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A comparison of reaction rate calculations using ENDF/B-VII with critical assembly measurements

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Abstract. We present critical assembly reaction rate data, and modeling of the same using the recently released ENDF/B-VII library. While some of the experimental measurements were performed as long as 50 years ago, the results have not been widely used/available outside of Los Alamos. Over the years, a variety of target foils were fabricated and placed in differing neutron spectrum/fluence environments within critical assemblies. Neutron-induced reactions such as (n,γ), (n,2n), and (n,f) on these targets were measured, typically referenced to ^{235}U(n,f) or ^{239}Pu(n,f). Because the cross section for the latter reactions are now well known, these experiments provide a rich data set for testing evaluated cross sections. Due to the large variety of critical assemblies that were historically available at Los Alamos, it was possible to make measurements in spectral environments ranging from hard (Pu Jezebel, center of Pu Flattop) through intermediate (Big Ten) to degraded (reflector region of Flattop). This broad range of configurations allows us to test both the cross section magnitudes and their energy dependencies. We will present data, along with reaction rate predictions using primarily MCNP5 in conjunction with ENDF/B-VII, for a number of target nuclei, including iridium, isotopes of uranium (e.g., 233, 235, 237, 238), neptunium (237), plutonium (239), and americium (241).

1 Introduction

Integral reaction rate measurements provide an important experimental constraint on, and guidance for, the modeling of nuclear cross sections. Such experiments, performed (for example) in critical assemblies, are also useful for testing new cross section evaluations. Recently, the lastest release of the Evaluated Nuclear Data File library, ENDF/B-VII, has been published [1]. The current paper presents a comparison of critical assembly model calculations, incorporating ENDF/B-VII data, to historic reaction rate measurements performed at Los Alamos. While some of the data presented here have been reported internally [2], many of these results have not been previously published outside of Los Alamos. Thus the current contribution is focused on making these results available to the larger nuclear data community.

2 Experimental

The data reported here represent many critical assembly experiments, dating from 1956 to 1974. A brief description of the critical assemblies is given in table 1.

In all cases, thin samples were prepared containing the relevant target nuclide, which were positioned in various locations (depending on the assembly) within the neutron flux.

After irradiation, the samples were retrieved from the assembly and processed using radiochemical techniques. Dissolution in strong acid, followed by chemical separation, was performed prior to determination of activation products via γ-spectroscopy and/or β^- counting.

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Table 1. Critical assemblies used in the collection of data for this report.

Assembly name	Core	Reflector	Reference
Popsy	Pu	Natural U	[3]
Jezebel	Pu	None	[4]
Godiva	^{235}U	None	[4]
Topsy	^{235}U	Natural U	[5]
Flattop	^{235}U or Pu	Natural U	[4]
Bigten	$\approx$ 10% ^{235}U	Depleted U	[4]

3 Calculations

Most of the calculations reported here were performed using MCNP5 [6], and utilized the recently released ENDF/B-VII cross section library [1]. The calculational descriptions of the critical assemblies were taken from [7].

4 Results and discussion

Due to the limited space available for this summary, commentary is necessarily brief. A more extensive publication is in preparation that will expand on the results presented here.

4.1 Iridium

Because it posesses isotopes that respond (relatively) uniquely to specific neutron energy ranges, iridium is useful as a spectral index, not unlike ^{238}U(n,f)/^{235}U(n,f). This is demonstrated in figure 1, where it is seen that ^{191}Ir(n,γ) and ^{193}Ir(n,n') can be used to provide a measure of neutron energy across a broad spectral region. Iridium activation data, measured in both U- and Pu-core critical assemblies, are presented in table 2.

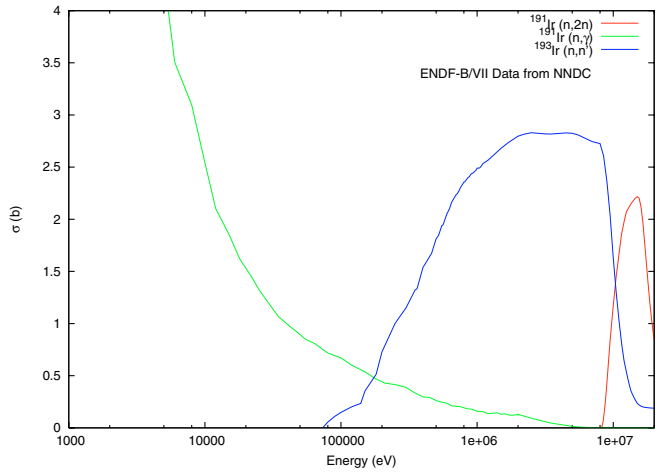

Fig. 1. ENDF/B-VII Ir cross section data, showing spectral sensitivity.

Table 2. Ir data.

Ratio to ^{235}U(n,f)					
^{238}U(n,f)	^{191}Ir(n,2n)	^{191}Ir(n,γ)	^{193}Ir(n,n')	Crit. Assy.	Position (cm)
2.180E-2	3.58E-4	3.907E-1	4.096E-2	Flattop-25	14.63
3.570E-2		3.519E-1	5.428E-2	Flattop-25	10.82
3.730E-2		3.390E-1	6.057E-2	Bigten	
5.760E-2	8.83E-4	3.181E-1	7.515E-2	Flattop-25	8.2
1.130E-1	1.44E-3	2.455E-1	1.312E-1	Flattop-25	5.72
1.298E-1	1.63E-3	2.406E-1	1.481E-1	Flattop-25	5.05
1.437E-1		2.217E-1	1.600E-1	Flattop-25	3.54
1.467E-1	1.81E-3	2.147E-1	1.680E-1	Flattop-25	1.11
1.477E-1	1.84E-3	2.127E-1	1.700E-1	Flattop-25	0.88
2.091E-1	3.03E-3	1.674E-1	2.141E-1	Jezebel	

Comparisons between experimental measurements and critical assembly calculations are shown in figures 2 and 3.

Overall, the agreement between the calculated activation ratios and experiment is quite good, except for ^{191}Ir(n,2n) in the lower energy experiments (reflector of Flattop), where conversion is small for this high threshold (≈8.2 MeV) reaction.

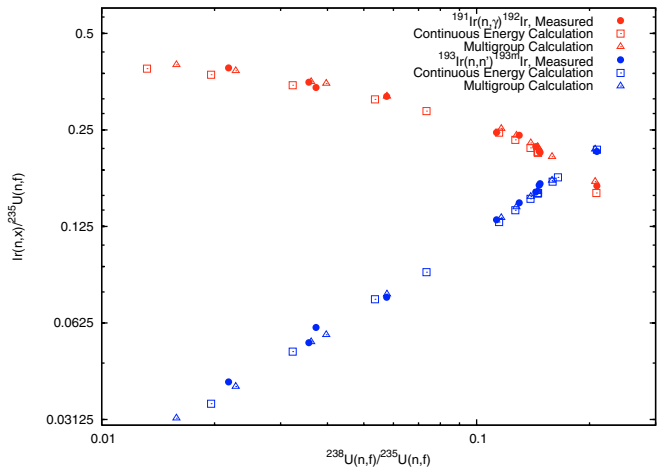

Fig. 2. Plot of ^{191}Ir and ^{193}Ir activations vs. ^{238}U(n,f)/^{235}U(n,f).

4.2 Uranium

Data for irradiation of ^{236}U targets is presented in table 3, and a comparison of MCNP5 calculations to the experimental

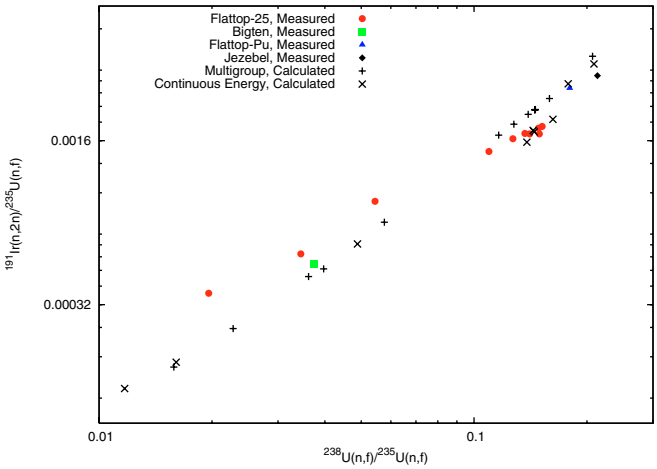

Fig. 3. Plot of data and calculation for ^{191}Ir(n,2n)/^{235}U(n,f), referenced to ^{238}U(n,f)/^{235}U(n,f).

results is shown in figures 4 and 5. It is seen that for ^{236}U(n,f), the agreement between calculation and experiment is good for irradiations in the assembly core, while a larger deviation is observed in the degraded spectrum of the reflector (fig. 4). For the ^{236}U(n,γ) reaction, the MCNP calculation is consistently low compared to data (fig. 5).

Table 3. ^{236}U data.

Ratio to ^{235}U(n,f)				
^{238}U(n,f)	^{236}U(n,f)	^{236}U(n,γ)	Assy.	loc. (cm)
2.050E-2	8.24E-2	1.780E-1	Flattop-25	15.3
3.490E-2	1.07E-1	1.720E-1	Flattop-25	11
6.240E-2	1.54E-1	1.530E-1	Flattop-25	8.1
1.254E-1	2.92E-1	1.280E-1	Flattop-25	5
1.270E-1	2.85E-1	1.300E-1	Flattop-25	4.9
1.414E-1	3.04E-1	1.240E-1	Flattop-25	3.9
1.468E-1	3.17E-1		Flattop-25	0.2
1.527E-1	3.33E-1	1.220E-1	Flattop-25	0.8
1.540E-1	3.15E-1	1.195E-1	Flattop-25	1.0

Table 4. ^{237}U data.

Ratio to ^{235}U(n,f)			
^{238}U(n,f)	^{237}U(n,f)	Assy.	loc. (cm)
0.1397	0.537	Flattop-25	1.11
0.02487	0.391	Flattop-25	13.97

Data for ^{237}U(n,f) is found in table 4 with model calculation comparison in figure 6. Interestingly, for this unstable target, the MCNP calculation agrees better for the lower average neutron energy datum, as compared to a harder spectrum.

Finally, data for ^{238}U is collected in tables 5 and 6, with comparative plots presented in figures 7 and 8.

The calculated results compare very favorably with the measured data, although larger discrepancies are again seen in the softer spectral environments of the Flattop reflector and Topsy.

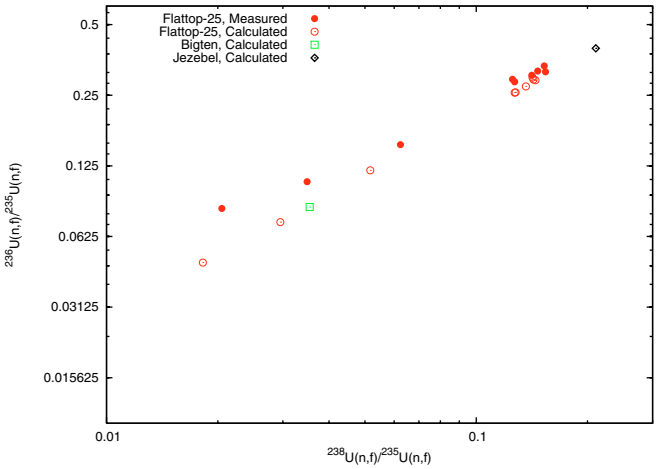

Fig. 4. Comparison of calculation to experiment: ^{236}U.

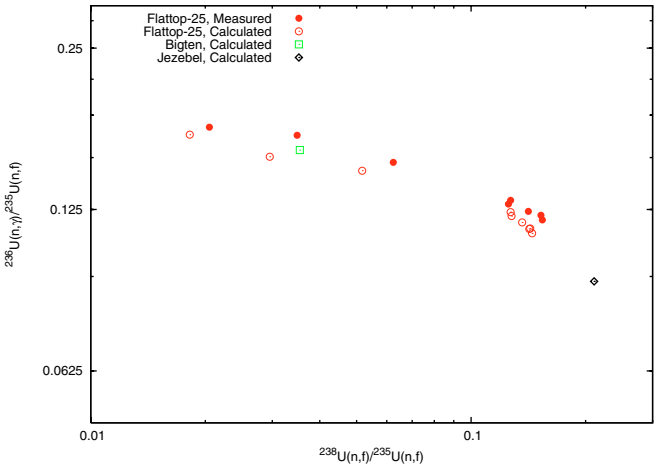

Fig. 5. Comparison of calculation to experiment: ^{236}U.

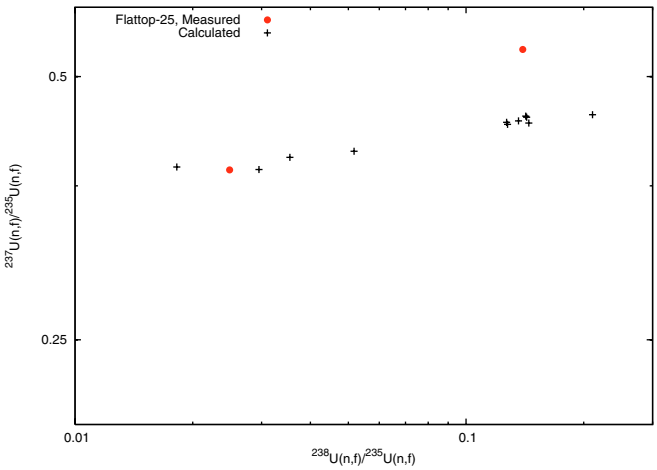

Fig. 6. Comparison of calculation to experiment: ^{237}U.

4.3 Americium

Measurement of the ^{241}Am(n,γ) reaction has been made in many environments. Data for irradiations in U- and Pu-core assemblies, respectively, are presented in tables 7 and 8.

Table 5. ^{238}U data (U assemblies).

Ratio to ^{235}U(n,f)				
^{238}U(n,f)	^{238}U(n,2n)	^{238}U(n,γ)	Assy.	loc. (cm)
1.1471E-2	3.7970E-4		Topsy	25.68
1.3617E-2	5.8553E-4	1.0611E-1	Topsy	20.24
2.04187E-2	8.96963E-4	1.17752E-1	Flattop-25	14.75
2.0602E-2	9.0648E-4	1.1220E-1	Topsy	15.67
2.7291E-2	1.2636E-3	1.1250E-1	Topsy	12.66
2.75553E-2	1.28007E-3	1.13307E-1	Flattop-25	12.78
3.75000E-2	1.73250E-3	1.06119E-1	Bigten	
4.23241E-2	1.69191E-3	1.09518E-1	Flattop-25	9.62
5.0311E-2	2.3696E-3	1.2716E-1	Topsy	9.66
7.00776E-2	3.15537E-3	1.00505E-1	Flattop-25	7.7
9.91197E-2	4.68075E-3	1.00904E-1	Flattop-25	6.31
9.93180E-2	4.70102E-3	9.49281E-2	Flattop-25	6.32
1.1342E-1	5.7278E-3	8.8276E-2	Topsy	5.49
1.24990E-1	5.84752E-3	9.07552E-2	Flattop-25	5.6
1.27369E-1	6.15464E-3	9.44058E-2	Flattop-25	5.16
1.40354E-1	6.65877E-3	9.05140E-2	Flattop-25	3.7
1.41642E-1	6.56435E-3	8.38096E-2	Flattop-25	3.69
1.4473E-1	7.4827E-3	7.6636E-2	Topsy	0.24
1.48382E-1	7.03968E-3	8.86881E-2	Flattop-25	0.01
1.49274E-1	6.96724E-3	8.81763E-2	Flattop-25	1.02
1.52446E-1	7.21574E-3	8.28697E-2	Flattop-25	0.4

Comparison to MCNP5 calculations using ENDF-B/VII is shown in figure 9.

Table 6. ^{238}U data (Pu assemblies).

Ratio to ^{235}U(n,f)				
^{238}U(n,f)	^{238}U(n,2n)	^{238}U(n,γ)	Assy.	loc. (cm)
6.93000E-2	3.5620E-3	9.45252E-2	Flattop-Pu	6.07
1.19100E-1	6.0741E-3	8.93488E-2	Flattop-Pu	4.53
1.58800E-1	8.4482E-3	8.20202E-2	Flattop-Pu	2.97
1.69100E-1	9.2667E-3	7.80227E-2	Flattop-Pu	1.44
2.17000E-2		1.25576E-1	Flattop-Pu	
2.62000E-2		1.15356E-1	Flattop-Pu	
2.12116E-1	1.40934E-2	6.69863E-2	Jezebel	
2.13603E-1	1.45441E-2	6.88015E-2	Jezebel	
2.09638E-1	1.42511E-2	6.79647E-2	Jezebel	
2.14693E-1	1.44533E-2	6.74996E-2	Jezebel	
2.08845E-1	1.42889E-2	6.73944E-2	Jezebel	

Overall, the agreement between the MCNP calculations and data are quite good, highlighting the significant improvement in the ENDF/B-VII evaluation, particularly for the harder Jezebel spectrum.

5 Conclusions

This brief summary has provided tabular data from a number of critical assembly experiments, and graphical comparisons of those data to MCNP calculations using the new ENDF/B-VII cross section evaluations. It is hoped that the additional experimental data presented here will be of use in the nuclear data community.

The authors would like to re-iterate the forthcoming full paper including these and other results that will contain a more thorough discussion of both the experimental measurements and their simulation via calculation.

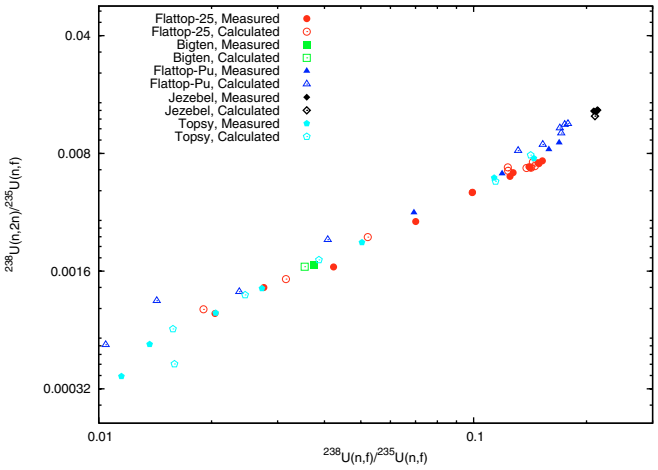

Fig. 7. Comparison of calculation to experiment: ^{238}U.

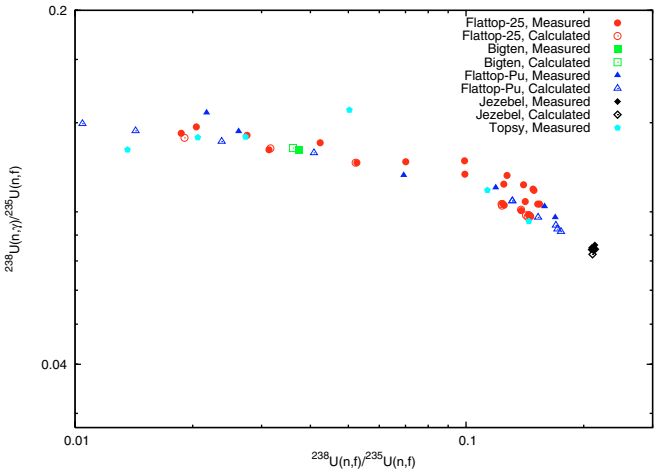

Fig. 8. Comparison of calculation to experiment: ^{238}U.

Table 7. ^{241}Am data (U assemblies).

Ratio to ^{235}U(n,f)			
^{238}U(n,f)	^{241}Am(n,γ)	Assy.	loc. (cm)
2.000E-2	5.5680E-1	Flattop-25	
3.300E-2	4.8610E-1	Flattop-25	
5.400E-2	4.2290E-1	Flattop-25	
1.260E-1	2.9710E-1	Flattop-25	
1.380E-1	2.7740E-1	Flattop-25	
1.460E-1	2.5360E-1	Flattop-25	
1.467E-1	2.5520E-1	Flattop-25	
1.500E-1	2.5010E-1	Flattop-25	
3.710E-2	4.95000E-1	Bigten	

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Table 8. ^{241}Am data (Pu assemblies).

Ratio to ^{235}U(n,f)			
^{238}U(n,f)	^{241}Am(n,γ)	Assy.	loc. (cm)
1.53515E-2	6.17458E-1	Flattop-Pu	
1.93834E-2	5.71464E-1	Flattop-Pu	
2.85215E-2	5.23705E-1	Flattop-Pu	
5.01347E-2	4.42311E-1	Flattop-Pu	
1.34348E-1	2.69738E-1	Flattop-Pu	
1.59120E-1	2.32849E-1	Flattop-Pu	
1.70192E-1	2.16007E-1	Flattop-Pu	
1.75940E-1	2.07189E-1	Flattop-Pu	
1.78760E-1	2.02827E-1	Flattop-Pu	
1.79638E-1	2.01488E-1	Flattop-Pu	
2.091E-1	1.74200E-1	Jezebel	

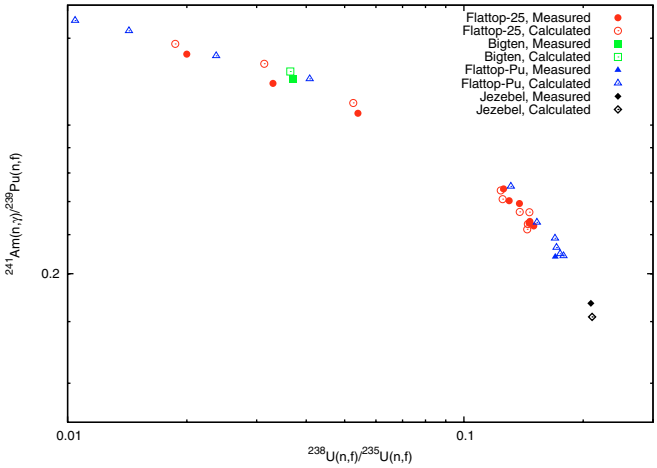

Fig. 9. Comparison of calculation to experiment: ^{241}Am.

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