Benchmarking FENDL-2.1 with Impact of ENDF/B-VII.0 Release on Nuclear Heating and Damage

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FENDL-2.1 Background

- Revision to FENDL-2.0 (1995/96)
- Compiled November 2003, INDC(NDS)-451
- 71 elements/isotopes
- Working libraries prepared by IAEA/NDS, see INDC(NDS)-467 (2004)
- Processing performed using NJOY-99.90 at IAEA-NDS and resulting processed files are available in ACE format for MCNP and in MATXS format for multi-group transport calculations (175n-42g)
- New reference data library for ITER neutronics calculations

Data Source for FENDL-2.1

No.	Library	NMAT	Materials
1	ENDF/B-VI.8 (E6)	40	^{2}H, ^{3}H, ^{4}He, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{16}O, ^{19}F, $^{28-30}$Si, ^{31}P, S, ^{35,37}Cl, K, $^{50,52-54}$Cr, ^{54,57,58}Fe, ^{59}Co, ^{61,62,64}Ni, ^{63,65}Cu, ^{197}Au, $^{206-208}$Pb, ^{209}Bi, $^{182-184,186}$W
2	JENDL-3.3 (J33)	18	^{1}H, ^{3}He, ^{23}Na, $^{46-50}$Ti, , ^{55}Mn, $^{92,94-98,100}$Mo, ^{181}Ta,V
3	JENDL-3.2 (J32)	3	Mg, Ca, Ga
4	JENDL-FF (JFF)	4	^{12}C, ^{14}N, Zr, ^{93}Nb
5	JEFF-3 (EFF) JEFF3	4	^{27}Al, ^{56}Fe, ^{58}Ni, ^{60}Ni
6	BROND-2.1 (BR2)	2	^{15}N, Sn

- Data for 40 isotopes/elements taken from ENDF/B-VI.8
- ENDF/B-VII.0 library officially released on December 15, 2006
- We "visually" examined changes made in data for these 40 isotopes/elements to assess possible impact on nuclear analysis of ITER and other fusion system

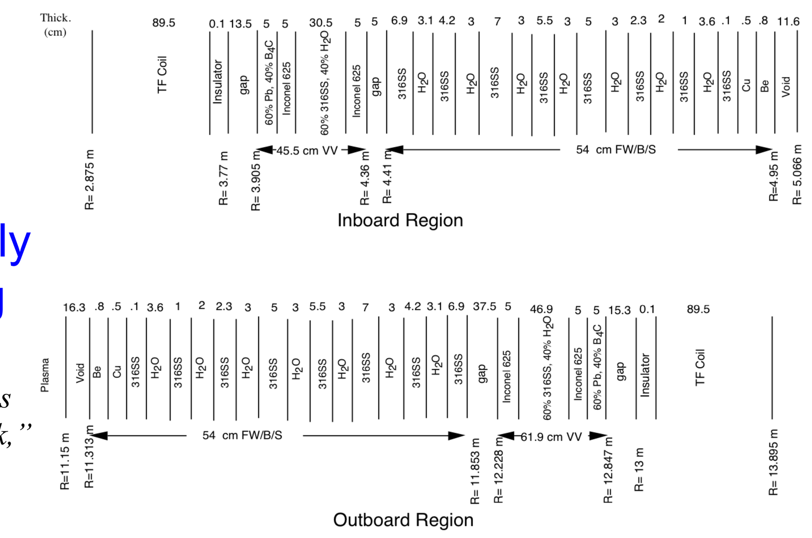
Findings of Data Comparison

- Minor impact on ITER nuclear analysis is expected except for ITER-TBM nuclear analysis due to changes in data for Li-6, Pb-208, and F-19
- Effects of changes could be large in other fusion systems
  - Power plants with breeding blankets
  - Inertial fusion systems (e.g., H-3 and Au-197 data are important for ICF target neutronics)

Analysis for ITER Calculational Benchmark

- To quantify these observations, we performed calculations for a 1-D cylindrical geometry calculational benchmark representative of an early ITER design that was utilized during FENDL development process

M. Sawan, "FENDL Neutronics Benchmark: Specifications for the Calculational Neutronics and Shielding Benchmark," IAEA Nuclear Data Section Report INDC(NDS)-316 (December 1994).



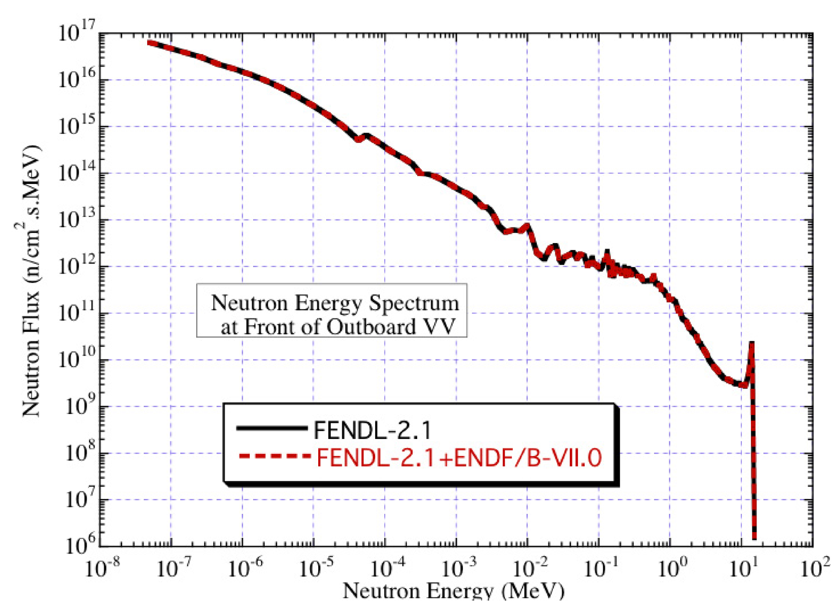
- This benchmark problem has been mainly used in discrete ordinate calculations using FENDL multi-group data
- FZK prepared MCNP geometry input and compared nuclear responses using different versions of FENDL, namely FENDL-1.0, 2.0 and 2.1
- *We used this MCNP model to carry out calculations using the FENDL-2.1 library with data for the 40 isotopes/elements replaced by the recent data from ENDF/B-VII.0*

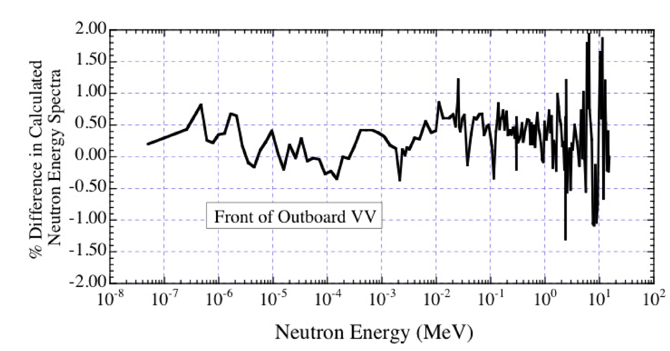
Peak Neutron and Gamma Flux Results

	FENDL-2.1		FENDL-2.1 +ENDF/B-VII.0		% Change	FENDL-2.1		FENDL-2.1 +ENDF/B-VII.0		% Change
	Neutron Flux	% Error	Neutron Flux	% Error		Gamma Flux	% Error	Gamma Flux	% Error	
IB										
FW										
Be	3.52E+14	0.05%	3.52E+14	0.05%	0.05%	3.18E+14	0.05%	3.18E+14	0.05%	0.12%
Cu	3.09E+14	0.05%	3.09E+14	0.05%	0.08%	3.08E+14	0.05%	3.08E+14	0.05%	0.10%
SS	2.96E+14	0.06%	2.96E+14	0.06%	0.10%	3.07E+14	0.06%	3.07E+14	0.06%	0.09%
VV	8.43E+11	0.19%	8.46E+11	0.19%	0.29%	4.84E+11	0.17%	4.85E+11	0.17%	0.26%
Magnet	3.42E+09	0.45%	3.45E+09	0.45%	1.04%	9.34E+08	0.42%	9.41E+08	0.42%	0.71%
OB										
FW										
Be	4.37E+14	0.03%	4.37E+14	0.03%	0.12%	3.61E+14	0.04%	3.62E+14	0.04%	0.15%
Cu	3.95E+14	0.03%	3.95E+14	0.03%	0.13%	3.60E+14	0.04%	3.61E+14	0.04%	0.14%
SS	3.80E+14	0.03%	3.80E+14	0.03%	0.14%	3.66E+14	0.04%	3.66E+14	0.04%	0.13%
VV	1.17E+12	0.09%	1.17E+12	0.09%	0.34%	6.60E+11	0.08%	6.62E+11	0.08%	0.27%
Magnet	4.93E+08	0.41%	4.97E+08	0.41%	0.79%	1.38E+08	0.40%	1.39E+08	0.40%	0.49%

Using ENDF/B-VII.0 data results in slightly higher flux values. However, the change is <1% with much smaller differences at the front FW zones facing the plasma

Neutron Energy Spectrum Comparison at Front of OB VV





Detailed neutron energy spectra with 175 energy bins agreed very well with differences <2% at front of OB VV

Peak Nuclear Heating (W/cm^3)

	FENDL-2.1		FENDL-2.1 +ENDF/B-VII.0		% Change
	Power Density	% Error	Power Density	% Error	
IB					
FW					
Be	1.008E+01	0.05	1.008E+01	0.05	-0.02
Cu	2.017E+01	0.06	2.019E+01	0.07	0.07
SS	1.783E+01	0.08	1.786E+01	0.08	0.16
VV SS	2.619E-02	0.18	2.632E-02	0.18	0.51
Magnet	3.659E-05	0.45	3.691E-05	0.45	0.87
OB					
FW					
Be	1.391E+01	0.03	1.391E+01	0.03	-0.02
Cu	2.474E+01	0.04	2.478E+01	0.05	0.13
SS	2.230E+01	0.05	2.233E+01	0.05	0.10
VV SS	3.573E-02	0.09	3.582E-02	0.09	0.24
Magnet	5.376E-06	0.43	5.419E-06	0.43	0.79

Peak Fe Damage (dpa/FPY)

	FENDL-2.1		FENDL-2.1 +ENDF/B-VII.0		% Change
	Fe dpa/FPY	% Error	Fe dpa/FPY	% Error	
IB					
FW	7.789E+00	0.07	7.795E+00	0.07	0.07
Blanket	4.430E+00	0.07	4.432E+00	0.07	0.05
VV	3.354E-03	0.24	3.365E-03	0.24	0.32
OB					
FW	1.182E+01	0.03	1.183E+01	0.03	0.13
Blanket	6.938E+00	0.03	6.945E+00	0.03	0.11
VV	5.018E-03	0.12	5.035E-03	0.12	0.33

- Nuclear heating and dpa results of the two libraries agree very well within <~0.8% for nuclear heating and <~0.3% for dpa and much smaller differences at front
- The large differences of up to ~70% observed in previous calculations are due to a bug in NJOY that was fixed in subsequent versions and used to process the "official" ACE formatted ENDF/B-VII.0 data used here

Peak He Production (appm/FPY)

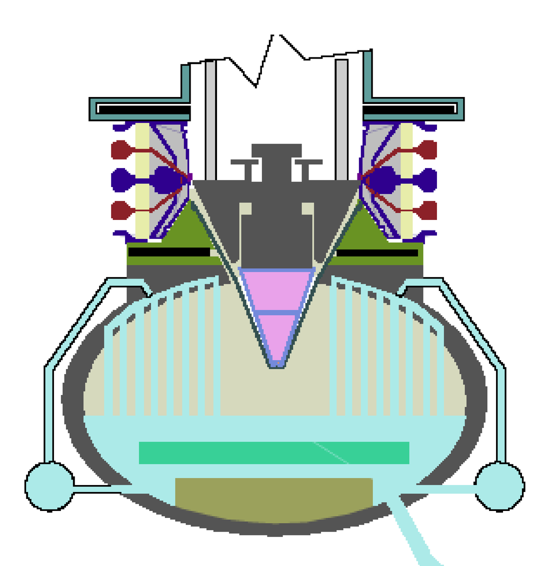
	FENDL-2.1		FENDL-2.1 +ENDF/B-VII.0		% Change
	He Prod.	% Error	He Prod.	% Error	
IB					
FW					
Be	4.10E+03	0.07%	4.10E+03	0.07%	0.06%
Cu	2.10E+02	0.07%	2.10E+02	0.07%	0.04%
SS	1.77E+02	0.06%	1.77E+02	0.06%	0.05%
VV SS	7.62E-02	0.22%	7.63E-02	0.22%	0.18%
Magnet	3.30E-04	0.63%	3.36E-04	0.62%	1.72%
OB					
FW					
Be	5.98E+03	0.03%	5.98E+03	0.03%	0.06%
Cu	3.23E+02	0.03%	3.23E+02	0.03%	0.04%
SS	2.45E+02	0.03%	2.45E+02	0.03%	0.03%
VV SS	1.08E-01	0.11%	1.08E-01	0.11%	0.28%
Magnet	4.86E-05	0.59%	4.94E-05	0.58%	1.69%

Peak IB Magnet Radiation Parameters

	FENDL-2.1		FENDL-2.1 +ENDF/B-VII.0		% Change
	Value	% Error	Value	% Error	
Fast n fluence (n/cm^2/FPY)	6.27E+16	0.46	6.36E+16	0.46	1.42
Insulator dose (Gy/FPY)	5.59E+05	0.47	5.64E+05	0.46	0.87
Cu dpa/FPY	3.75E-05	0.49	3.82E-05	0.46	1.76
Nuclear heating (mW/cm^3)	3.66E-02	0.45	3.69E-02	0.45	0.87

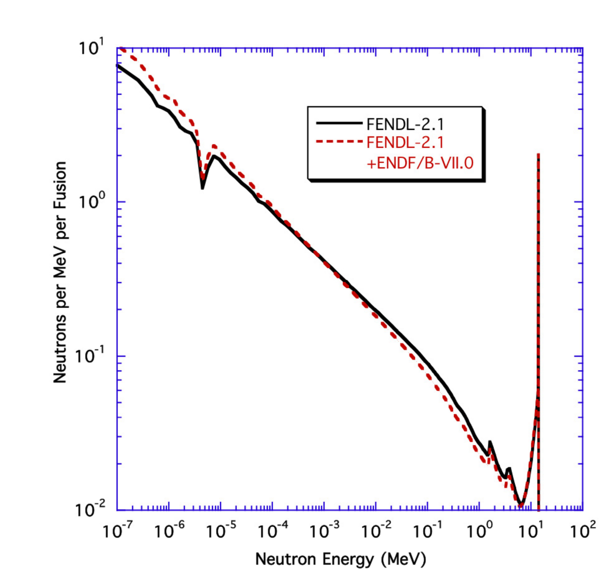
- Calculated gas production rates are very close using the two libraries with nearly identical results in FW and blanket
- Changes in peak magnet radiation parameters are small

Analysis for ICF System

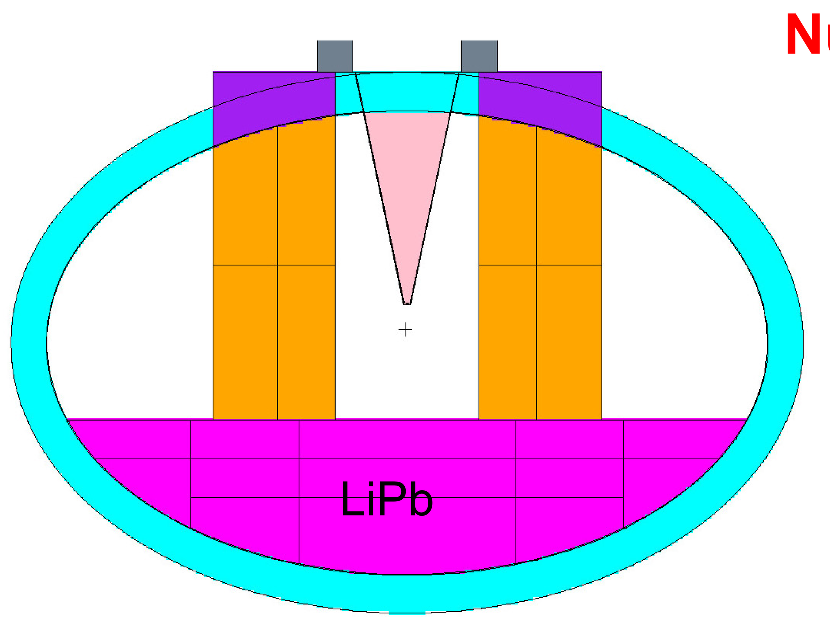


- We performed 3-D calculations for the chamber of a power plant concept that utilizes the Z-pinch driven inertial confinement technology
- Thick PbLi jets are utilized to breed tritium, absorb energy, and shield the chamber wall

Energy Spectrum of Neutrons Emitted from Target



- Changes in ENDF/B-VII.0 result in softer neutron spectrum emitted from target
- Total number of neutrons emitted from target per fusion reduces from 1.047 to 1.039. This is primarily due to reduced neutron multiplication in tritium. Gamma production in target per fusion changed slightly from 4.73×10^{-3} to 4.75×10^{-3}



Nuclear Heating in Target and Chamber

	FENDL-2.1		FENDL-2.1+ENDF/B-VII.0		% Change
	MeV per fusion	% error	MeV per fusion	% error	
Target					
DT	1.469E+00	0.22	1.426E+00	0.22	-2.94
Be	9.636E-03	0.07	9.688E-03	0.07	0.54
CH	2.953E-04	0.06	2.962E-04	0.06	0.30
Au	4.387E-04	1.38	4.330E-04	1.40	-1.30
Chamber					
Jets	9.507E+00	0.12	9.134E+00	0.11	-3.93
Nozzle	9.342E-01	0.34	9.480E-01	0.33	1.48
Pool	2.928E+00	0.30	2.899E+00	0.29	-0.97
Wall	1.875E+00	0.15	1.951E+00	0.15	4.04
RTL	6.719E-01	0.53	6.678E-01	0.53	-0.62

Total target heating decreased by ~3% and total chamber heating reduced by ~2%

Peak Damage Parameters in Chamber Wall

	FENDL-2.1		FENDL-2.1+ENDF/B-VII.0		% Change
	Value	err%	Value	err%	
dpa	1.233E+03	0.49	1.251E+03	0.48	1.48
He appm	3.848E+03	1.71	3.826E+03	1.71	-0.56

Tritium Breeding in LiPb

	FENDL-2.1		FENDL-2.1+ENDF/B-VII.0		% Change
	Tritons per fusion	% error	Tritons per fusion	% error	
Jets	7.13E-01	0.12%	7.15E-01	0.12%	0.28%
Nozzle	5.32E-02	0.27%	5.46E-02	0.27%	2.59%
Pool	3.64E-01	0.21%	3.75E-01	0.21%	3.20%
RTL	5.44E-03	0.27%	5.42E-03	0.27%	0.52%
TBR	1.14E+00		1.15E+00		1.32%

Conclusions

- The results presented in this work clearly show that the previously observed differences in nuclear heating and radiation damage are removed when the correctly processed ENDF/B-VII.0 data are used
- Differences in all nuclear parameters are very small for the ITER calculational benchmark implying that minimal impact is expected on ITER analysis and updating the FENDL-2.1 library is not urgently needed for ITER analysis
- However, a larger effect is expected when used in analysis of other fusion systems with breeding blankets (Demo and power plants)
- Calculations for an inertial fusion power plant showed relatively large changes in nuclear parameters due to large changes in H-3 and Au-197 data that affect the energy spectrum of neutrons emitted from the ICF target
- The results confirm the need for updating FENDL-2.1 for use in analysis of fusion systems beyond ITER