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Title: Development and Testing of a Revised ENDF/B-VII Capture Cross Section for Cd-113

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Development and Testing of a Revised ENDF/B-VII Capture Cross Section for ^{113}Cd

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A recent paper observed that, relative to ENDF/B-V, ENDF/B-VI produces a marked deterioration in the agreement between calculated and measured values of k_{eff} for a series of benchmarks[4] with cadmium in a highly enriched uranium (HEU) nitrate solution. Subsequent calculations confirm that ENDF/B-VII.0 also produces poor results for those benchmarks.

In response, a new evaluation for the thermal capture cross section of ^{113}Cd has been developed. The new cross section has been shown to produce marked improvement in the agreement between calculated and benchmark values of k_{eff} for that series of benchmarks. It is anticipated that the new ^{113}Cd evaluation will be included in the next interim release of ENDF/B-VII.

Development and Testing of a Revised ENDF/B-VII Capture Cross Section for ^{113}Cd

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OVERVIEW OF PRESENTATION

Description of the experiments

Statement of the problem

Changes to the ^{113}Cd capture cross section

Results with the revised ^{113}Cd capture cross section

Summary and Conclusions

Cd SOLUTION BENCHMARKS

A series of 21 experiments with highly enriched uranyl nitrate solutions containing Cd was performed at Pacific Northwest Laboratory in 1978-79

Two different cylindrical stainless-steel vessels containing a highly enriched uranium (HEU) nitrate solution were surrounded by an effectively infinite reflector of water around and beneath it

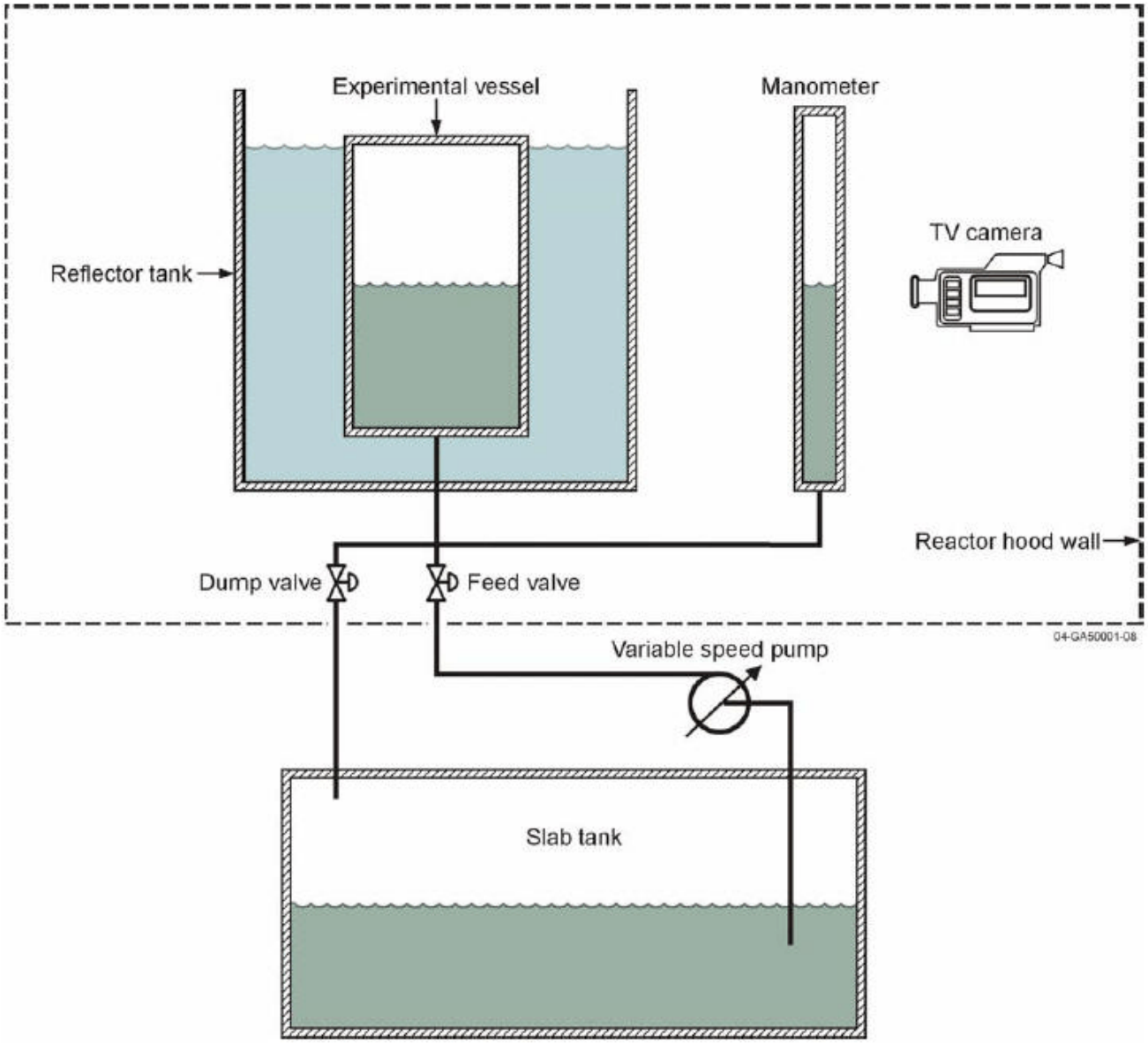
The nitrate solution contained Cd for 16 of the 20 benchmarks, and the water reflector contained Cd for 9 of the benchmarks

The height of the reflector was substantially greater than that of the solution in the vessel in all cases

Criticality was obtained by adjusting the height of the solution

HEU-SOL-THERM-049 in the ICSBEP Handbook contains benchmark specifications for 20 benchmarks based on those experiments (two essentially identical experiments are combined into a single benchmark)

SIMPLIFIED DIAGRAM OF THE EXPERIMENTS



ENDF/B-V, ENDF/B-VI, and ENDF/B-VII.0 RESULTS

A recent paper* pointed out that ENDF/B-VI produces poor results for these benchmarks, even though ENDF/B-V produces reasonable results

The Cd cross sections in ENDF/B-VII.0, released in December 2006, are similar to those in ENDF/B-VI

MCNP5 calculations with ENDF/B-VII.0 nuclear data produce slightly better results than ENDF/B-VI for 14 of the 16 benchmarks that contain Cd in the vessel

Those improvements are primarily the result of better nuclear data for uranium isotopes, especially ^{235}U

Even so, ENDF/B-VII.0 still produces poor results for a majority of the 20 benchmarks

* S. S. Kim, “Analysis of High Enriched Uranyl Nitrate Solution Containing Cadmium,” PHYSOR 2006 (September 2006)

MCNP RESULTS FOR THE BENCHMARKS WITH THE SMALLER VESSEL (24.18 cm DIAMETER)

Case	In-Vessel Cd Conc. (mg/g)	Benchmark k_{eff}	Calculated k_{eff}		
			ENDF/B-V	ENDF/B-VI	ENDF/B-VII.0
1	0	1.0012 ± 0.0026	1.0023 ± 0.0004	0.9972 ± 0.0004	0.9992 ± 0.0002
2*	0	1.0012 ± 0.0029	1.0008 ± 0.0004	0.9948 ± 0.0004	0.9954 ± 0.0002
3	1.208	1.0012 ± 0.0026	1.0005 ± 0.0004	0.9928 ± 0.0004	0.9960 ± 0.0001
4	2.393	1.0012 ± 0.0025	1.0003 ± 0.0004	0.9917 ± 0.0004	0.9953 ± 0.0001
5	3.897	1.0012 ± 0.0025	1.0024 ± 0.0004	0.9922 ± 0.0004	0.9961 ± 0.0001
6	4.069	1.0012 ± 0.0025	1.0066 ± 0.0004	0.9956 ± 0.0004	1.0000 ± 0.0001
7	4.196	1.0012 ± 0.0024	1.0064 ± 0.0004	0.9958 ± 0.0004	1.0002 ± 0.0001
8	4.271	1.0012 ± 0.0024	1.0054 ± 0.0004	0.9943 ± 0.0004	0.9987 ± 0.0001

* Reflector contains Cd

$\sigma < |\Delta k| \leq 2\sigma$ $|\Delta k| > 2\sigma$

MCNP RESULTS FOR THE BENCHMARKS WITH THE LARGER VESSEL (29.16 cm DIAMETER)

Case	In-Vessel Cd Conc. (mg/g)	Benchmark k_{eff}	Calculated k_{eff}		
			ENDF/B-V	ENDF/B-VI	ENDF/B-VII.0
9	0	1.0012 ± 0.0020	1.0006 ± 0.0004	0.9960 ± 0.0004	0.9976 ± 0.0001
10*	0	1.0012 ± 0.0024	0.9942 ± 0.0004	0.9881 ± 0.0004	0.9891 ± 0.0002
11*	1.240	1.0012 ± 0.0022	0.9974 ± 0.0004	0.9893 ± 0.0004	0.9908 ± 0.0001
12*	2.250	1.0012 ± 0.0021	0.9997 ± 0.0004	0.9896 ± 0.0004	0.9924 ± 0.0001
13*	3.362	1.0012 ± 0.0021	1.0006 ± 0.0004	0.9894 ± 0.0004	0.9919 ± 0.0001
14*	4.189	1.0012 ± 0.0020	1.0007 ± 0.0004	0.9890 ± 0.0004	0.9923 ± 0.0001
15*	4.577	1.0012 ± 0.0021	1.0022 ± 0.0004	0.9908 ± 0.0004	0.9941 ± 0.0001
16*	4.897	1.0012 ± 0.0020	1.0014 ± 0.0004	0.9894 ± 0.0004	0.9921 ± 0.0001
17*	5.047	1.0012 ± 0.0021	1.0011 ± 0.0004	0.9883 ± 0.0004	0.9915 ± 0.0001
18	5.032	1.0012 ± 0.0020	1.0009 ± 0.0004	0.9895 ± 0.0004	0.9936 ± 0.0001
19	5.937	1.0012 ± 0.0020	1.0018 ± 0.0004	0.9905 ± 0.0004	0.9939 ± 0.0001
20	6.626	1.0012 ± 0.0019	0.9994 ± 0.0004	0.9876 ± 0.0004	0.9918 ± 0.0001

* Reflector contained Cd

$\sigma < |\Delta k| \leq 2\sigma$ $|\Delta k| > 2\sigma$

ANALYSIS AND REVISIONS

A close comparison of the ENDF/B-V, ENDF/B-VI, and ENDF/B-VII.0 results indicated that the most likely cause of the deterioration is increased thermal absorption by Cd

Almost all thermal absorption in Cd occurs in a single isotope, ^{113}Cd

Most of the thermal absorption in ^{113}Cd occurs in a single resonance at 0.178 eV

A revised thermal capture cross section for ^{113} Cd was generated

A new set of cross sections based on the revised evaluation for ^{113}Cd was created and processed into a library for MCNP

REVISIONS TO THE THERMAL CAPTURE CROSS SECTION FOR ^{113}Cd

The ENDF/B-VII.0 thermal capture cross section for ^{113}Cd was reviewed, with particular attention to the resonance at 0.178 eV

The ENDF/B-VII.0 2200 m/sec capture cross section for ^{113}Cd is 20615 b, compared to 20726 b for ENDF/B-VI

The ENDF/B-VII.0 value is based on an evaluation by S. Mughabghab that recommends a value of 20615 ± 400 b for the 2200 m/sec capture cross section, consistent with pulsed-neutron measurements

Consistent with more recent measurements, the scattering width of that resonance was decreased from 0.65333 meV to 0.62200 meV

That change reduced the thermal capture cross section from 20751 b to 19800 b and reduced the resonance integral from 391.7 b to 376.6 b

MCNP RESULTS FOR THE BENCHMARKS WITH THE SMALLER VESSEL (24.18 cm DIAMETER)

Case	In-Vessel Cd Conc. (mg/g)	Benchmark k_{eff}	Calculated k_{eff}	
			ENDF/B-VII.0	ENDF/B-VII.0 + Revised ^{113}Cd
1	0	1.0012 ± 0.0026	0.9992 ± 0.0002	0.9992 ± 0.0002
2*	0	1.0012 ± 0.0029	0.9954 ± 0.0002	0.9963± 0.0002
3	1.208	1.0012 ± 0.0026	0.9960 ± 0.0001	0.9981 ± 0.0001
4	2.393	1.0012 ± 0.0025	0.9953 ± 0.0001	1.0003 ± 0.0001
5	3.897	1.0012 ± 0.0025	0.9961 ± 0.0001	1.0025 ± 0.0001
6	4.069	1.0012 ± 0.0025	1.0000 ± 0.0001	1.0068 ± 0.0001
7	4.196	1.0012 ± 0.0024	1.0002 ± 0.0001	1.0054 ± 0.0001
8	4.271	1.0012 ± 0.0024	0.9987 ± 0.0001	1.0003 ± 0.0001

* Reflector contained Cd

$\sigma < |\Delta k| \leq 2\sigma$

$|\Delta k| > 2\sigma$

MCNP RESULTS FOR THE BENCHMARKS WITH THE LARGER VESSEL (29.16 cm DIAMETER)

Case	In-Vessel Cd Conc. (mg/g)	Benchmark k_{eff}	Calculated k_{eff}	
			ENDF/B-VII.0	ENDF/B-VII.0 + Revised ^{113}Cd
9	0	1.0012 ± 0.0020	0.9976 ± 0.0001	0.9976 ± 0.0001
10*	0	1.0012 ± 0.0024	0.9891 ± 0.0002	0.9895 ± 0.0002
11*	1.240	1.0012 ± 0.0022	0.9908 ± 0.0001	0.9943 ± 0.0001
12*	2.250	1.0012 ± 0.0021	0.9924 ± 0.0001	0.9971 ± 0.0001
13*	3.362	1.0012 ± 0.0021	0.9919 ± 0.0001	0.9983 ± 0.0001
14*	4.189	1.0012 ± 0.0020	0.9923 ± 0.0001	0.9993 ± 0.0001
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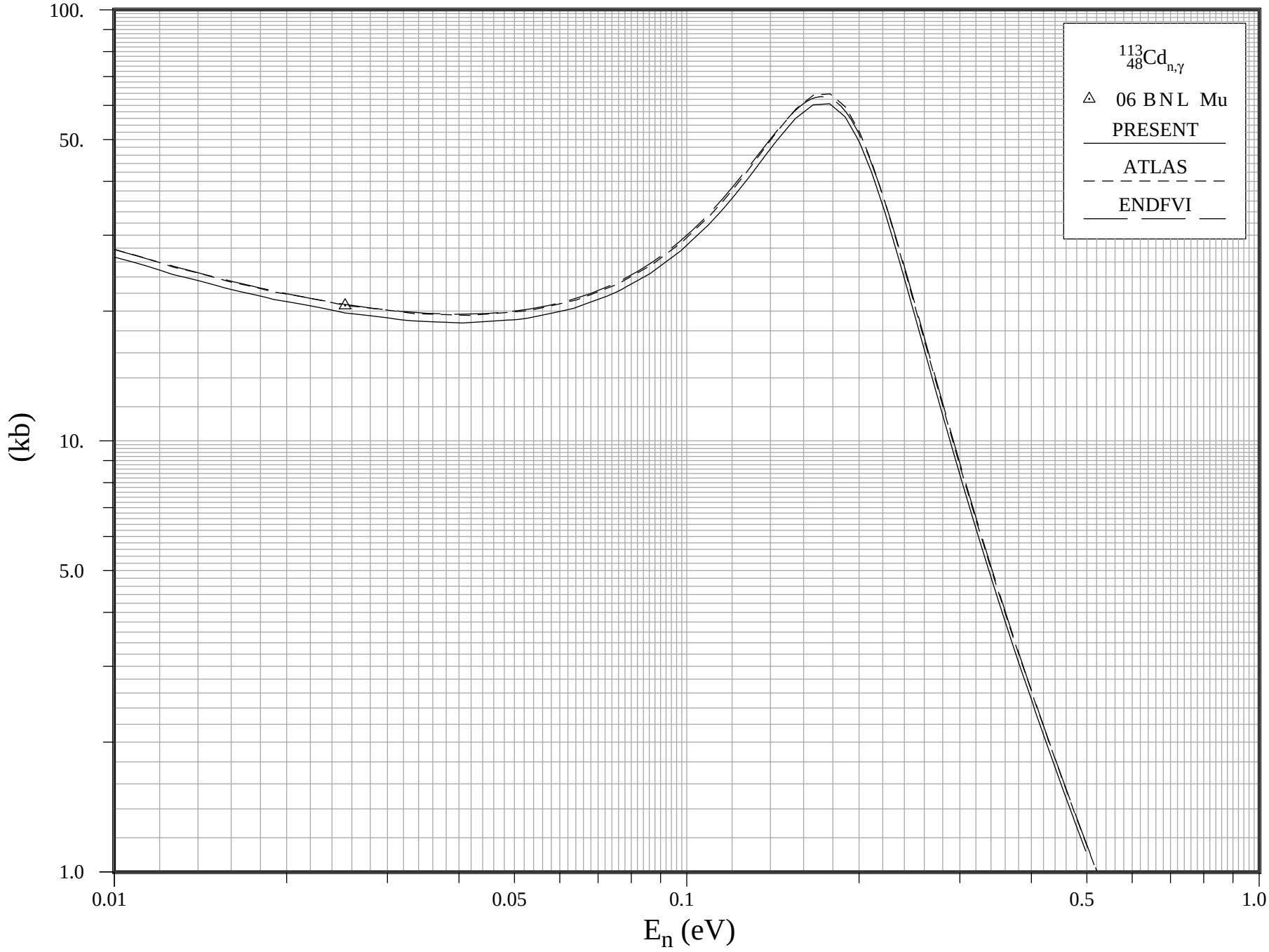
18	5.032	1.0012 ± 0.0020	0.9936 ± 0.0001	1.0014 ± 0.0001
19	5.937	1.0012 ± 0.0020	0.9939 ± 0.0001	1.0023 ± 0.0001
20	6.626	1.0012 ± 0.0019	0.9918 ± 0.0001	1.0007 ± 0.0001

* Reflector contained Cd

$\sigma < |\Delta k| \leq 2\sigma$

$|\Delta k| > 2\sigma$


100.
50.
10.
5.0
1.0
(kb)
0.01
0.05
0.1
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E_n (eV)
$^{113}_{48}Cd_{n,\gamma}$
06 BNL Mu
PRESENT
ATLAS
ENDFVI

SUMMARY AND CONCLUSIONS

A new evaluation for the thermal capture cross section of ^{113}Cd has been developed

The resulting cross section has been shown to produce marked improvement in the agreement between calculated and benchmark values of k_{eff} for a series of thermal benchmarks containing Cd

It is anticipated that the new ^{113}Cd evaluation will be included in the next interim release of ENDF/B-VII