	<0.625 eV	0.625 eV-100 keV	<100 keV	
Ta-2.5W-1	0.0%	14.0%	86.0%	0.17
Ta-2.5W-2	0.0%	20.7%	79.3%	9.25
Ta-2.5W-3	0.0%	31.1%	68.9%	7.67
Ta-2.5W-4	3.7%	43.4%	52.9%	7.48

Considerable differences for experiments with Ta in the keV region.
There are also differences in the experiments with moderators.

Thermal Epithermal eXperiments (TEX)

TEX is a project to perform critical experiments that span a wide range of fission energy. The ^{239}Pu experiments of TEX were performed with Ta as a diluent.

Preliminary results with ZPPR

Adding tantalum worsened the calculated results, with **intermediate and fast systems calculating approximately 0.5-1.5% differences** pointing to issues with the tantalum cross sections.

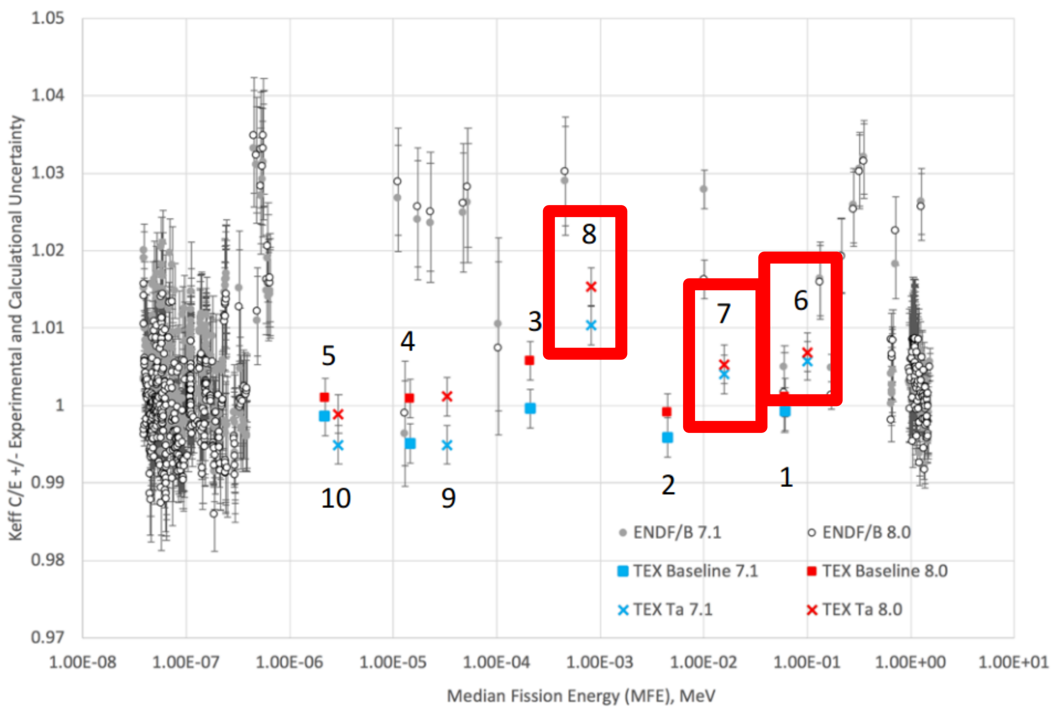


Fig. 2. Plutonium TEX Calculational over Experimental (C/E) Results (colored markers), Overlaid with Plutonium Benchmark Configurations (gray markers) as a Function of Medium Fission Energy.

Tantalum CS for fusion and ADS

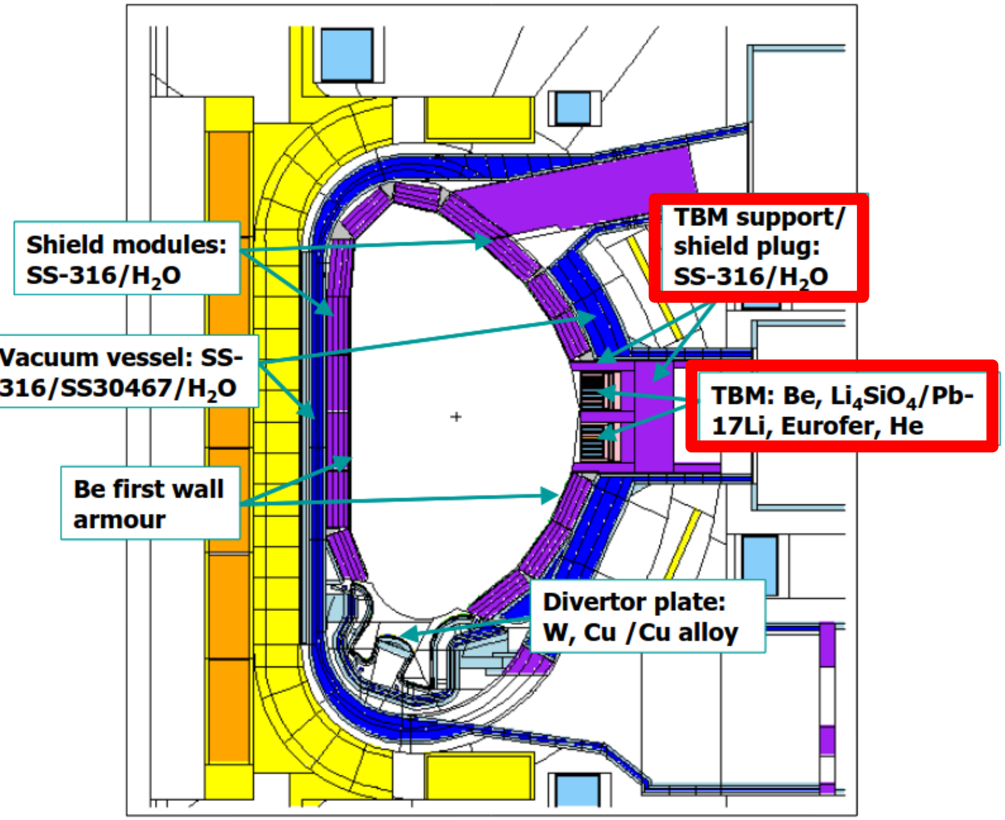
Tantalum is considered one of the high-priority elements for which well-qualified evaluated data sets are required for the ITER and IFMIF fusion projects.

Test Blanket Module (TBM) includes Eurofer, that contains Tantalum.
Ta is also present in the super-conducting magnets of the reactor.

Previous works claim an uncertainty lower than 10% is needed in the Ta capture cross section from thermal to 1keV. This energy region is important due to the activation of Ta by thermalized neutrons.

Tantalum have been also considered as the target for producing neutrons in Accelerator Driven Systems (ADS).

The ITER reactor



Previous measurements

The previous measurements used for the evaluations and the recent measurements are:

	Type	Range
Harvey (1953)	Transmission	1-700 eV
Belanova (1973)	Transmission	2-70 eV
Mughabghab (1975)	Compilation	4-200 eV
Yamamuro (1980)	Capture	3-100 keV
Mackin (1984)	Capture	2.6-1900 keV
Tsubone (1987)	Transmission	100-4000 eV
Meaze (2005)	Transmission	1-100 eV
McDermott (2017)	Capture	0.1 eV-1 MeV
Brown (2018)	Cap/Trans	0.3-500 keV

Limitations of previous measurements

	Type	Range
Harvey (1953)	Transmission	1-700 eV
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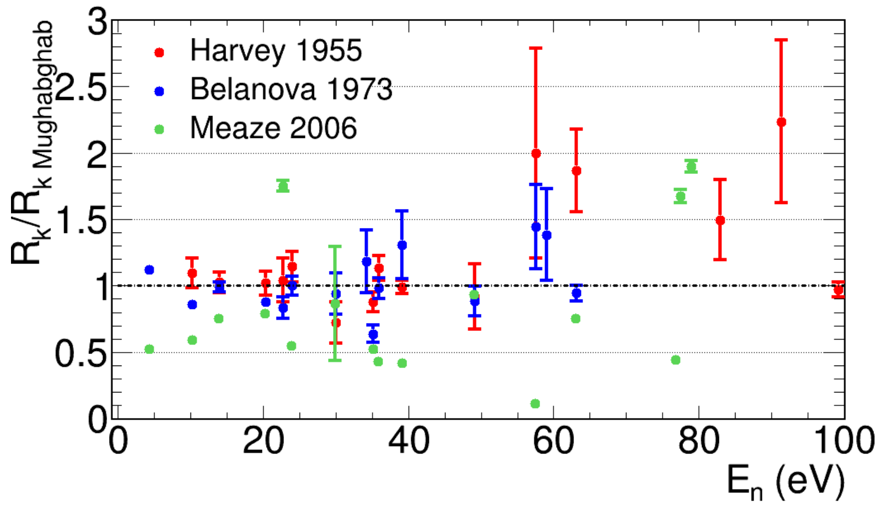
Meaze reports very different RP. The Γ_γ parameters are four times larger



The Brown and McDemortt measurement have considerable limitations:

- **All the detectors are at the same angle.**
- **The samples have more than 1 mm thickness**, so considerable multiple scattering and photon attenuation corrections are needed (>30%).
- The measurements **of Macklin, Tsobune and Yamamuro also use samples thicker** than 1 mm.

The RP or the yield of **the McDemortt measurement are not available.**

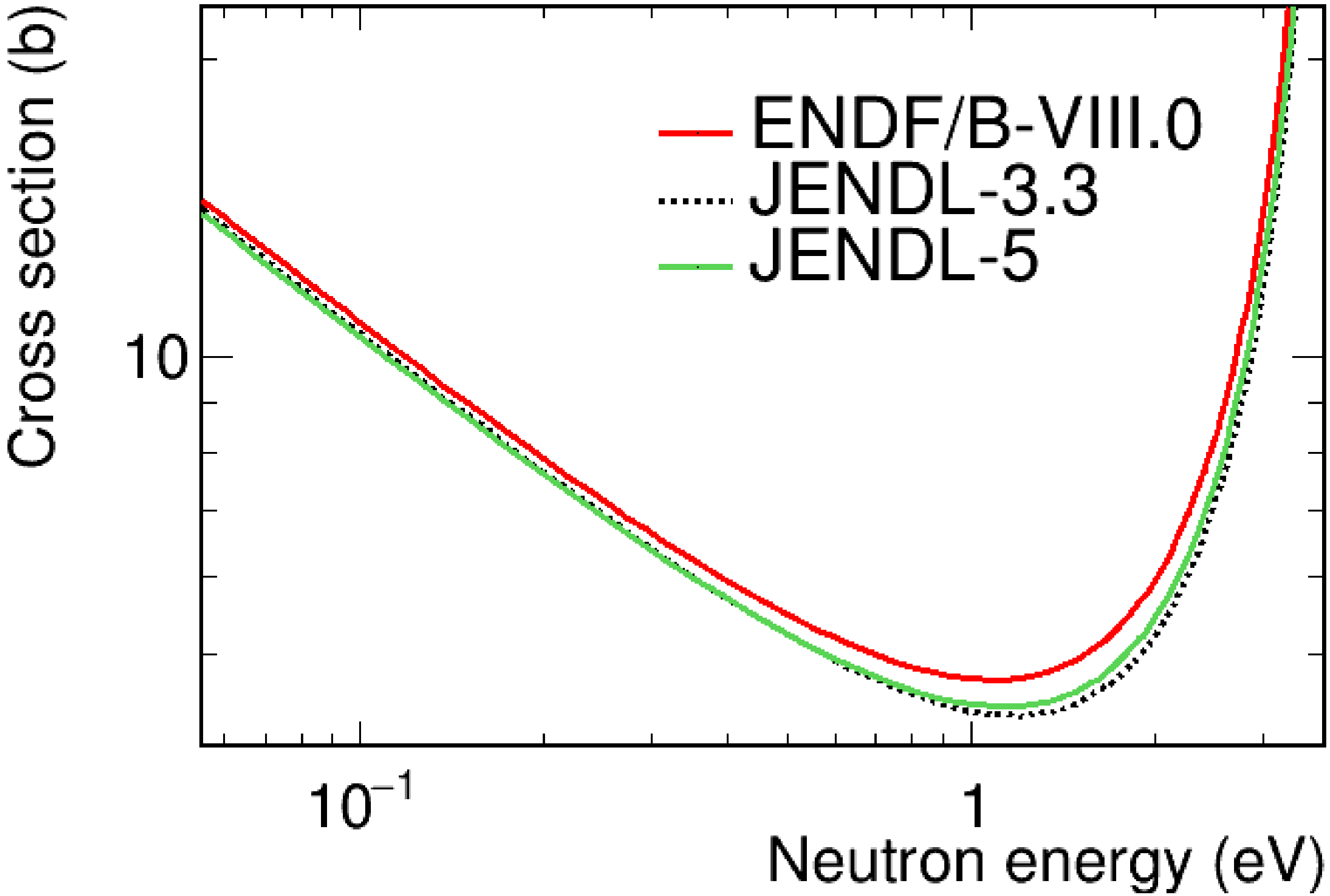
Evaluations

The JENDL-4 and JEFF-3.3 libraries take the values from JENDL-3.3

	Based in	Range RP
ENDF/B-VIII.0	Mughabghab and Macklin	4-300 eV
JENDL-3.3	Mughabghab, Macklin, Tsubone and Yamamuro	4-2400 eV
JENDL-5.0	Mughabghab, Macklin, Tsubone, Yamamuro and **Endo** (**new measurement at J-PARC** not published yet between 1 and 200 eV)	4-2400 eV

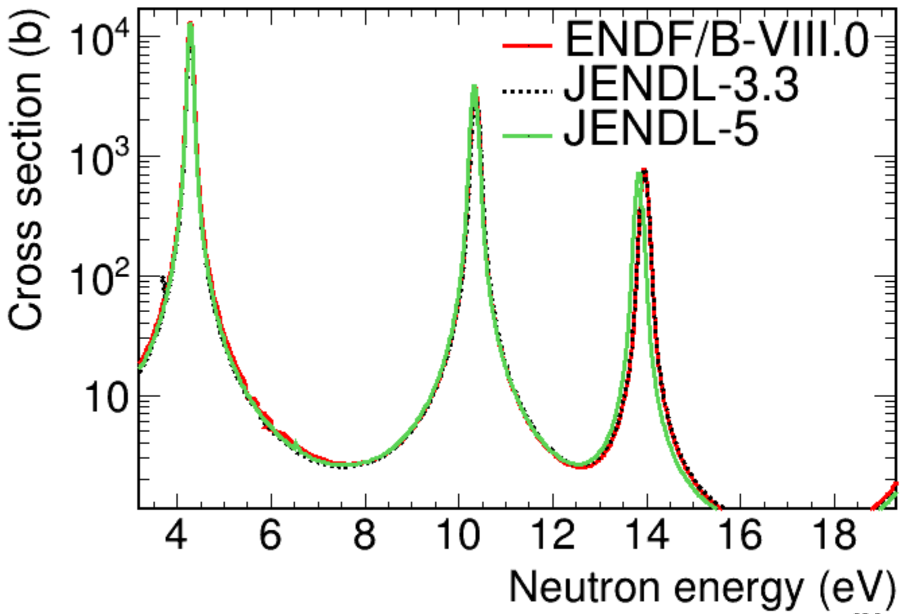
Differences between evaluations

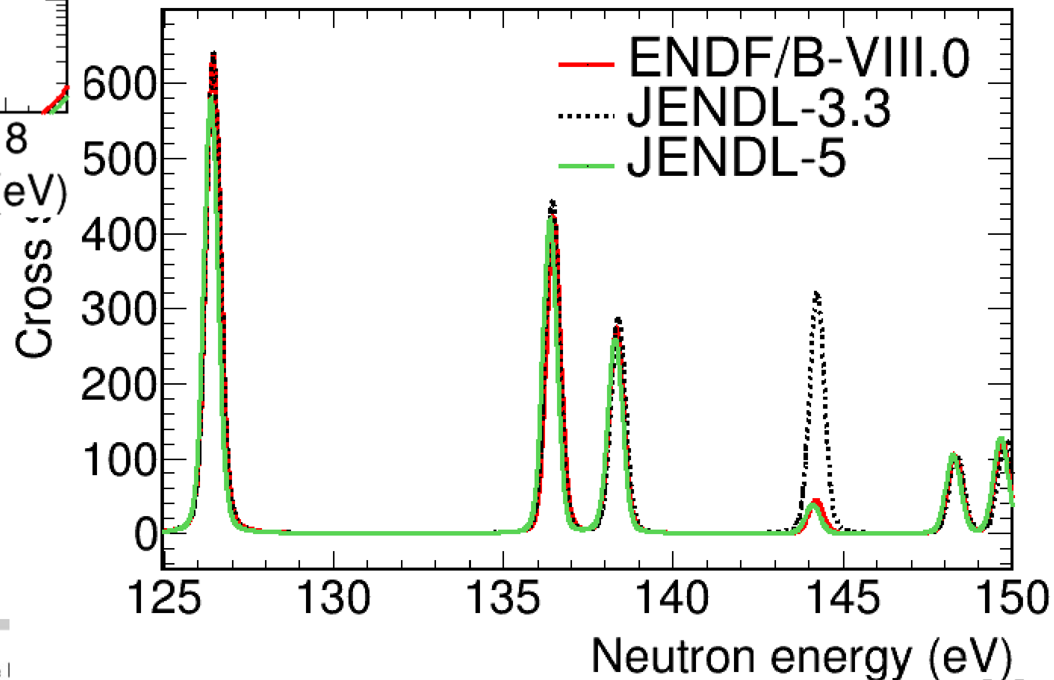
At energies below 4 eV ENDF/B-VIII.0 is ~5% higher than JENDL-5



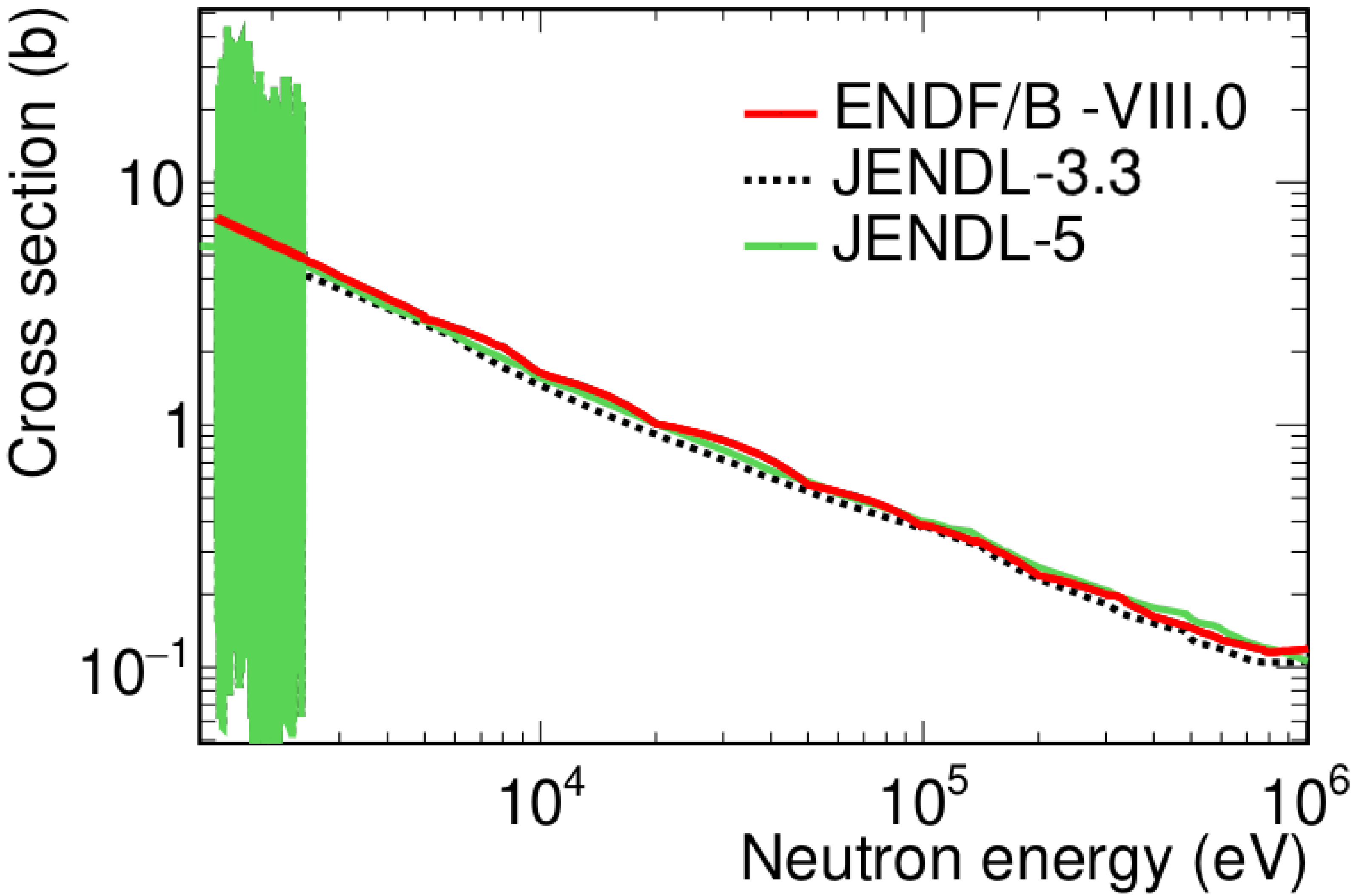
Differences between evaluations

Differences in the RRR between ENDF-8, JENDL-3.3 and JENDL-5

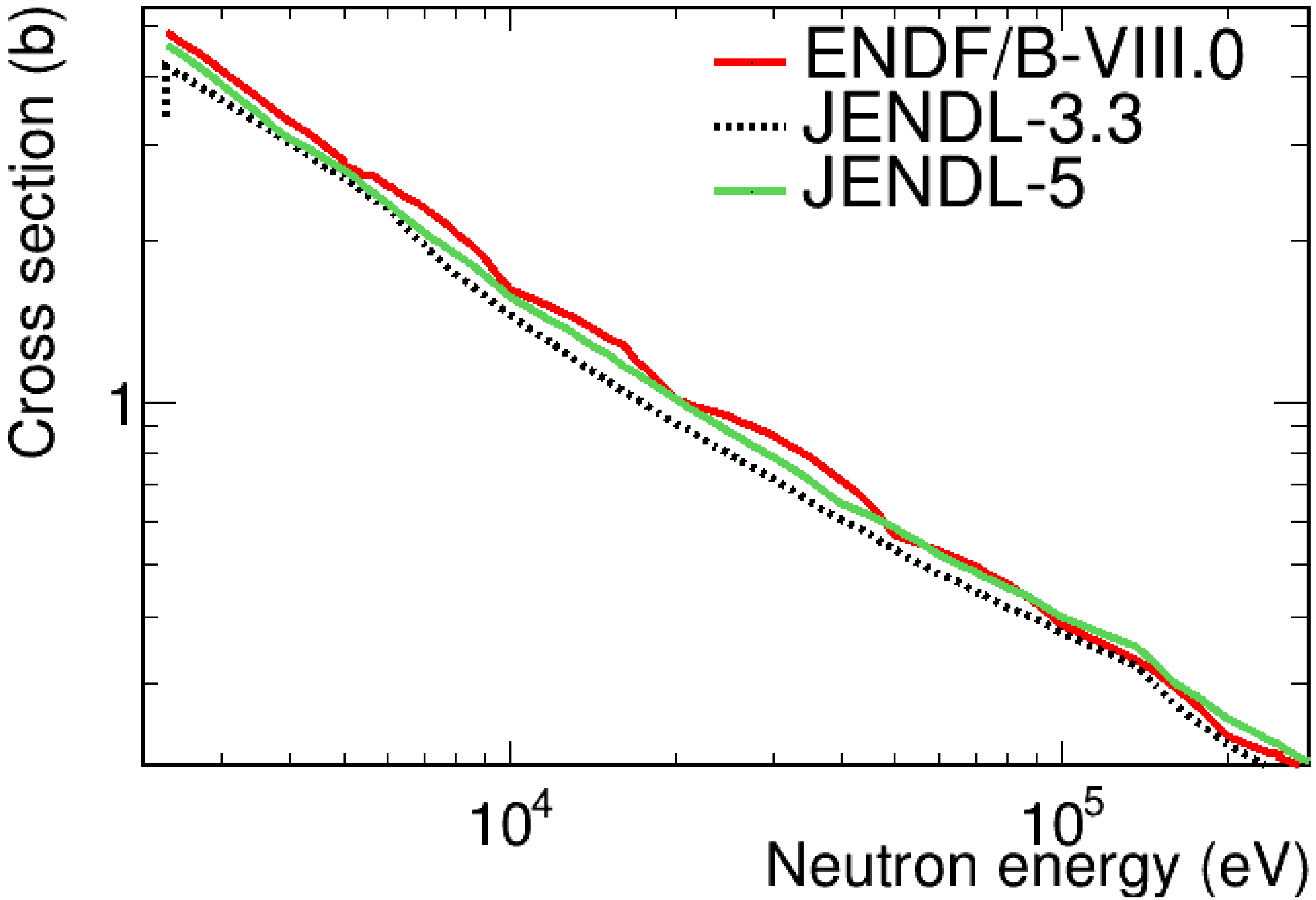




Differences between evaluations

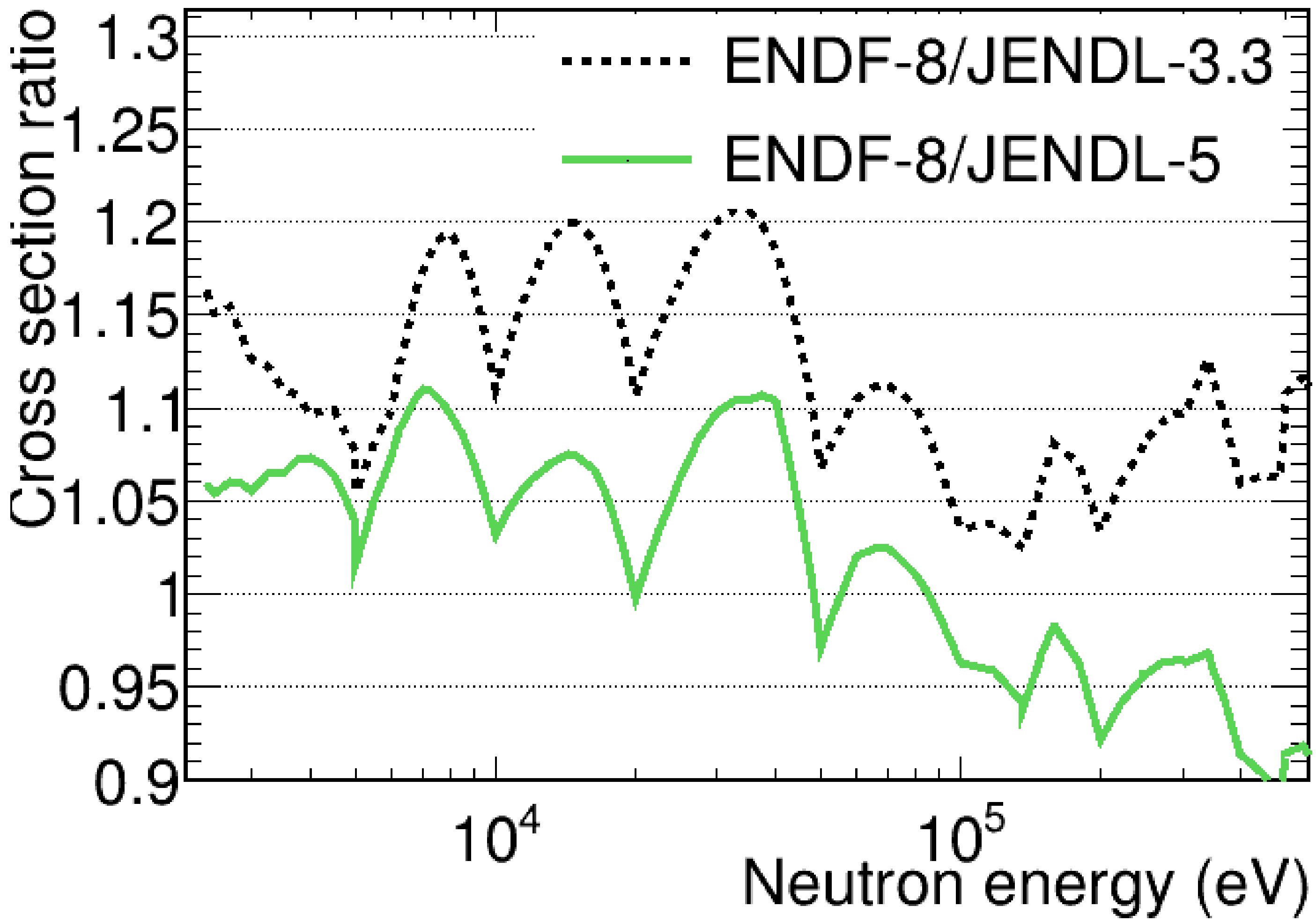


Differences between evaluations



Differences between evaluations

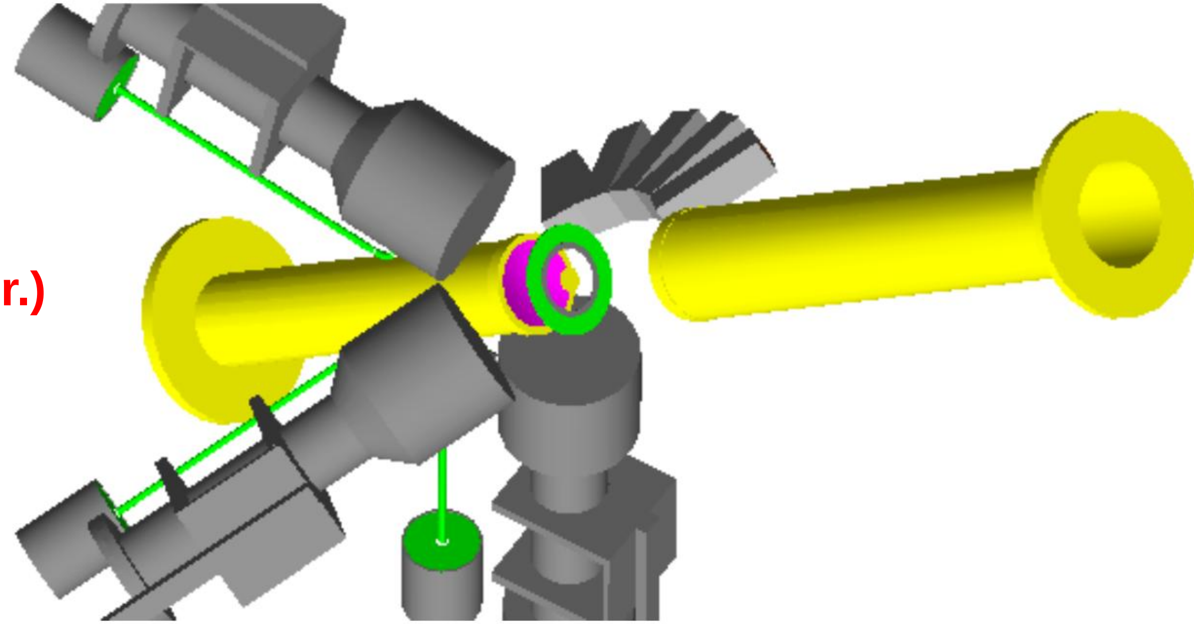
Differences in the URR are as high as 10% between ENDF-8 and JENDL-5



The n_TOF measurement at EAR1

Two samples of Ta (99.99% of ^{181}Ta and $1.2 \cdot 10^{-4}$ ^{180m}Ta) in the range **from 0.1 eV to 500 keV** with an aimed accuracy of 5%:

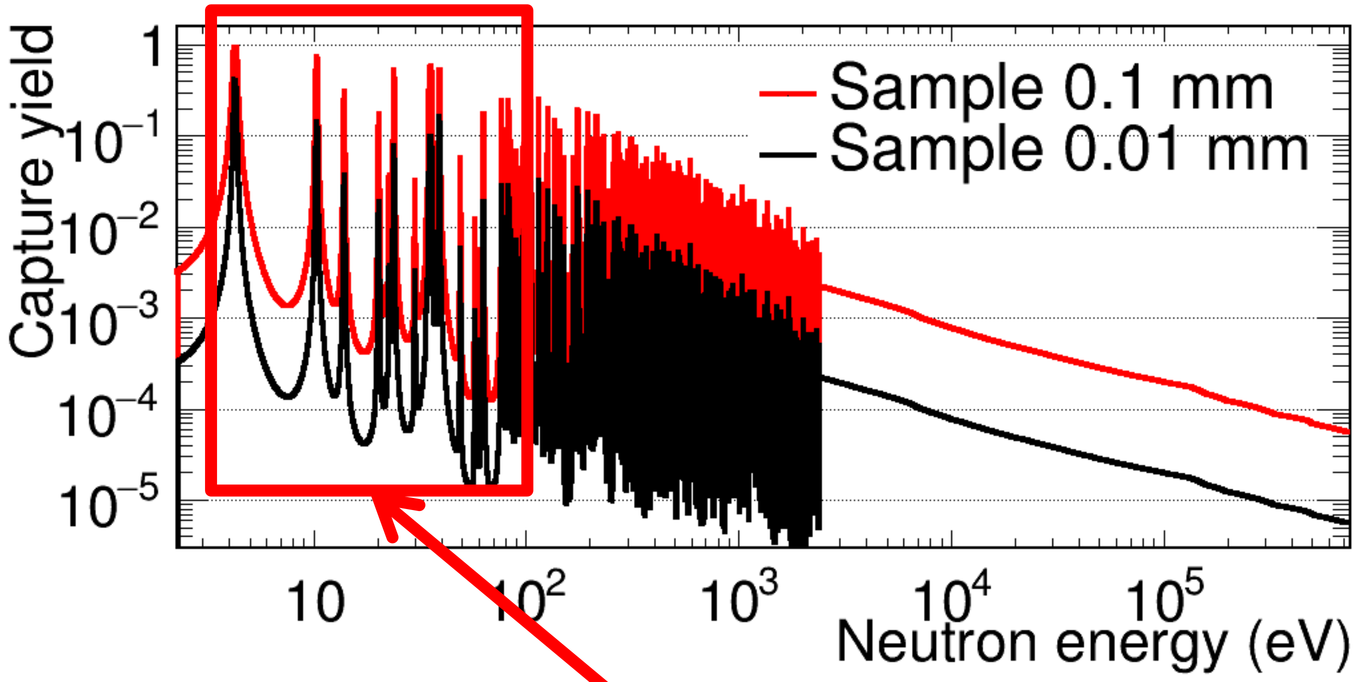
- 3 carbon fibre C_6D_6 detectors (ε_{cas} = ~2) at 125º
- 5 sTED at various angles (ε_{cas} = ~0.2) for the possible anisotropies
- **The total efficiency is ~7%**
- S_n (^{182}Ta) = 6.062 MeV
- **TED and PHWT (~2% uncer.)**
- **Two metallic samples** available at GoodFellow with purities higher than 99.999% would be used



- The measurement would be **self-normalized** with the saturated resonances of Ta and also a gold sample would be measured to check the normalization

The measurement with the Thick sample (0.1 mm)

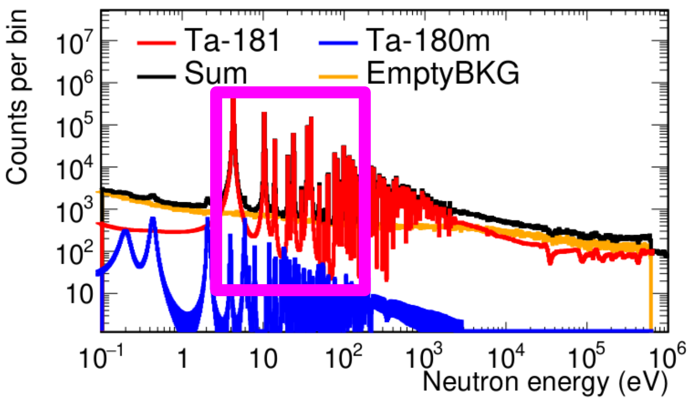
A *Thick* sample of 0.1 mm would be measured, this samples is thinner than the ones used in previous measurements, so no strong shelf-shielding, photon attenuation or multiple corrections would be needed.



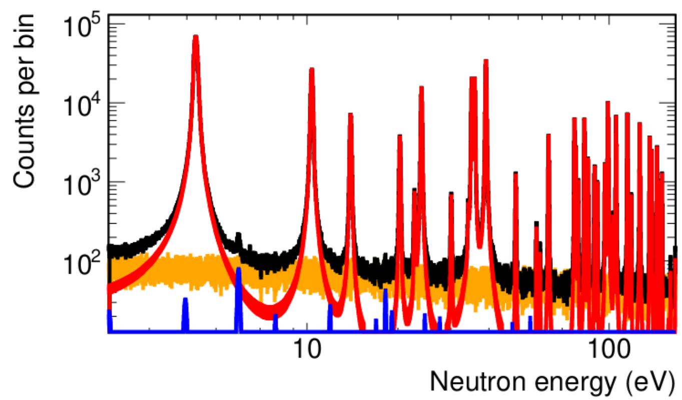
The yield for the *Thick* sample at energies below 200 is close to 1, in order to avoid the considerable corrections a *Thin* sample of 0.01 mm would be used.

The counting rates estimations

Two samples to measure two different energy regions, the counts estimates with $7x10^{17}$ protons.

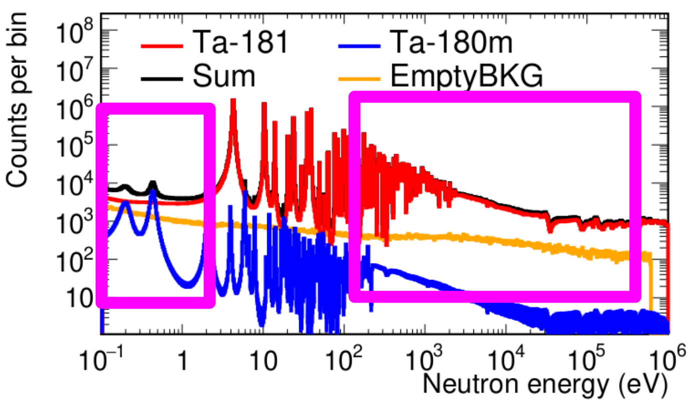


(a) *Thin* sample (0.01 mm), 100 bins per decade

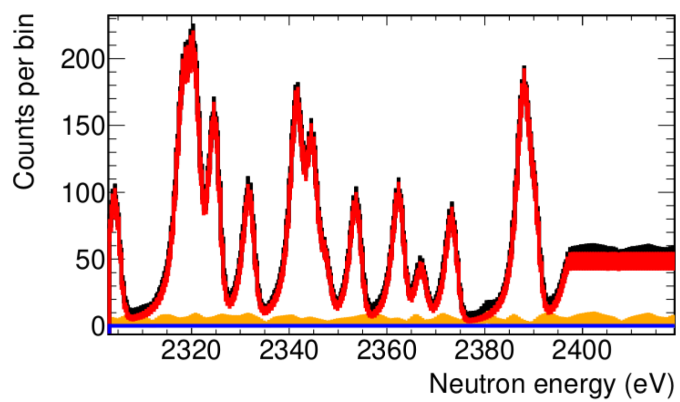


(b) *Thin* sample (0.01 mm), 1000 bins per decade

At least 2000 counts per resonance to fit the RP



(c) *Thick* sample (0.1 mm), 100 bins per decade



(d) *Thick* sample (0.1 mm), 10000 bins per decade

~3% statistical uncertainty in the URR 100 bins decade

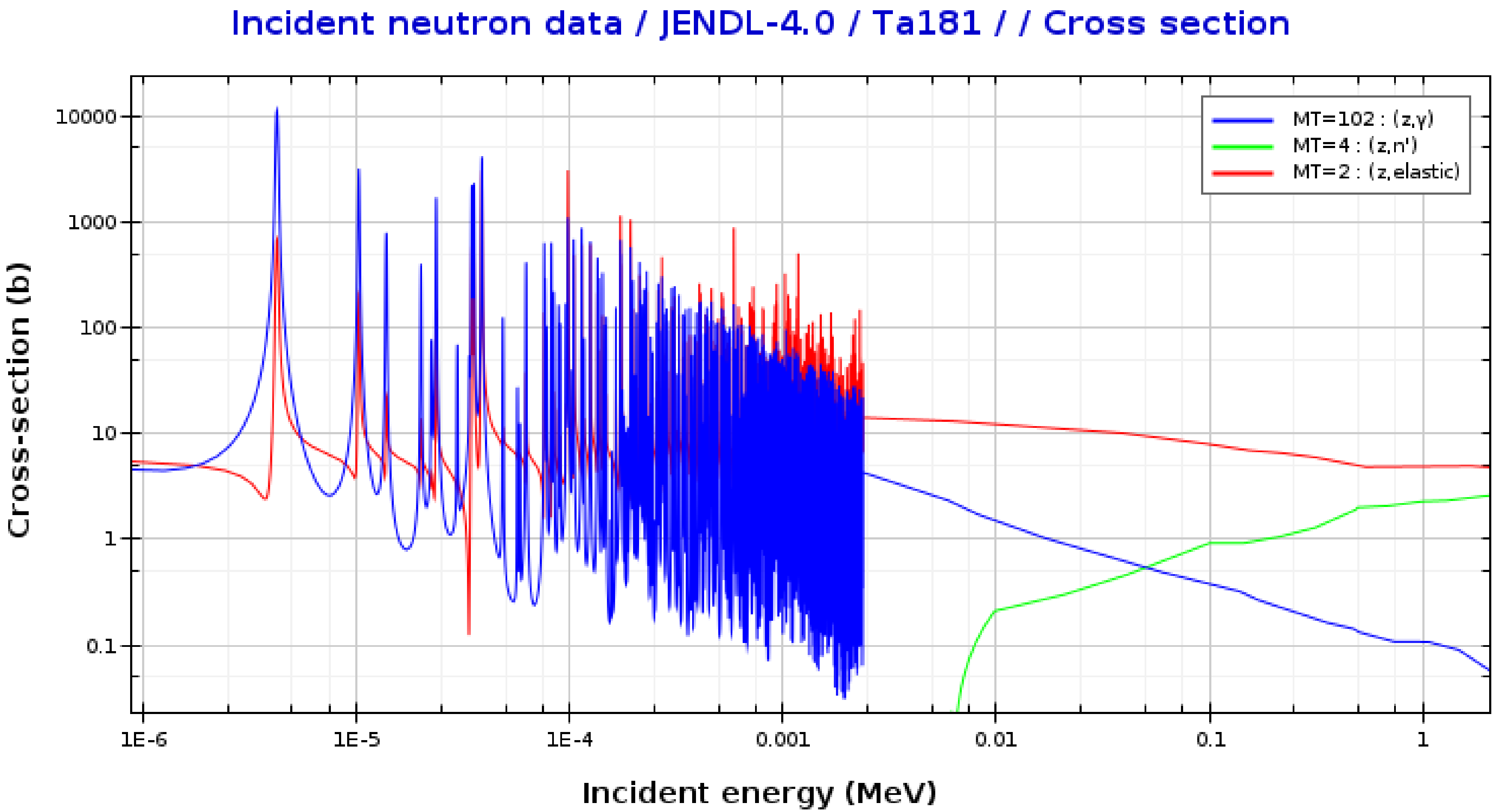
Summary, conclusions and requested protons

- The capture cross section of Ta is important **for nuclear reactors in space and fusion reactors**.
- **Recent critical experiments show discrepancies**, that may indicate issues with the cross section of Ta.
- The **previous data are discrepant and affected by important experimental corrections** like the self-shielding or angular correlations between γ-rays. There are considerable **difference between the recent evaluations.**
- We propose to measure **the capture C.S. from 0.1 eV to 500 keV at EAR1 with various C_6D_6 detectors** at different angles with an estimated **uncertainty of 5%.**
- **Two metallic samples** would be used to cover all the energy range.
- The requested **number of protons are $2x10^{18}$.**

Measurement	Protons (10^{17})
Thick sample(0.1 mm)	7
Thin sample (0.01 mm)	7
Backgrounds and normalization	6
Total	20

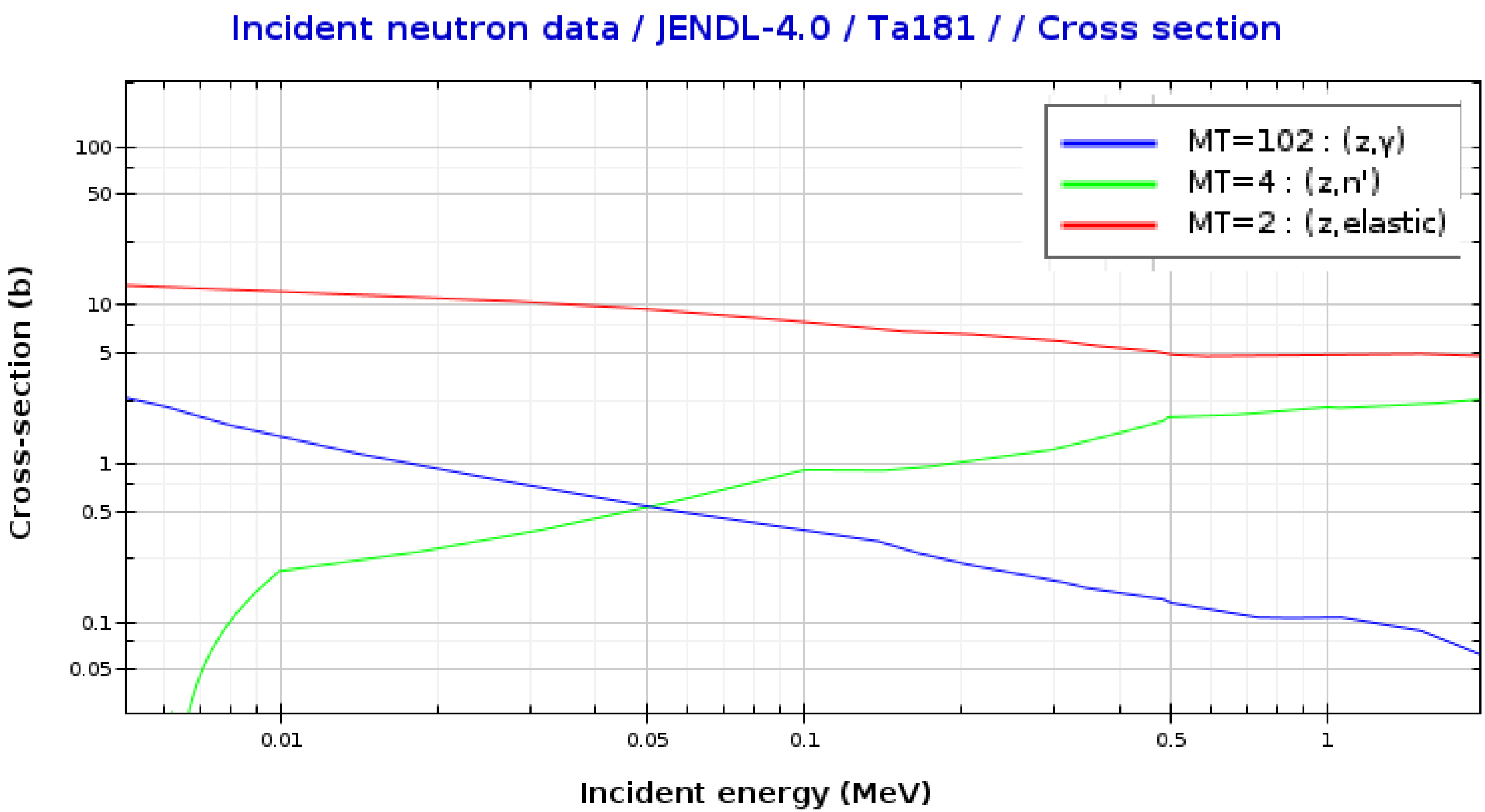
Back-up slides

CS Ta-181



Incident neutron data / JENDL-4.0 / Ta181 / / Cross section
MT=102 : (z,γ)
MT=4 : (z,n')
MT=2 : (z,elastic)
Cross-section (b)
10000
1000
100
10
1
0.1
1E-6
1E-5
1E-4
0.001
0.01
0.1
1
Incident energy (MeV)

CS Ta-181


Incident neutron data / JENDL-4.0 / Ta181 / / Cross section
MT=102 : (z,γ)
MT=4 : (z,n')
MT=2 : (z,elastic)
Cross-section (b)
100
50
10
5
1
0.5
0.1
0.05
0.01
0.05
0.1
0.5
1
Incident energy (MeV)

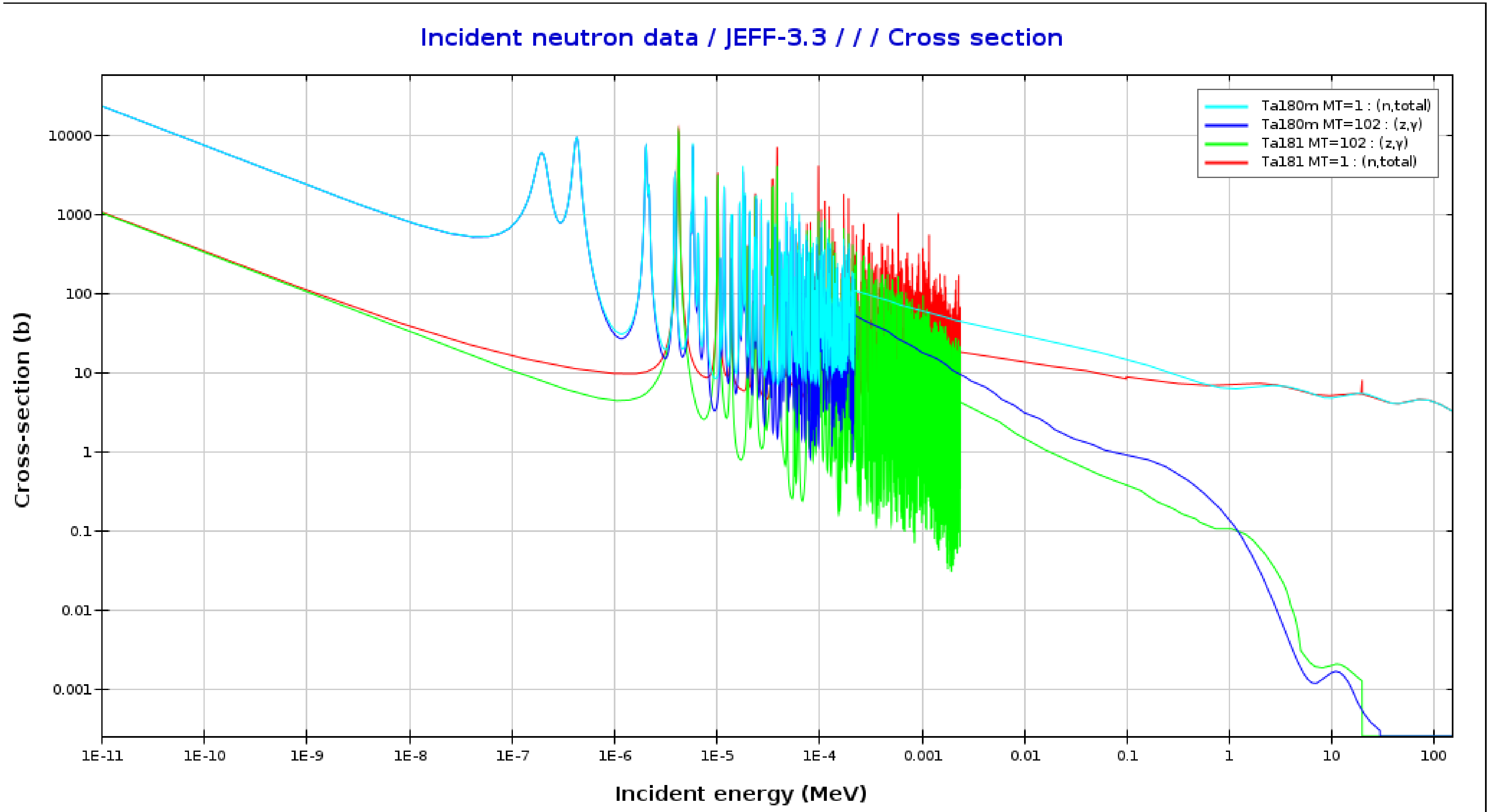
References

References
[1] L. Summerer et al., Proceedings of ICAPP France, 7325 (2007).
[2] V. C. Truscello, et al., SP-100, the US Space Nuclear Reactor Power Program (1983).
[3] Prometheus Project Final Report (Report). NASA/JPL. p. 191 (2005).
[4] M. A. Gibson et al., NASA TN, ID 20170002010 (2017).
[5] P. R. McClure et al., Nuc. Tech., 206 (2020).
[6] K. Stephenson et al., Proceedings of the 8th European Space Power Conference, 108 (2007).
[7] D. Bogart et al., NASA TN, ID 19700007991 (1970).
[8] R. R. Hickman et al., NASA TN, ID 20100021082 (2010).
[9] P. J. Ring and E. D. Sayre. AIP Conference Proceedings 699, 806 (2004).
[10] M. Zerkle et al., Tech. Rep. B-TM-1639, Bettis Atomic Power Laboratory (2006).
[11] D. Loaiza et al., Nucl. Sci. Eng. 160, 217 (2008).
[12] C. Percher et al., “Final design for (TEX)“ 13592-US-ANS (2015).
[13] C. Percher et al., “Thermal Epithermal eXperiments (TEX)”, Proceedings 11th ICNC (2019).
[14] OCED-NEA. ADS and FR in advanced nuclear fuel cycles. ISBN: 92-64-18482-1 (2002).
[15] L. Yang and W. Zhan Sci. China Technol. Sci. 58, 1705–1711 (2015).
[16] A. I. Dubrouski and A. I. Kiyavitskaya Phys. Part. Nuclei Lett. 17, 19–26 (2020).
[17] F. Brossa et al., Jour. Nuc. Mat., 103, 261-265 (1981).
[18] E. Tejado et al., Jour. Nuc. Mat., 467, 2, 949-955 (2015).
[19] V. A. Makhlai et al., Jour. Mat. Ene., 9, 116-122 (2016).
[20] U. Fischer et al. AIP Conf. Proceedings, 769, 1478–1485, (2005).
[21] E.T. Cheng et al., JAERI-Conf–2000-005, (2000).
[22] J. A. Harvey, D. J. Hughes, R. S. Carter, and V. E. Pilcher. Phys. Rev. 99, 10 (1955).
[23] T. S. Belanova et al., Sov. Atomic Energy, vol. 38, no. 6, pp. 553–554 (1975).
[24] S. Mughabghab and D. Gader, BNL, Upton, NY, USA, Tech. Rep. BNL325 (1973).
[25] AKM. M. H. Meaze et al., Jour. Kor. Phys. Soc., 48, 4, 827834 (2006).
[26] B. J. McDermott et al., Phys. Rev. C 96, 014607 (2017).

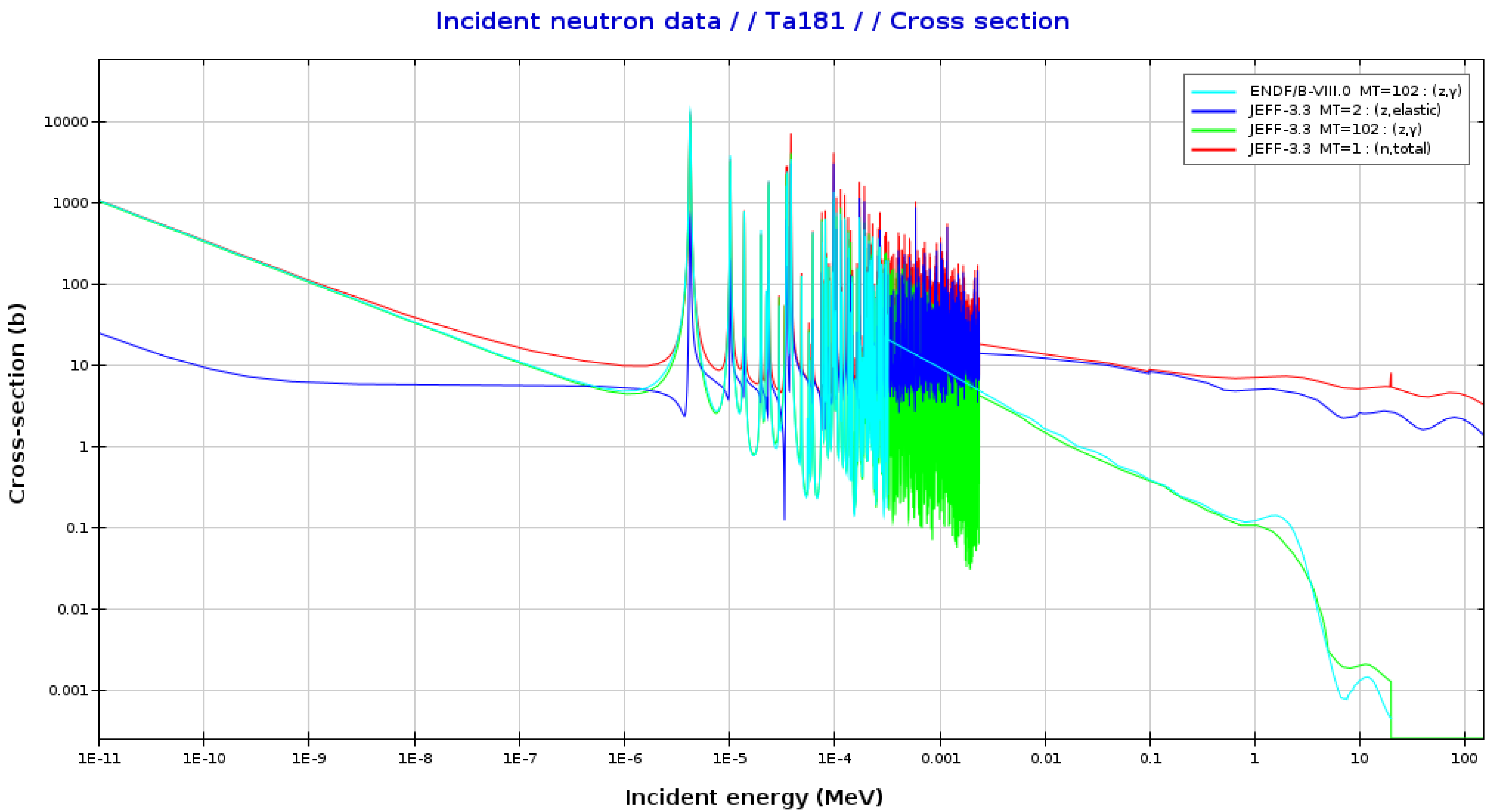
References

[27] R. L. Macklin, Nucl. Sci. Eng. 86, 362 (1984).
[28] I. Tsubone et al., J. Nuc. Sci. Tech., vol. 24, no. 12, pp. 975–987 (1987).
[29] N. Yamamuroet et al., J. Nuc. Sci. Tech., vol. 17, no. 8, pp. 582–592 (1980).
[30] J. M. Brown et al., Nucl. Sci. Eng. 194:3, 221-231 (2020).
[31] J. M. Brown et al., PhD Thesis (2019).
[32] D. A. Brown et al., Nucl. Data Sheets 148, 1 (2018).
[33] A. J. M. Plompen et al., Eur. Phys. J. A 56, 181 (2020).
[34] K. Shibata et al., J. Nuc. Sci. Tech. 48:1, 1-30 (2011).
[35] K. Shibata et al., J. Nucl. Sci. Technol., vol. 39, no. 11, pp. 1125–1136 (2002).
[36] O. Iwamoto et al., ”Japanese Evaluated Nuclear Data Library 5”, to be published.
[37] N. W. Thompson et al., ”Progress on Using a LSDS”, AccApp 15 (2015).
[38] M. Weiser et al., Pure Appl. Chem., vol. 85, no. 5, pp. 1047–1078 (2013).
[39] P. F. Mastinu et al.; New C6D6 detectors,CERN-n TOF-PUB-2013-002 (2013).
[40] V. Alcayne et al. The sTED detector. Talk in the n TOF CM (2022).
[41] U. Abbondanno et al, Nucl. Instrum. Methods A, 521 (2004).
[42] Webpage of Goodfellow. Retrieve August 2022..

Capture C.S. of 181 and 180m



Capture C.S.



Incident neutron data / / Ta181 / / Cross section
ENDF/B-VIII.0 MT=102 : (z,γ)
JEFF-3.3 MT=2 : (z,elastic)
JEFF-3.3 MT=102 : (z,γ)
JEFF-3.3 MT=1 : (n,total)
Cross-section (b)
10000
1000
100
10
1
0.1
0.01
0.001
1E-11
1E-10
1E-9
1E-8
1E-7
1E-6
1E-5
1E-4
0.001
0.01
0.1
1
10
100
Incident energy (MeV)

SPIN

Er	T=300 K							
	I	ℓ	J	Γ	Γn	Γγ	Γf	σ(T)
-44.0000...	7/2	0	4	0.2549110	0.1999110	0.055000...	0.000000	19954.29...
-11.7000...	7/2	0	3	0.075685...	0.020685...	0.055000...	0.000000	14897.59...
4.280000...	7/2	0	4	0.056200...	0.003200...	0.053000...	0.000000	12458.72...
10.36000...	7/2	0	3	0.068999...	0.004000...	0.064999...	0.000000	3490.344...
13.95000...	7/2	0	4	0.055013...	0.001013...	0.054000...	0.000000	791.4041...
20.29000...	7/2	0	3	0.053097...	0.001097...	0.052000...	0.000000	391.6341...
22.72000...	7/2	0	3	0.060240...	0.000240...	0.060000...	0.000000	71.70551...
23.92000...	7/2	0	4	0.067155...	0.005155...	0.062000...	0.000000	1812.799...
30.02000...	7/2	0	3	0.055320...	0.000320...	0.055000...	0.000000	64.43455...
34.19000...	7/2	0	4	0.060168...	0.000168...	0.060000...	0.000000	35.91727...
35.14000...	7/2	0	3	0.087285...	0.018285...	0.068999...	0.000000	2778.407...
35.90000...	7/2	0	4	0.079222...	0.014222...	0.064999...	0.000000	2734.333...
39.12000...	7/2	0	4	0.1042666	0.044266...	0.060000...	0.000000	7198.116...
49.13000...	7/2	0	3	0.055200...	0.001200...	0.054000...	0.000000	117.3634...

JENDL-5

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History
14-11 Evaluated with CCONE code by K.Shibata (JAEA)  /1/
18-07 Activation cross sections and MF=3,6/MT=600-849 added.
20-10 Energies of discrete primary photons were corrected.
21-10 Resolved resonance parameters were replaced by N.Iwamoto.
21-11 above 20 MeV, JENDL-4.0/HE merged by O.Iwamoto
21-11 (MF6/MT5) recoil spectrum added by O.Iwamoto
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MF= 2 Resonance parameters                                  7328 1451   23
  MT=151 Resolved and unresolved resonance parameters       7328 1451   24
    Resolved resonance region: 1.0e-5 eV - 2.4 keV          7328 1451   25
      Parameters were taken from Refs./2,3,4/ for positive  7328 1451   26
      resonances, and ENDF/B-IV for a negative resonance.   7328 1451   27
      These parameters remain unchanged from JENDL-4.0.     7328 1451   28
      The latest data obtained by Meaze et al./5/ were not  7328 1451   29
      adopted, since the radiation widths at many resonances 7328 1451  30
      were extremely large.                                 7328 1451   31
      The parameters of 4.27,10.3,13.8,20.2,22.7,23.9,30.0, 7328 1451   32
      34.2,35.1,35.9,39.1,49.1,63.0,76.8,78.8,82.8,89.5,91.3, 7328 1451 33
      96.9,99.2,105.4,115.0,126.3,136.3,138.2,144.1,148.2,  7328 1451   34
      149.6-eV s-wave resonances were replaced into the results 7328 1451 35
      of J-PARC MLF ANNRI/6/.                               7328 1451   36
                                                            7328 1451   37
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References                                                        732
 1) K.Shibata, J. Nucl. Sci. Technol., 53, 957 (2016).            732
 2) S.F. Mughabghab and D.I. Gardner, BNL-325, 3rd ed. (1973).    732
 3) R.L. Macklin, Nucl. Sci. Eng., 86, 362 (1984).                732
 4) I. Tsubone et al., J. Nucl. Sci. Technol., 24, 975 (1987).    732
 5) A.K.M. Moinul Haque Meaze, J. Korean Phys. Soc., 48, 827      732
    (2006).                                                       732
 6) S.Endo et al., J. Nucl. Sci. Technol., in press (2022).       732
 7) O.Iwamoto, J. Nucl. Sci. Technol., 44, 687 (2007).            732
 8) S.F. Mughabghab, Atlas of Neutron Resonances (2006).          732
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The LSDS experiment

PROGRESS ON USING A LEAD SLOWING-DOWN SPECTROMETER TO MEASURE NEUTRON CAPTURE CROSS SECTIONS

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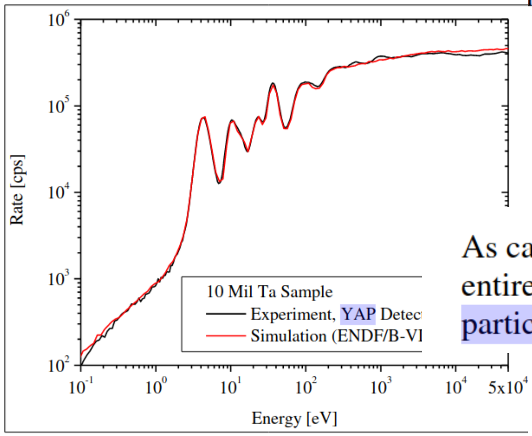
BSTRACT

uclear data is required for simulations of nuclear reactors and other nuclear applications. The accuracy
this data is crucial, and is increasing becoming a limiting factor on the accuracy of nuclear simulations.
ıe progress of further developing the method of using a Lead Slowing-Down



As can be seen in Figure 2, the simulation and experimental results for natural tantalum (which is almost entirely ^{181}Ta) match very well from 0.1 eV to 300 eV, but above this point there are differences. This is particularly interesting as the unresolved resonance region in tantalum begins above 330 keV. The

Figure 2: Measurements of Tantalum and Sil

http://homepages.rpi.edu/~danony/Papers