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MCNP Analysis of Various Cross Section Source Data on the ICT-003 (TRIGA) Benchmark

TH Trumbull

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Introduction

- A. Trkov reported a large change in the ICT-003 (Slovenia TRIGA) Benchmark when using the ENDF/B-VII.0 cross section data set (June 2010)
  - Approximately 500 pcm increase in reactivity was observed.
  - This reactivity increase was largely eliminated if JENDL-4.0 ZR91 was substituted into the data set.
- KAPL performed an analysis of ICT-003 using MCNP coupled with various sets of cross section data.
  - Isotopic analyses and cross section comparisons performed to isolate the reactivity effects of the various data sets.

Analysis Approach - I

- Geometry
  - MCNP Model copied directly from ICSBEP Handbook (2009) for IEU-COMP-THERM-003, Core 132.
- Nuclear Data
  - ENDF/B-VI.0 and ENDF/B-VI.8 libraries taken from MCNP CD
    - endf60
    - endf66, actia, actib
  - ENDF/B-VII.0 libraries generated at KAPL
    - All materials Doppler broadened to 293.6 K.
    - Moderators also generated
      - H-H2O, C-GRAPH, H-ZRH, ZR-ZRH
    - NJOY99.259
      - Probability tables using PURR for all materials with URR data.
      - 0.1% RECONR/BROADR tolerances.

Analysis Approach - II

- Material substitutions
  - Using ENDF/B-VII.0 as a base, substitute various versions of materials and record the effects.
    - Change in eigenvalue, neutron balances
- Cross Section Plotting
  - Examine differences in pointwise cross section plots
- Cross Section Modifications
  - Modify resonance parameters to change the cross section.
  - Substitute modified material in the problem and examine effects on reactivity and neutron balances.

Results - I

- Perform some initial runs to recreate Trkov/Kahler results and establish baseline:
  - ENDF/B-VI.0, ENDF/B-VI.8, ENDF/B-VII.0 and ENDF/B-VII.0 + JENDL-4.0 Zr-91.
- Kahler (Email to Lubitz/Trumbull August 2010):
  - ENDF/B-VI.0: 0.99937(29)
  - ENDF/B-VI.8 (Iso. Zr.): 1.00031(28)
  - ENDF/B-VII.0 (Iso. Zr): 1.00596(28)
- A. Trkov (June 2010 miniCSEWG):
  - ENDF/B-VII.0: 1.00610
  - ENDF/B-VII.0 + JENDL-4.0 Zr-91: 1.00094
- KAPL (Trumbull MCNP runs, October 2010):
  - ENDF/B-VI.0: 0.99940(28)
  - ENDF/B-VI.8 (Iso. Zr.): 0.99960(28)
  - ENDF/B-VII.0 (Iso. Zr): 1.00606(28)
  - ENDF/B-VII.0 + JENDL-4.0 Zr-91: 1.00051(29)
- ICSBEP Benchmark value
  - ICT-003, Core 132 1.0006(56)

KAPL reproduced ENDF/B-VII.0 reactivity bias and reduction in reactivity from JENDL-4 Zr-91.

Results - II

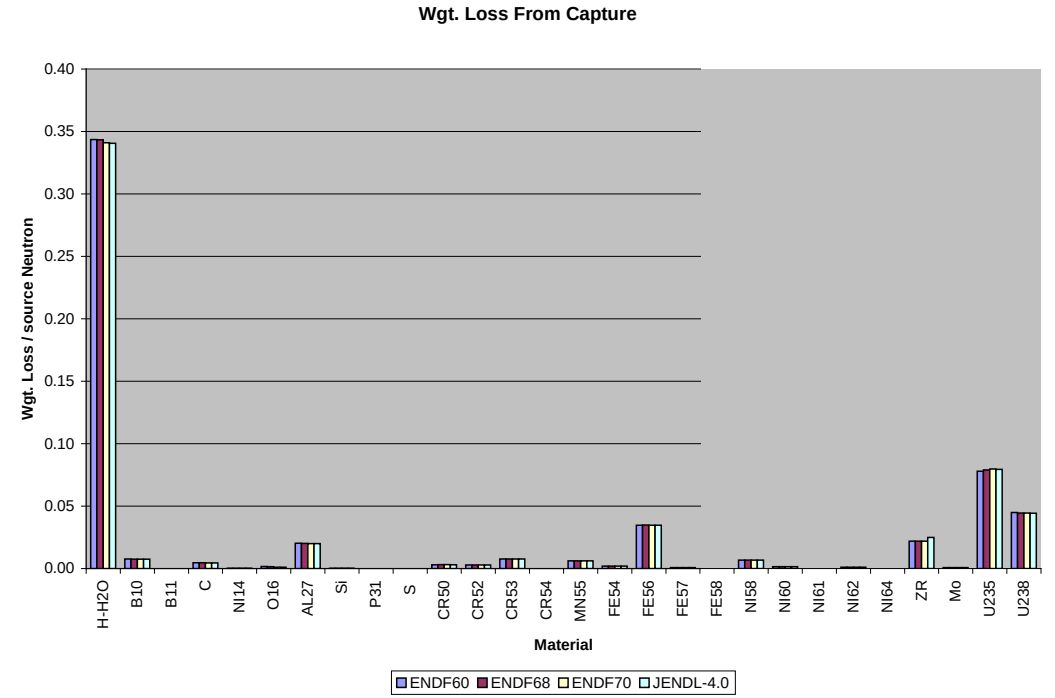
MCNP5 Neutron capture fraction comparisons for:

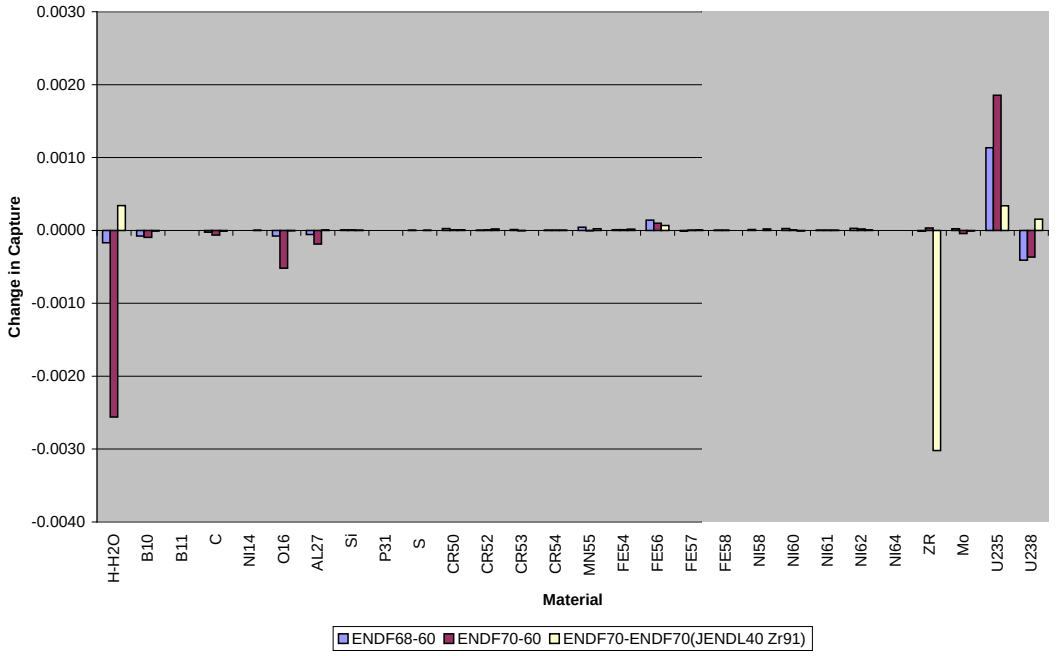
ENDF/B-VI.0,

ENDF/B-VI.8,

ENDF/B-VII.0, and

ENDF/B-VII.0 + JENDL-4.0 Zr-91 MCNP Runs.





Results – III

Moderator Substitutions:

Job Name	*k*-eff(95%CI)	Δ*k*-eff(95%CI)	Comments
Ict3e7	1.00606(28)	----------	Base Case ENDF/B-VII.0 (Processed at KAPL)
Ict3e7a	1.00564(28)	-0.00042(40)	ENDF/B-VI.3 H-H2O (SAB2002 library shipped with MCNP5)
Ict3e7b	1.00413(28)	-0.00193(40)	ENDF/B-VI.3 H-ZRH (SAB2002 library shipped with MCNP5)
Ict3e7c	1.00371(28)	-0.00235(40)	ENDF/B-VI.3 H-ZRH and ZR-ZRH (SAB2002 library shipped with MCNP5)
Ict3e7d	1.00557(28)	-0.00049(40)	ENDF/B-VI.3 Graphite (SAB2002 library shipped with MCNP5)

1. -235 pcm effect from swapping ENDF/B-VI.3 H-ZRH and ZR-ZRH for ENDF/B-VII.0 H-ZRH & ZR-ZRH.
2. H-ZRH & ZR-ZRH are contributors, but not the major cause of the reactivity bias.

Results – IV

Zirconium isotope substitutions for fast cross sections:

Job Name	*k*-eff(95%CI)	Δ*k*-eff(95%CI)	Comments
Ict3e7	1.00606(28)	----------	Base Case ENDF/B-VII.0 (Processed at KAPL)
Ict3e7e	1.00598(28)	-0.00008(40)	ENDF/B-VI.8 ZR90 (endf66b library shipped with MCNP5)
Ict3e7f	1.00180(28)	-0.00426(40)	ENDF/B-VI.8 ZR91(endf66b library shipped with MCNP5)
Ict3e7g	1.00626(28)	0.00020(40)	ENDF/B-VI.8 ZR92(endf66b library shipped with MCNP5)
Ict3e7h	1.00564(28)	-0.00042(41)	ENDF/B-VI.8 ZR94(endf66b library shipped with MCNP5)
Ict3e7i	1.00494(28)	-0.00112(41)	ENDF/B-VI.8 ZR96(endf66b library shipped with MCNP5)
Ict3e7o	1.00051(29)	-0.00555(41)	JENDL-4.0 ZR91 (processed at KAPL)

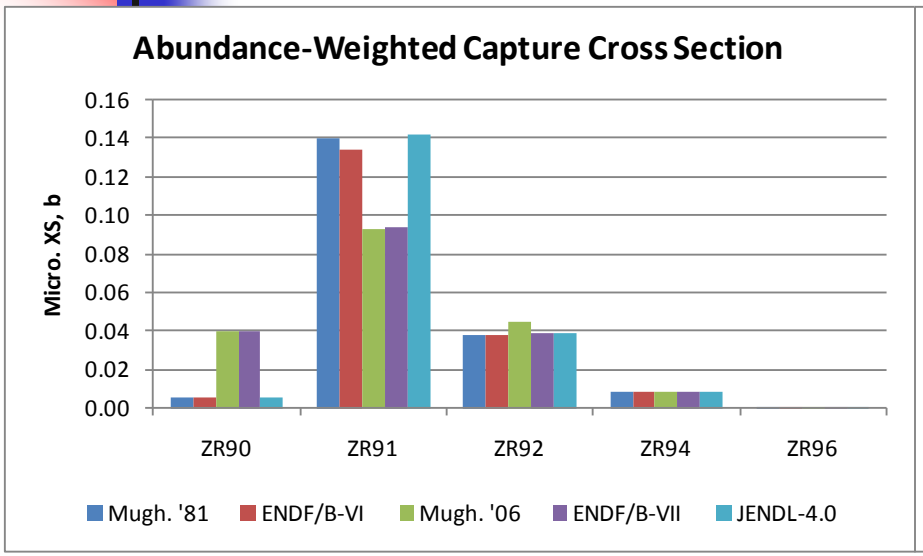
1. -426 pcm effect from swapping ENDF/B-VI.8 ZR91 for ENDF/B-VII.0 ZR91.
2. -555 pcm effect from swapping in JENDL-4.0 ZR91 for ENDF/B-VII.0 ZR91.
3. The ENDF/B-VII.0 ZR91 constitutes the majority of the effect in the increased reactivity.

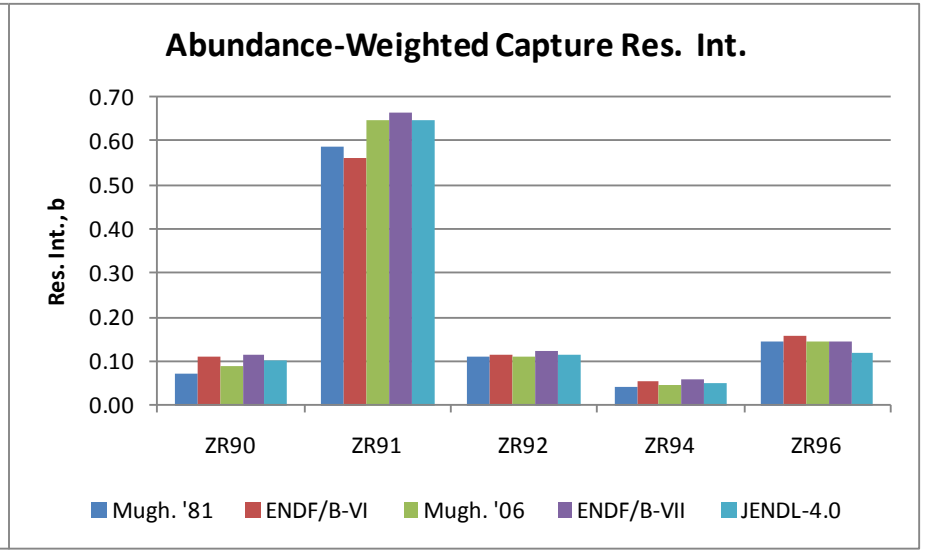
RI's and 2200 m/s Comparisons - I

Source	Material	2200 m/s Capture	Unc.	Capture RI	Unc.	Abundance	Abundance Weighted Capture	Abundance Weighted RI
Mughabghab, 1981	ZR-Nat	0.1850	0.0030	0.9500	0.1500			
	ZR90	0.0110	0.0050	0.1400		0.5145	0.0057	0.0720
	ZR91	1.2400	0.2500	5.2000	0.7000	0.1132	0.1404	0.5886
	ZR92	0.2200	0.0600	0.6300		0.1719	0.0378	0.1083
	ZR94	0.0499	0.0024	0.2300	0.0100	0.1728	0.0086	0.0397
	ZR96	0.0229	0.0010	5.3000	0.3000	0.0276	0.0006	0.1463
					Totals:	1.0000	0.1931	0.9550
Mughabghab, 2006	ZR-Nat	0.1850	0.0030	1.1000	0.1500			
	ZR90	0.0770	0.0160	0.1700	0.0200	0.5145	0.0396	0.0875
	ZR91	0.8300	0.0800	5.7600	0.4000	0.1122	0.0931	0.6463
	ZR92	0.2600	0.0800	0.6400		0.1715	0.0446	0.1098
	ZR94	0.0494	0.0017	0.2650	0.0150	0.1738	0.0086	0.0461
	ZR96	0.0229	0.0010	5.1500	0.2600	0.0280	0.0006	0.1442
					Totals:	1.0000	0.1866	1.0338

Source	Material	2200 m/s Capture	Capture RI	Abundance Weighted Capture	Abundance Weighted RI
ENDF/B-VI	ZR-Nat	0.1860	0.9650		
	ZR90	0.0112	0.2151	0.0058	0.1107
	ZR91	1.1867	4.9408	0.1343	0.5593
	ZR92	0.2194	0.6742	0.0377	0.1159
	ZR94	0.0491	0.3214	0.0085	0.0555
	ZR96	0.0232	5.6243	0.0006	0.1552
ENDF/B-VII.0	ZR-Nat	0.1821	1.1050		
	ZR90	0.0779	0.2258	0.0401	0.1162
	ZR91	0.8324	5.9054	0.0934	0.6626
	ZR92	0.2292	0.7221	0.0393	0.1238
	ZR94	0.0499	0.3320	0.0087	0.0577
	ZR96	0.0228	5.1697	0.0006	0.1448
JENDL-4.0	ZR-Nat	0.1956	1.0347		
	ZR90	0.0107	0.2001	0.0055	0.1030
	ZR91	1.2609	5.7530	0.1415	0.6455
	ZR92	0.2292	0.6751	0.0393	0.1158
	ZR94	0.0507	0.2982	0.0088	0.0518
	ZR96	0.0203	4.2376	0.0006	0.1187

RI's and 2200 m/s Comparisons - II



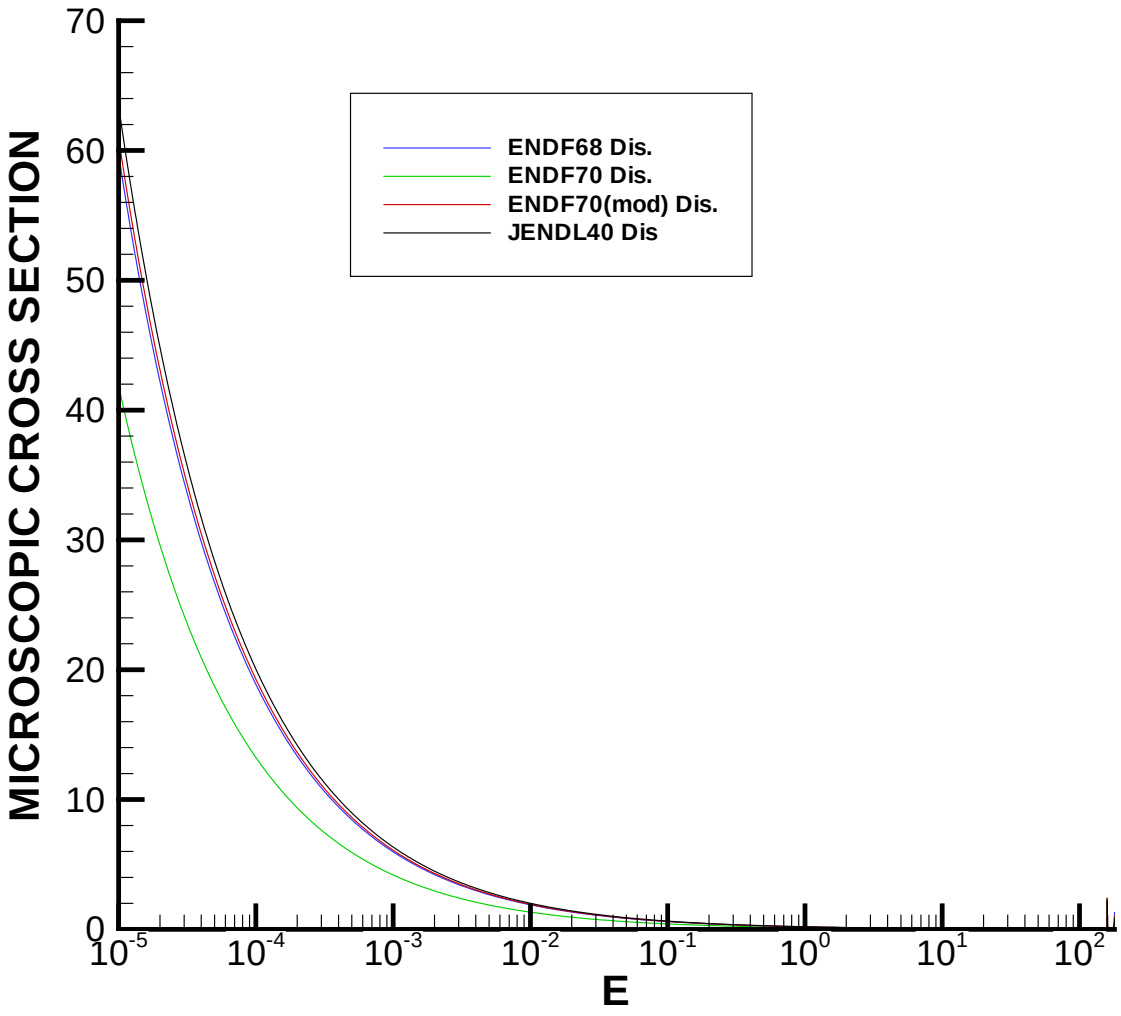


ZR91 Cross Section Comparisons – RI's and 2200 m/s values

ZR91	Disappearance 2200 m/s	0.5 eV Res. Int.
ENDF/B-VI.8	1.18670	4.94080
ENDF/B-VII.0	0.83236	5.90540
JENDL-4.0	1.26090	5.75300
ENDF/B-VII.0(mod)	1.21170	6.06660

- ENDF/B-VII.0(mod)
  - Increase bound-level $\Gamma\gamma$ values to bring thermal capture cross section back to JENDL-4.0 & ENDF/B-VI.8 values.
    - A 60% increase in $\Gamma\gamma$ for both negative-energy resonances gets close.
    - *k*-eff using ENDF/B-VII.0(mod) is 1.00156(29).
    - Thermal capture still needs to increase a bit.

ZR91 Cross Section Comparisons – Thermal pointwise values



Summary & Recommendations

- The observed increase in reactivity for the TRIGA (ICT003) benchmark is due to a combination of effects
  - ZR91 thermal cross section accounts for the majority of the effect.
    - Thermal cross section has been lowered compared to ENDF/B-VI.8 and JENDL-4.0.
  - New H-ZRH based on Mattes evaluation accounts for roughly the balance.
- Additional analysis of all the ENDF/B-VII.0 Zr isotopes is warranted.
  - ZR91 is a key player, but ZR96 showed a 112 pcm effect, as well.
  - JENDL-4.0 Zr isotopes should also be considered.