Progress in Nuclear Data Development for Fusion

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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, INDC (NDS)-467 (2004)
- Reference data library for nuclear analysis of ITER and other fusion systems

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

- Majority (40) of materials in FENDL-2.1 taken from ENDF/B-VI.8
- Investigated effect of recently released ENDF/B-VII.0 (December 2006) on results for ITER calculational benchmark and four FNG ITER relevant integral experiments

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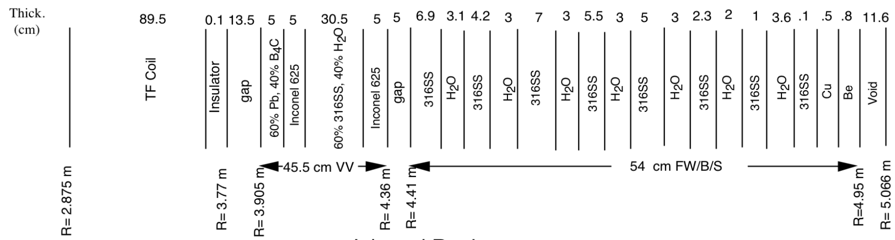
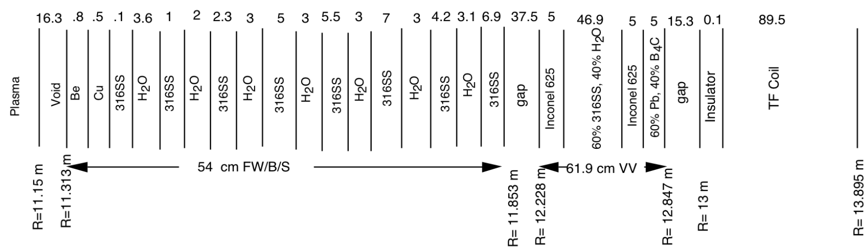
Calculational and Experimental Benchmarks

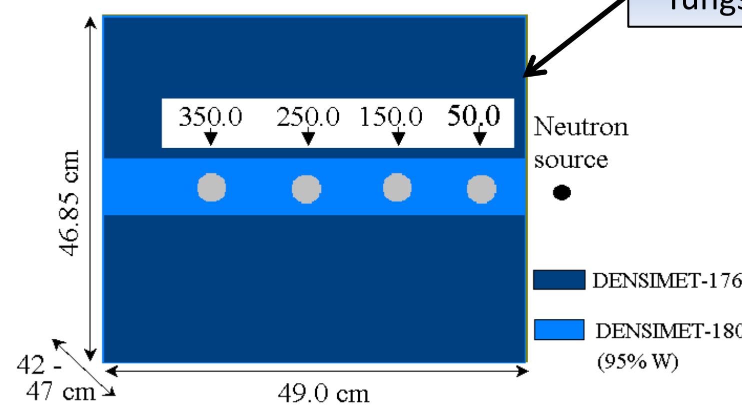


Inboard Region

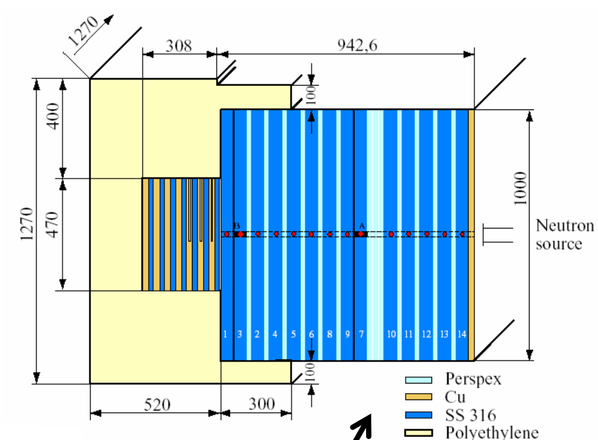


Outboard Region

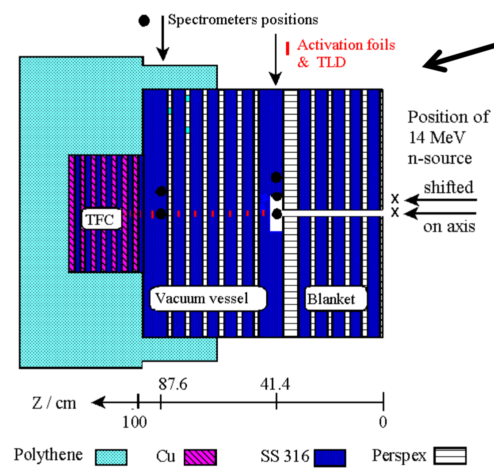
Tungsten

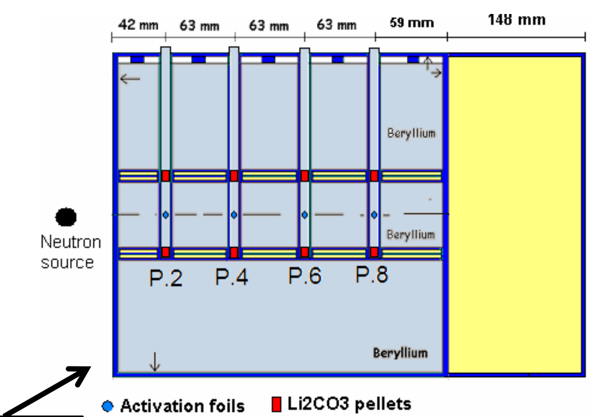


Streaming



Bulk shielding





HCPB breeder

Findings of ENDF/B-VII.0 Data Impact

- 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
- Calculations of foil activation and tritium breeding for ITER relevant FNG integral experiments yield nearly similar results for FENDL-2.1 and ENDF/B-VII.0
- 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)

- M. Sawan, "Impact of ENDF/B-VII.0 Release on Fusion Evaluated Nuclear Data Library FENDL-2.1," Fusion Sci. and Technol., **56**, 766-770 (2009).
- M.E. Sawan, "Benchmarking FENDL-2.1 with Impact of ENDF/B-VII.0 Release on Nuclear Heating and Damage," Proc. 23rd IEEE/NPSS Symposium on Fusion Engineering (SOFE), San Diego, CA, May 31-June 5, 2009.

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FENDL-3 Development

(http://www-nds.iaea.org/fendl3/)

- An effort was initiated by the IAEA in 2008 to update the FENDL library with the objective of improving the status of nuclear databases for fusion devices including IFMIF
- The library (FENDL-3) represent a substantial extension of FENDL-2.1 library toward higher energies, with inclusion of incident charged particles and the evaluation of related uncertainties (covariance data)
- FENDL-3 will be released at the end of the 3 years of the Coordinated Research Project (CRP) activities

FENDL-3/SLIB Starter Library

- A starter library (FENDL-3/SLIB) was generated based on several agreed upon rules of creation
  - Replace present evaluations with updates
  - Adopt evaluations from libraries with standards (H-1 from ENDF)
  - Use isotopic evaluations where available
- The library includes 88 isotopes with updated evaluations from ENDF/B-VII.0, JENDL-HE, JEFF-3.1, and BROND
- Only evaluation switch occurred for H-1 and He-3 (JENDL-3.3 → ENDF/B-VII.0)
- FENDL-3/SLIB materials: 48 from ENDF/B-VII.0, 35 from JENDL-HE, 3 from JEFF-3.1, 2 from BROND-2
- Sn is the only material with elemental rather than isotopic evaluation

A. Trkov, R. Forrest and A. Mengoni, "Summary Report from 1st RCM on Nuclear Data Libraries for Advanced Systems – Fusion Devices (FENDL-3)," INDC(NDS)-547, IAEA (March 2009)

Results with Initially Processed FENDL-3/SLIB

	FENDL-2.1		FENDL-2.1 +ENDF/B-VII.0		FENDL.3/SLIB		FENDL-2.1		FENDL-2.1 +ENDF/B-VII.0		FENDL.3/SLIB	
	Neutron Flux	1 σ % Error	Value	% Change	Value	% Change	Gamma Flux	1 σ % Error	Value	% Change	Value	% Change
IB												
FW												
Be	3.52E+14	0.05%	3.52E+14	0.05%	3.520E+14	0.07%	3.18E+14	0.05%	3.18E+14	0.12%	3.184E+14	0.14%
Cu	3.09E+14	0.05%	3.09E+14	0.08%	3.089E+14	0.03%	3.08E+14	0.05%	3.08E+14	0.10%	3.080E+14	0.11%
SS	2.96E+14	0.06%	2.96E+14	0.10%	2.960E+14	0.01%	3.07E+14	0.06%	3.07E+14	0.09%	3.071E+14	0.15%
VV	8.43E+11	0.19%	8.46E+11	0.29%	8.560E+11	1.52%	4.84E+11	0.17%	4.85E+11	0.26%	4.903E+11	1.32%
Magnet	3.42E+09	0.45%	3.45E+09	1.04%	3.619E+09	5.88%	9.34E+08	0.42%	9.41E+08	0.71%	9.687E+08	3.72%
OB												
FW												
Be	4.37E+14	0.03%	4.37E+14	0.12%	4.375E+14	0.15%	3.61E+14	0.04%	3.62E+14	0.15%	3.619E+14	0.20%
Cu	3.95E+14	0.03%	3.95E+14	0.13%	3.952E+14	0.18%	3.60E+14	0.04%	3.61E+14	0.14%	3.609E+14	0.15%
SS	3.80E+14	0.03%	3.80E+14	0.14%	3.804E+14	0.17%	3.66E+14	0.04%	3.66E+14	0.13%	3.664E+14	0.12%
VV	1.17E+12	0.09%	1.17E+12	0.34%	1.183E+12	1.31%	6.60E+11	0.08%	6.62E+11	0.27%	6.679E+11	1.19%
Magnet	4.93E+08	0.41%	4.97E+08	0.79%	6.695E+08	35.74%	1.38E+08	0.40%	1.39E+08	0.49%	1.632E+08	18.17%

- 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
- Using FENDL-3/SLIB results in much higher flux values (by up to 36%) particularly at the magnet that is heavily shielded by water-cooled shield and vacuum vessel
- FENDL-3/SLIB results in significantly softer neutron energy spectrum at the heavily shielded OB magnet (E>0.1 MeV flux increases by only 3% while the E<0.1 MeV flux increases by 82%)
- Magnet heating in magnet increased by ~18% due to larger gamma generation from softer neutron spectrum

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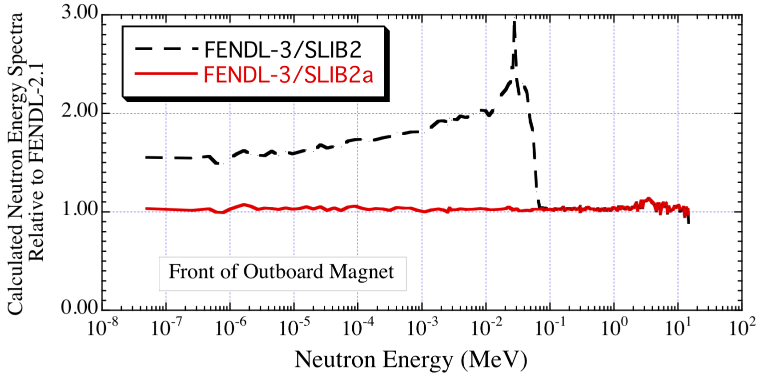
Identifying and Fixing Processing Errors in FENDL-3/SLIB Files

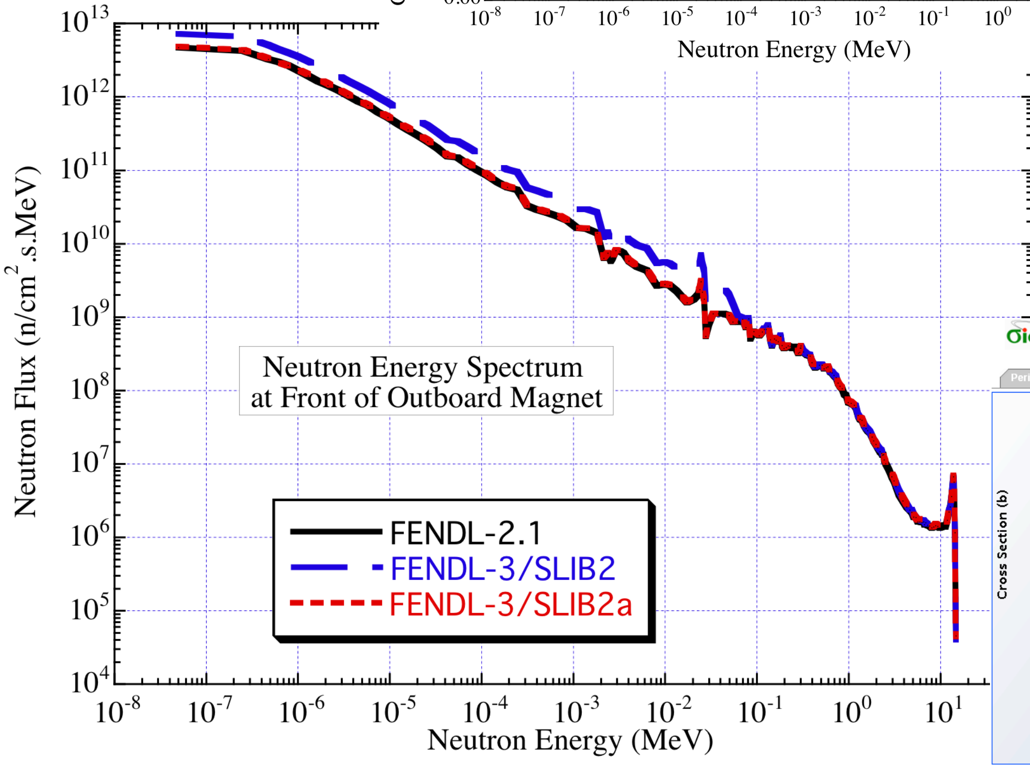
- To further investigate increase in low energy (E<0.1 MeV) neutron flux observed with FENDL-3/SLIB we performed simple calculations for slabs with all water, all SS316, and SS316/H_2O mixture
- Small change (~5%) for pure water but a factor of ~7 increase for SS/water implied that large differences are not related to change in H data
- Largest difference obtained in Mo (JENDL-3.3→JENDL-HE)
- Independent assessment by A. Trkov (JSI) confirmed differences
- An anomaly was noticed in plots of neutron emission spectra

- The symptoms suggested an NJOY processing problem which is specific for combination of data representation in JENDL-HE files
- A temporary patch to NJOY was proposed that solves processing problems for all affected materials
- New processed ACE files (FENDL-3/SLIB2a) in Feb. 2010

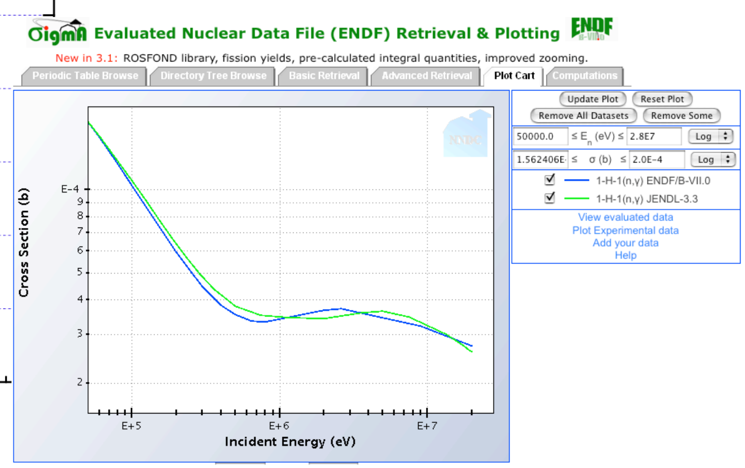
	FENDL-2.1		FENDL.3/SLIB2		FENDL.3/SLIB2a	
	Neutron Flux	1 σ % Error	Value	% Change	Value	% Change
IB						
FW						
Be	3.52E+14	0.05%	3.520E+14	0.07%	3.520E+14	0.08%
Cu	3.09E+14	0.05%	3.089E+14	0.03%	3.089E+14	0.03%
SS	2.96E+14	0.06%	2.960E+14	0.01%	2.960E+14	0.00%
VV	8.43E+11	0.19%	8.560E+11	1.52%	8.559E+11	1.52%
Magnet	3.42E+09	0.45%	3.619E+09	**5.88%**	3.492E+09	**2.17%**
OB						
FW						
Be	4.37E+14	0.03%	4.375E+14	0.15%	4.375E+14	0.15%
Cu	3.95E+14	0.03%	3.952E+14	0.18%	3.952E+14	0.18%
SS	3.80E+14	0.03%	3.804E+14	0.17%	3.804E+14	0.17%
VV	1.17E+12	0.09%	1.183E+12	1.31%	1.183E+12	1.31%
Magnet	4.93E+08	0.41%	6.695E+08	**35.74%**	5.077E+08	**2.94%**

FENDL-3/SLIB vs. FENDL-2.1





- Using FENDL-3/SLIB instead of FENDL-2.1 in ITER relevant calculations gives 1.5-3.5% higher nuclear parameters in regions that are heavily shielded with water-cooled SS (VV, magnets) and differences could be due to change in H-1 evaluation used
- *These results should be taken into account when calculating ITER magnet parameters with FENDL-2.1*



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Proposed Added Materials in FENDL-3

- Following the 1st RCM meeting in December 2008, we reviewed the list of material in the FENDL-2.1 general purpose data library regarding its completeness to satisfy the needs for fusion neutronics analysis
- We solicited input from the fusion neutronics community for possible addition of materials that are needed and are missing from the FENDL-2.1 library
- 17 elements were identified for consideration to be added in the new library to enhance its usefulness for the different fusion applications:

  Re, Zn, Ag, Ba, Y, Cd, Ce, Ar, Er, Sb, Rh, Sc, Br, Ge, I, Lu, La

- We identified the application needed for each proposed material and gave a priority to help us with decision if we want to limit the number of materials added
- Availability of evaluations for these elements was determined
- In addition, 6 isotopes are missing from FENDL-2.1 and need to be considered for inclusion in FENDL-3:

  C-13, O-17, O-18, V-50, W-180, Pb-204

Expanded FENDL-3 General Purpose Neutron Library

- During the 2nd RCM held in March 2010, a decision was made to nearly double the number of materials in the library and the source of evaluation for each material was agreed on
- Materials added to the library were based on input contributed by the fusion neutronics community for ITER and IFMIF. These are 23 elements with their constituent isotopes:

Re, Zn, Ag, Ba, Y, Cd, Ce, Ar, Er, Sb, Rh, Sc, Br, Ge, I, Lu, La, Cs, Pt, Hf, Gd, U, Th

- Only 3 actinide isotopes will be added as they are needed for neutron measurement by fission chambers (U-235, U-238) or exist in the ITER concrete (Th-232)
- Total number of isotopes in library increased to ***166*** which includes the 6 isotopes missing in FENDL-2.1
- Evaluations to be utilized for these materials were selected

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Other Components of FENDL-3 Package

- The activation data files for neutrons, protons and deuterons were discussed. The activation library which will be part of the FENDL-3 package will be based on EAF-2010
- Issues related to the generation of the general purpose charged particle data library were also addressed. This library will be based primarily on TENDL-2009 or -2010
- An effort will be made to provide a covariance data library that is as complete as possible. The shadow library TENDL-2010 should be utilized as needed

Schedule for Release of FENDL-3

- ENDF data libraries (FENDL-3/T) to be provided by April 2011
- This will be followed by processing with NJOY ACER, testing and correction before release at end of 2011
- Processed ACE files to be available two months after release of ENDF data files to allow time for testing and benchmarking before the next RCM meeting in fall of 2011
- Multi-group processing will follow testing of ACE files

M.E. Sawan, "Summary Report from 2nd RCM on Nuclear Data Libraries for Advanced Systems – Fusion Devices (FENDL-3)," INDC(NDS)-567, IAEA (June 2010)

Summary

An updated comprehensive (ns to 150 MeV, activation, p, d, covariance) fusion evaluated nuclear data library FENDL-3 that is suitable for all fusion systems will be developed, validated, and released by the end of 2011