Impact of FENDL-2.1 Updates on Nuclear Analysis of ITER and Other Fusion Systems

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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

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)

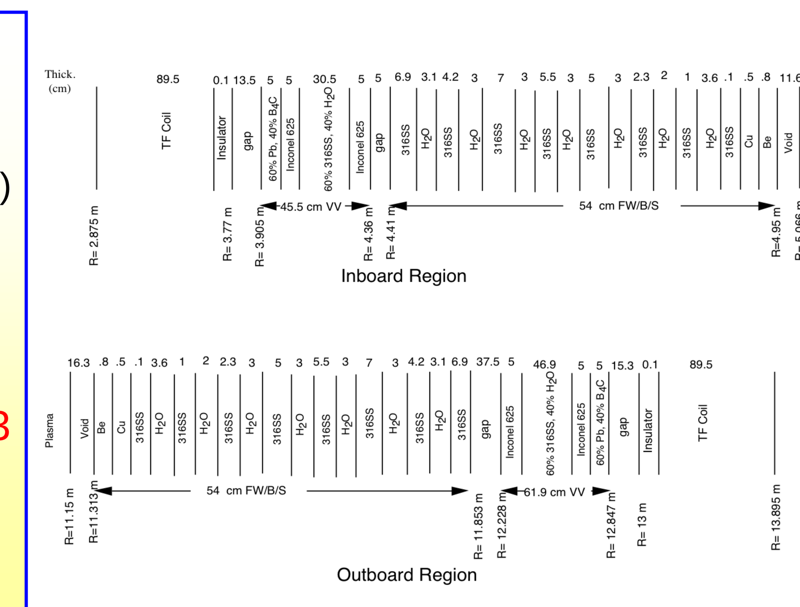
FENDL-3 Development

- 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
- 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
  - ▪ Use updated evaluations
  - ▪ Adopt evaluations with standards (H-1 from ENDF)
  - ▪ Use isotopic evaluations
- ➢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: 47 from ENDF/B-VII.0, 35 from JENDL-HE, 4 from JEFF-3.1, 2 from BROND-2

ITER Calculational Benchmark

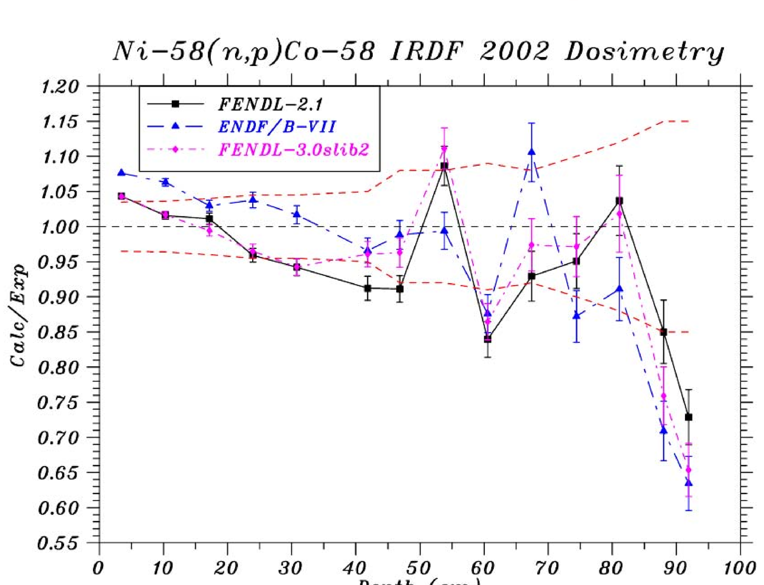


- ➢To quantify impact of data changes, we performed MCNP calculations for a 1D ITER calculational benchmark that was utilized during FENDL development process
- ➢Calculations carried out using FENDL-2.1 library, FENDL-2.1 with data for the 40 materials replaced by ENDF/B-VII.0, and the FENDL-3/SLIB ACE library (release 2 posted 6/24/2009 designated SLIB2)
- ➢Results for flux, heating, dpa, and gas production were compared

FENDL-2.1 vs. Initially Processed FENDL-3/SLIB2 Data

- Using FENDL-3/SLIB2 results in much higher flux values (by up to 36%)particularly at the magnet that is heavily shielded by water-cooled SS shield and vacuum vessel
- FENDL-3/SLIB2 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

FENDL-3/SLIB2 Calculation for FNG Bulk Shield Experiment



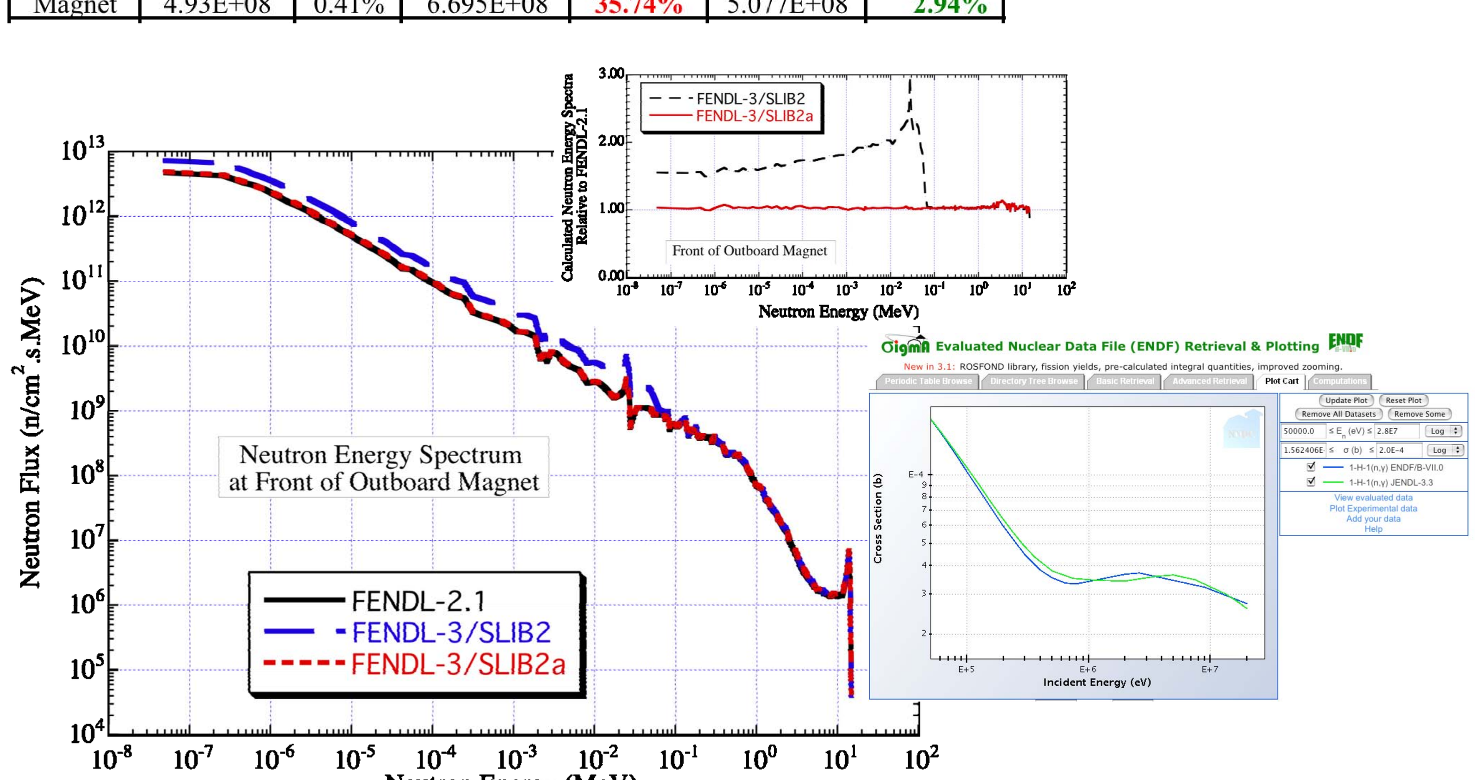
- ➢ Small difference compared to FENDL-2.1
- ➢ Bulk shield mock-up thickness is much smaller than magnet shielding in ITER

Identifying and Fixing Processing Errors in FENDL-3/SLIB2 Files

- ➢ To further investigate increase in low energy (E<0.1 MeV) neutron flux observed with FENDL-3/SLIB2 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

Peak Neutron Flux Results

	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%**



Peak Nuclear Heating Results

	FENDL-2.1		FENDL-3/SLIB2		FENDL-3/SLIB2a	
	Power Density	1 σ % Error	Value	% Change	Value	% Change
IB						
FW						
Be	1.008E+01	0.05	1.008E+01	0.02	1.008E+01	0.02
Cu	2.017E+01	0.06	2.021E+01	0.15	2.021E+01	0.15
SS	1.783E+01	0.08	1.787E+01	0.26	1.787E+01	0.26
VV SS	2.619E-02	0.18	2.657E-02	1.44	2.656E-02	1.44
Magnet	3.659E-05	0.45	3.789E-05	**3.56**	3.729E-05	**1.92**
OB						
FW						
Be	1.391E+01	0.03	1.392E+01	0.05	1.392E+01	0.05
Cu	2.474E+01	0.04	2.478E+01	0.15	2.478E+01	0.15
SS	2.230E+01	0.05	2.233E+01	0.12	2.233E+01	0.12
VV SS	3.573E-02	0.09	3.614E-02	1.14	3.614E-02	1.15
Magnet	5.376E-06	0.43	6.361E-06	**18.32**	5.500E-06	**2.30**

Comments on Results

- ➢ Using the corrected processed FENDL-3 starter library (FENDL-3/SLIB2a) removed the large overestimate at deep penetration locations
- ➢ Neutron and gamma fluxes at VV and magnet that are heavily shielded by water-cooled SS are higher by 1-3% than predicted by FENDL-2.1
- ➢ Energy spectra from FENDL-3/SLIB2a and FENDL-2.1 are close with differences up to ~10% at E>2 MeV
- ➢ Lower (n,γ) cross sections for H-1 at high energy could be reason for higher (High E) neutron flux in regions heavily shielded by water-cooled SS
- ➢ Nuclear parameters at magnet are higher by ~1.5-3.5% than predicted by FENDL-2.1 with largest differences in fast neutron fluence and dpa

Conclusions

- ➢Replacing ENDF/B-VI.8 data in FENDL-2.1 by ENDF/B-VII.0 resulted in minor change (<1%) in nuclear parameters for ITER relevant calculations. However, larger changes in calculated ICF target neutronics parameters were observed in previous analysis
- ➢Calculations of foil activation and tritium breeding for ITER relevant integral experiments yield nearly similar results for FENDL-2.1 and ENDF/B-VII.0
- ➢Using the initial ACE FENDL-3/SLIB2 files instead of FENDL-2.1 resulted in large increase in nuclear parameters behind the thick water-cooled shield. This was identified as processing error and was corrected in a recent processed library FENDL-3/SLIB2a
- ➢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 (vacuum vessel, 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*