Status of FENDL-3 Validation and Application for ITER

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CSEWG Meeting
November 20, 2013
BNL

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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 to improve status of nuclear databases for fusion devices including IFMIF
- The library (FENDL-3) is 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)
- A starter FENDL-3 with 180 isotopes was released at the end of the 3 years of the Coordinated Research Project (CRP) activities and the fourth release referred to as FENDL-3.0 is being validated and tested

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FENDL-3

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

Processed libraries:

- **FENDL/MC-3.0**:
  Continuous energy data in ACE format
- **FENDL/MG-3.0**:
  Multi-group in 175n/42g Vitamin J and 212n/42g Vitamin J+ structures. MATXS and GENDF formats
- **FENDL/A-3.0:**
  In PENDF and GENDF formats

INDC(NDS)-0628 – R. Forrest, et al, "FENDL-3 Summary documentation," December 2012.

› Nuclear Data

IAEA Nuclear Data Services Home Page

› FENDL 3

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- Activity lines
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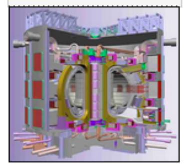
- Contacts

› Documents

- Background information
- Contract preparation forms
- Glossary
- Related documentation

› Meetings

- 3rd RCM
- 2nd RCM
- 1st RCM
- TM November 2007



Nuclear Data Libraries for Advanced Systems: Fusion Devices

Fusion Evaluated Nuclear Data Library FENDL 3.0

Output of the CRP on Nuclear Data Libraries for Advanced Systems: Fusion Devices

Background

Participants at the Technical Meeting in October/November 2007 (INDC(NDS)-0525) defined the objectives of the CRP which were the updating and extension of FENDL-2.1 to make it applicable to both fusion devices such as ITER and DEMO and to material test facilities such as IFMIF. This would involve more materials, an extension of the energy range to higher energies and data for charged particle-induced reactions. In addition more emphasis on covariance data would make the library suitable for all fusion technology studies. The reports of the three RCMs are available (INDC(NDS)-0547, INDC(NDS)-0567 and INDC(NDS)-0602) as well as the summary documentation of the FENDL-3.0 library (INDC(NDS)-0628).

FENDL-3.0

The FENDL-3.0 package contains evaluated nuclear data in ENDF-6 format both as General Purpose and Activation Files. In each case data are given for neutron-, proton- and deuteron-induced reactions up to a typical energy of 150 MeV for General Purpose and 60 MeV for Activation files. Not all targets in the General Purpose library contain covariance data and so an extract of the TENDL-2011 library with all the 180 targets of FENDL-3.0 is provided as a "shadow library" so that complete uncertainty calculations can be done. Processing of the basic files has been done so that a series of files are available for applications (INDC(NDS)-0611 and INDC(NDS)-06zz). These include:

- FENDL/MC-3.0: Pointwise continuous-energy cross section data in ACE format for MCNP calculations; also includes probability tables (PT) in the unresolved resonance range.
- FENDL/MG-3.0: Contains multigroup cross section data in the 175n/42g Vitamin J and the 212n/42g Vitamin J+ energy structures for multigroup transport codes in two formats:
  - FENDL/MG-3.0 (MATXS), which includes files in MATXS format from the NJOY module MATXSR.
  - FENDL/MG-3.0 (GENDF), which contains data in GENDF format from the NJOY modules GROUPR and GAMINR.
- Data are available for 180 materials relevant for fusion at 300K. Additionally, the SIGACE package can be downloaded for Doppler broadening of ACE-formatted file - useful for generating ACE-formatted files at temperatures higher than 300K.
- For the sake of completeness, NJOY inputs to generate ACE, MATXS and GENDF files are supplied. Furthermore, NJOY-99.90 local updates, as well as the auxiliary programs and WINDOWS batch files used to update and verify the FENDL-3.0 transport sublibraries, are also available.
- FENDL/A-3.0 is available in PENDF and GENDF formats. In addition the neutron-induced file is also available in a Generalised Nuclear Data (XML) format.

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

FENDL-3 (neutron) working files (Update: 2012-05-29)

#)	MAT	Material	Lab.	Date	Authors	Source	Emax(eV)	Size	File
1)	125	1-H-1	LANL	EVAL-OCT05	G.M.Hale	FENDL-3.0	1.50E+08	58kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
2)	128	1-H-2	LANL	EVAL-FEB97	P.G.Young,G.M.Hale,M.B.Chadwick	ENDF/B-VII	1.50E+08	85kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
3)	131	1-H-3	LANL	EVAL-NOV01	G.M.Hale	ENDF/B-VII	6.00E+07	99kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
4)	225	2-He-3	JAERI	EVAL-JUN87	K.SHIBATA	JENDL-4	6.00E+07	41kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
5)	228	2-He-4	LANL	EVAL-SEP10	Hale	ENDF/B-VII	6.00E+07	227kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
6)	325	3-Li-6	LANL	EVAL-APR06	G.M.Hale,P.G.Young	FENDL-3.0	2.00E+08	1432kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
7)	328	3-Li-7	LANL	EVAL-AUG88	P.G.Young	FENDL-3.0	2.00E+08	1066kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
8)	425	4-Be-9	LLNL,LANL	EVAL-OCT09	G.HALE,PERKINS ET AL,FRANKLE	FENDL-3.0	2.00E+08	1961kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
9)	525	5-B-10	LANL	EVAL-APR06	G.M.Hale,P.G.Young	FENDL-3.0	2.00E+08	1483kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
10)	528	5-B-11	LANL	EVAL-MAY89	P.G.Young	FENDL-3.0	2.00E+08	1519kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
11)	625	6-C-12	Kyushu U.	EVAL-JUL03	Y.Watanabe	FENDL-3.0	1.50E+08	6082kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
12)	628	6-C-13	NRG	EVAL-NOV10	A.J.Koning,D.Rochman	TENDL-2010	2.00E+08	1632kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
13)	715	7-N-15	LANL	EVAL-DEC05	V.KOSCHEEV	FENDL-3.0	2.00E+08	1249kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
14)	725	7-N-14	JNDC	EVAL-JUN89	Y.KANDA(KYU) T.MURATA(NAIG)+	FENDL-3.0	1.50E+08	8185kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
15)	825	8-O-16	LANL	EVAL-DEC05	Hale,Young,Chadwick,Caro,Lubitz	ENDF/B-VII	1.50E+08	2986kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
16)	828	8-O-17	NRG	EVAL-NOV10	A.J.Koning,D.Rochman	TENDL-2010	2.00E+08	2134kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
17)	831	8-O-18	NRG	EVAL-NOV10	A.J.Koning,D.Rochman	TENDL-2010	2.00E+08	1933kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
18)	925	9-F-19	CNDC,ORNL	EVAL-OCT03	Z.X.Zhao,C.Y.Fu,D.C.Larson,Leal+	FENDL-3.0	1.50E+08	5963kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
19)	1125	11-NA-23	SIT.SHIMZ	EVAL-MAY 6	K.Kosako	FENDL-3.0	1.50E+08	6073kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
20)	1225	12-MG-24	KYUSHU	EVAL-DEC 3	Sun Weili,Y.Watanabe	FENDL-3.0	1.50E+08	11481kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
21)	1228	12-MG-25	KYUSHU	EVAL-DEC 3	Sun Weili,Y.Watanabe	FENDL-3.0	1.50E+08	11423kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
22)	1231	12-MG-26	KYUSHU	EVAL-DEC 3	Sun Weili,Y.Watanabe	FENDL-3.0	1.50E+08	11291kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
23)	1325	13-Al-27	LANL	EVAL-FEB97	M.B.CHADWICK & P.G.YOUNG	JEFF-311	1.50E+08	2195kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
24)	1425	14-Si-28	LANL,ORNL	EVAL-DEC02	M.B.Chadwick,P.G.Young,D.Hetrick	ENDF/B-VII	1.50E+08	1870kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
25)	1428	14-Si-29	LANL,ORNL	EVAL-JUN97	M.B.Chadwick,P.G.Young,D.Hetrick	ENDF/B-VII	1.50E+08	1846kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
26)	1431	14-Si-30	LANL,ORNL	EVAL-JUN97	M.B.Chadwick,P.G.Young,D.Hetrick	ENDF/B-VII	1.50E+08	1570kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
27)	1525	15-P-31	NRG	EVAL-OCT10	A.J.Koning,D.Rochman	TENDL-2010	2.00E+08	2443kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
28)	1625	16-S-32	NRG	EVAL-OCT10	A.J.Koning,D.Rochman	TENDL-2010	2.00E+08	2514kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
29)	1628	16-S-33	NRG	EVAL-NOV10	A.J.Koning,D.Rochman	TENDL-2010	2.00E+08	2685kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
30)	1631	16-S-34	NRG	EVAL-NOV10	A.J.Koning,D.Rochman	TENDL-2010	2.00E+08	2322kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
31)	1637	16-S-36	NRG	EVAL-NOV10	A.J.Koning,D.Rochman	TENDL-2010	2.00E+08	2093kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
32)	1725	17-Cl-35	ORNL,LANL	EVAL-OCT03	Sayer,Guber,Leal,Larson,Young+	FENDL-3.0	1.50E+08	10829kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
33)	1731	17-Cl-37	ORNL,LANL	EVAL-OCT03	Sayer,Guber,Leal,Larson,Young+	FENDL-3.0	1.50E+08	7423kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
34)	1825	18-AR-36	SIT.SHIMZ	EVAL-MAY 6	K.Kosako	FENDL-3.0	1.50E+08	5719kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
35)	1831	18-AR-38	SIT.SHIMZ	EVAL-MAY 6	K.Kosako	FENDL-3.0	1.50E+08	5703kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
36)	1837	18-AR-40	SIT.SHIMZ	EVAL-MAY 6	K.Kosako	FENDL-3.0	1.50E+08	5539kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
37)	1925	19-K-39	NRG	EVAL-FEB12	A.J.Koning,D.Rochman	TENDL-2012	2.00E+08	2958kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
38)	1928	19-K-40	NRG	EVAL-FEB12	A.J.Koning,D.Rochman	TENDL-2012	2.00E+08	3197kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
39)	1931	19-K-41	NRG	EVAL-FEB12	A.J.Koning,D.Rochman	TENDL-2012	2.00E+08	2913kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
40)	2025	20-CA-40	SAEI	EVAL-MAY 3	K.Kosako	FENDL-3.0	1.50E+08	6164kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
41)	2031	20-CA-42	SAEI	EVAL-MAY 3	K.Kosako	FENDL-3.0	1.50E+08	6350kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
42)	2034	20-CA-43	SAEI	EVAL-MAY 3	K.Kosako	FENDL-3.0	1.50E+08	6413kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
43)	2037	20-CA-44	SAEI	EVAL-MAY 3	K.Kosako	FENDL-3.0	1.50E+08	6003kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp
44)	2043	20-CA-46	SAEI	EVAL-MAY 3	K.Kosako	FENDL-3.0	1.50E+08	5689kb	[endf] [ace] [xdr] [gendf] [matxs] [fig:ace,htr] [njoy:inp

www-nds.iaea.org/fendl3/000pages/StarterLib/2011-12-01/neutron/ace/09F_019.ace

Procedure for Benchmark Analyses

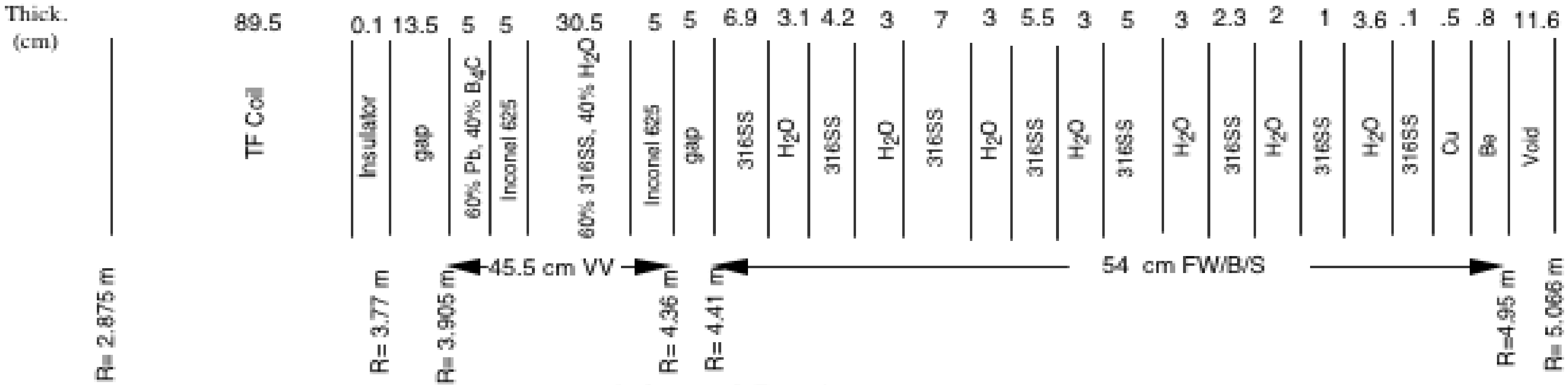
- Calculation for ITER computational benchmark
- Re-calculate FNG and FNS fusion benchmark experiments
  - Using MCNP5 and FENDL-3.0 ACE data
  - Using available MCNP input deck & FNG neutron source
- Compare to experimental data
- Compare to results obtained with FENDL-2.1 (and occasionally JEFF-3.1, JENDL-4)

ITER Computational Shield Benchmark

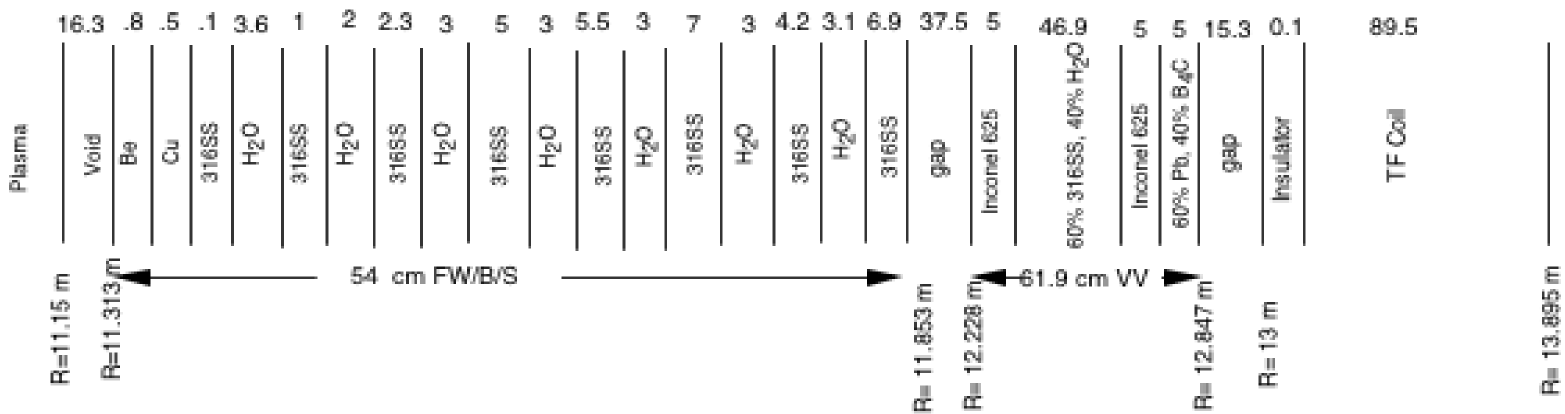
- ITER 1D blanket/shield/VV/TF-coil configuration
  - Set up as part of the FENDL-1 benchmarking efforts

    Reference: M. Sawan, FENDL Neutronics Benchmark: Specifications for the calculational and shielding benchmark, INDC(NDS)-316, December 1994
  - Suitable computational benchmark for ITER neutronics calculations
- Benchmarking of FENDL-3.0 vs. FENDL-2.1 (MC data)
- Results for flux, heating, dpa, and gas production were compared to the results of FENDL-2.1
- Results provide guidance to ITER regarding the need of changing the reference library to FENDL-3.0 or just adding a correction/safety factor to the the current results

ITER Computational Shield Benchmark



Inboard Region



Outboard Region

Peak Nuclear Heating Results

	FENDL-2.1		FENDL-3.0		
	Power Density	1 σ % Error	Power Density	1 σ % Error	% Change
IB					
FW					
Be	1.008E+01	0.05	1.007E+01	0.05	-0.06
Cu	2.017E+01	0.06	1.990E+01	0.07	-1.34
SS	1.785E+01	0.08	1.773E+01	0.08	-0.65
VV SS	2.635E-02	0.18	2.597E-02	0.18	-1.43
Magnet	5.422E-05	0.45	5.509E-05	0.45	1.60
OB					
FW					
Be	1.391E+01	0.03	1.390E+01	0.03	-0.07
Cu	2.476E+01	0.04	2.444E+01	0.05	-1.29
SS	2.230E+01	0.05	2.221E+01	0.05	-0.39
VV SS	3.576E-02	0.09	3.536E-02	0.09	-1.13
Magnet	7.800E-06	0.43	7.941E-06	0.43	1.81

- The harder and higher neutron flux in VV and magnet results in higher neutron heating
- Gamma heating is the dominant nuclear heating.
- Net result is modest increase in total magnet heating

Gas Production

He

	FENDL-2.1		FENDL-3.0		
	He appm/FPY	1 σ % Error	He appm/FPY	1 σ % Error	% Change
IB					
FW					
Be	4.100E+03	0.07	4.103E+03	0.07	0.06
CuBeNi	2.103E+02	0.07	2.111E+02	0.07	0.38
SS316	1.773E+02	0.06	1.847E+02	0.06	4.21
VV					
Inconel	6.811E-02	0.32	7.995E-02	0.31	17.37
SS316	7.659E-02	0.22	8.249E-02	0.22	7.70
Magnet (Cu)	3.819E-04	0.62	4.020E-04	0.61	5.27
OB					
FW					
Be	5.981E+03	0.03	5.984E+03	0.03	0.05
CuBeNi	3.233E+02	0.03	3.248E+02	0.03	0.48
SS316	2.454E+02	0.03	2.561E+02	0.03	4.36
VV					
Inconel	9.042E-02	0.16	1.069E-01	0.16	18.28
SS316	1.076E-01	0.11	1.164E-01	0.11	8.19
Magnet (Cu)	5.570E-05	0.57	6.002E-05	0.56	7.75

H

	FENDL-2.1		FENDL-3.0		
	H appm/FPY	1 σ % Error	H appm/FPY	1 σ % Error	% Change
IB					
FW					
Be	6.103E+01	0.07	6.106E+01	0.07	0.05
CuBeNi	6.463E+02	0.07	6.461E+02	0.07	-0.03
SS316	6.020E+02	0.08	5.950E+02	0.08	-1.16
VV					
Inconel	5.762E-01	0.30	5.783E-01	0.30	0.37
SS316	1.170E-01	0.35	1.196E-01	0.34	2.16
Magnet (Cu)	1.080E-03	0.65	1.135E-03	0.64	5.07
OB					
FW					
Be	8.968E+01	0.03	8.968E+01	0.03	0.01
CuBeNi	9.994E+02	0.03	1.000E+03	0.03	0.06
SS316	9.414E+02	0.03	9.307E+02	0.03	-1.14
VV					
Inconel	7.670E-01	0.15	7.757E-01	0.15	1.14
SS316	1.677E-01	0.17	1.731E-01	0.17	3.18
Magnet (Cu)	1.566E-04	0.61	1.684E-04	0.60	7.50

T

	FENDL-2.1		FENDL-3.0		
	T appm/FPY	1 σ % Error	T appm/FPY	1 σ % Error	% Change
IB					
FW					
Be	6.101E+01	0.07	6.104E+01	0.07	0.05
CuBeNi	1.564E+00	0.07	1.563E+00	0.07	-0.04
SS316	1.196E-01	0.08	1.203E-01	0.08	0.63
VV					
Inconel	2.951E-06	0.52	6.922E-06	0.45	134.54
SS316	2.487E-05	0.36	2.546E-05	0.36	2.37
Magnet (Cu)	1.354E-06	0.87	1.431E-06	0.85	5.67
OB					
FW					
Be	8.964E+01	0.03	8.965E+01	0.03	0.01
CuBeNi	2.447E+00	0.03	2.448E+00	0.03	0.04
SS316	1.869E-01	0.04	1.882E-01	0.04	0.73
VV					
Inconel	3.782E-06	0.26	9.027E-06	0.23	138.66
SS316	3.574E-05	0.18	3.695E-05	0.18	3.37
Magnet (Cu)	1.825E-07	0.86	1.982E-07	0.84	8.62

- Large increase in helium produced in VV and magnet due to higher and harder neutron flux and higher cross sections
- Smaller increase in hydrogen production
- Large difference in tritium production due to missing processed reactions in some libraries, e.g., T production reaction (205) was missing in FENDL-2.1
- We conclude that it is very important that the processed data for FENDL-3.0 include all necessary reactions used for gas production by adding the missing reactions (204, 205, 206)

Peak IB Magnet Radiation Parameters

	FENDL-2.1		FENDL-3.0		% Change
	Value	1 σ % Error	Value	1 σ % Error	
Fast fluence ($n/cm^2/FPY$)	6.208E+16	0.45	6.480E+16	0.45	4.38
Insulator dose (Gy/FPY)	6.859E+05	0.43	7.091E+05	0.43	3.38
Cu dpa/FPY	3.898E-05	0.48	4.064E-05	0.48	4.27
Heating (mW/cm^3)	5.422E-02	0.40	5.509E-02	0.40	1.60

- Nuclear parameters at magnet are higher by ~1.6-4.4% than predicted by FENDL-2.1
- Largest effect is on fast n fluence (>4%) due to the harder and larger neutron flux
- Similar effect observed in Cu dpa produced by high energy neutrons
- Increase in insulator dose and winding pack nuclear heating is reduced due to the contribution from gamma heating

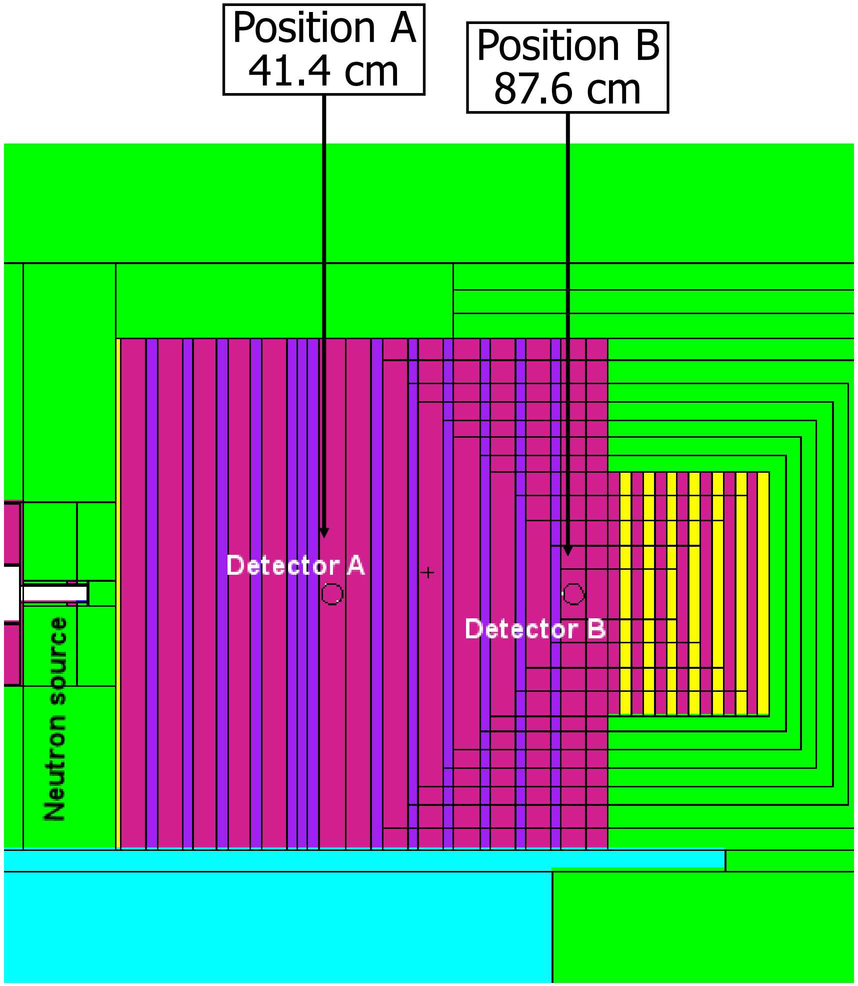
FNG Fusion Benchmark Experiments

- ITER bulk shield experiment
  - *Measurement of neutron/ photon flux spectra in assembly, reaction rates (activation foils)*
- W bulk shield experiment
  - *Measurement of neutron/ photon flux spectra, reaction rates (activation foils)*
- HCPB breeder mock-up experiment
  - *Measurement of Tritium generated in Li_2CO_3 pellets, neutron/photon flux spectra in assembly , reaction rates (activation foils)*
- HCLL breeder mock-up experiment
  - *Measurement of Tritium generated in Li_2CO_3 pellets, neutron/photon flux spectra in assembly, reaction rates (activation foils)*

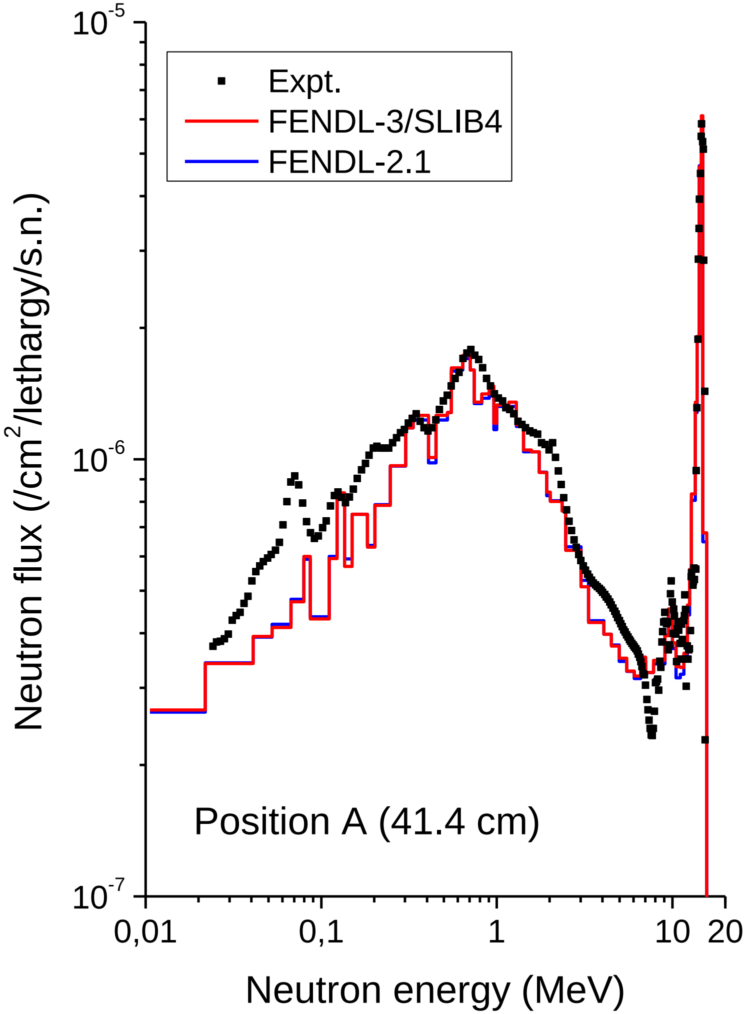
ITER Bulk Shield Mock-up Experiment at FNG

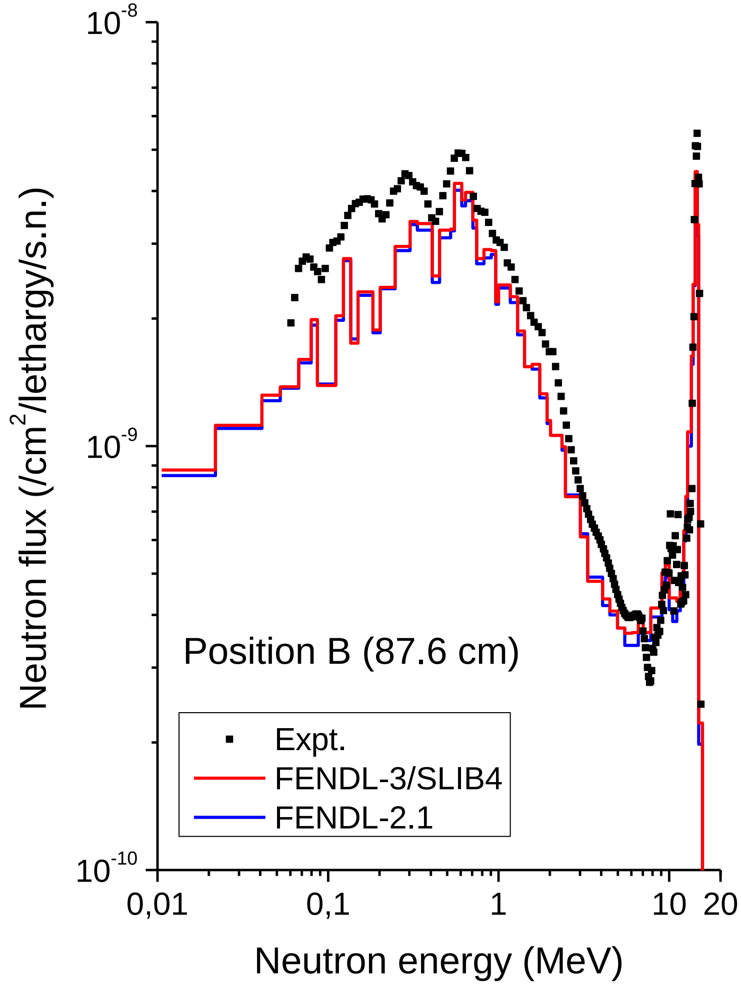
Measurements of neutron/photon flux spectra by TUD (K. Seidel et al.)

- Mock-up of ITER inboard blanket/shield system with thickness of 94 cm (alternating plates of SS-316 and of Perspex)
- Backed by 30 cm thick block of alternating SS-316 and Cu plates simulating TF-coil
- Neutron and photon flux spectra measured at positions A (41.4 cm) and B (87.6 cm)
- Neutron spectra measured in the energy range between about 20 keV and 15 MeV.
  - A set of gas-filled proportional counters and a stilbene scintillation spectrometer used in the energy range up to 3 MeV.
  - NE-213 scintillation spectrometer for energy range 1 to 15 MeV.
- Photon flux spectra measured with NE-213 spectrometer above 0.2 MeV.



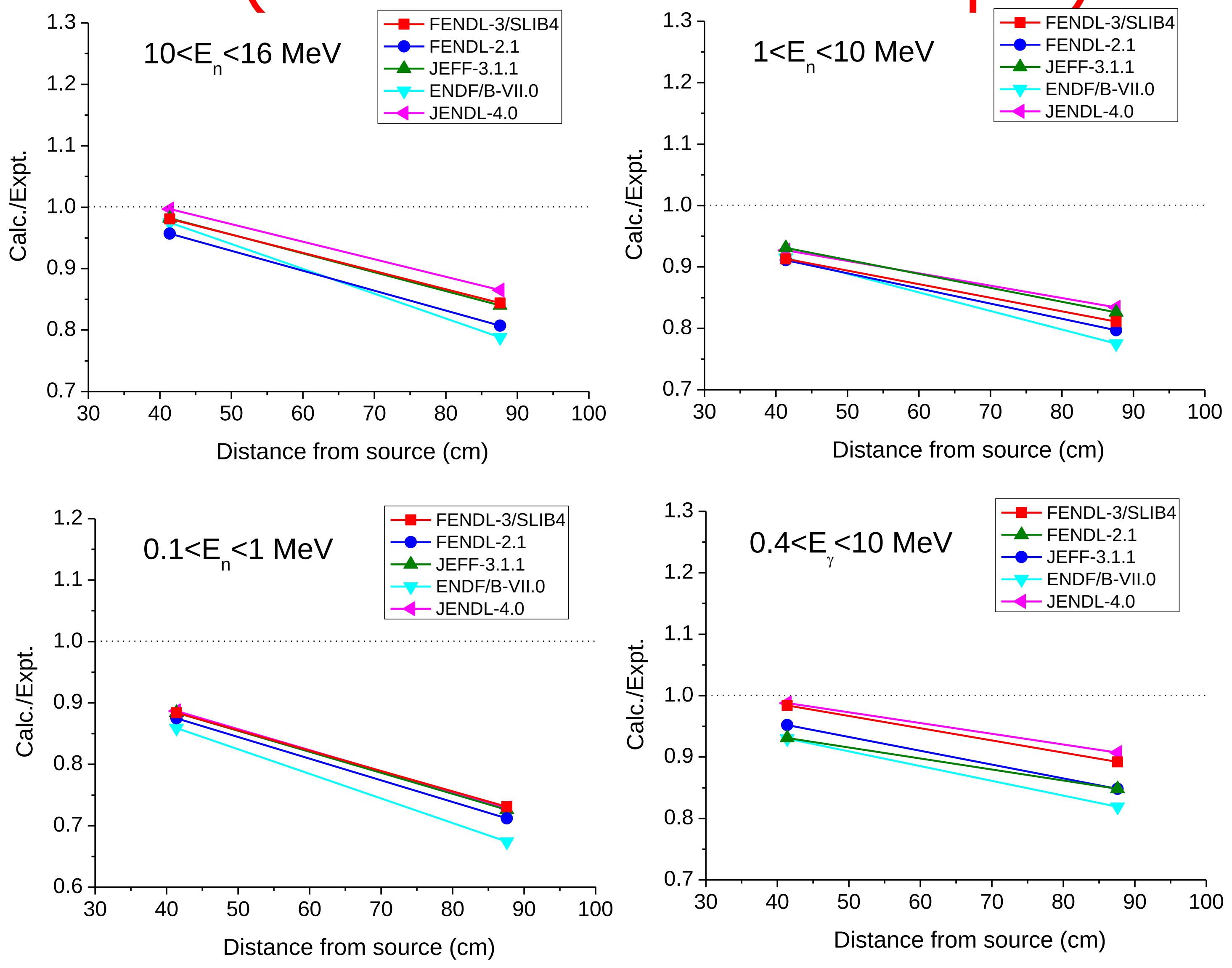
Neutron spectra (ITER bulk shield expt.)





- FENDL-3.0 well reproduces the experimental data and there is no significant difference between the results obtained with FENDL-2.1

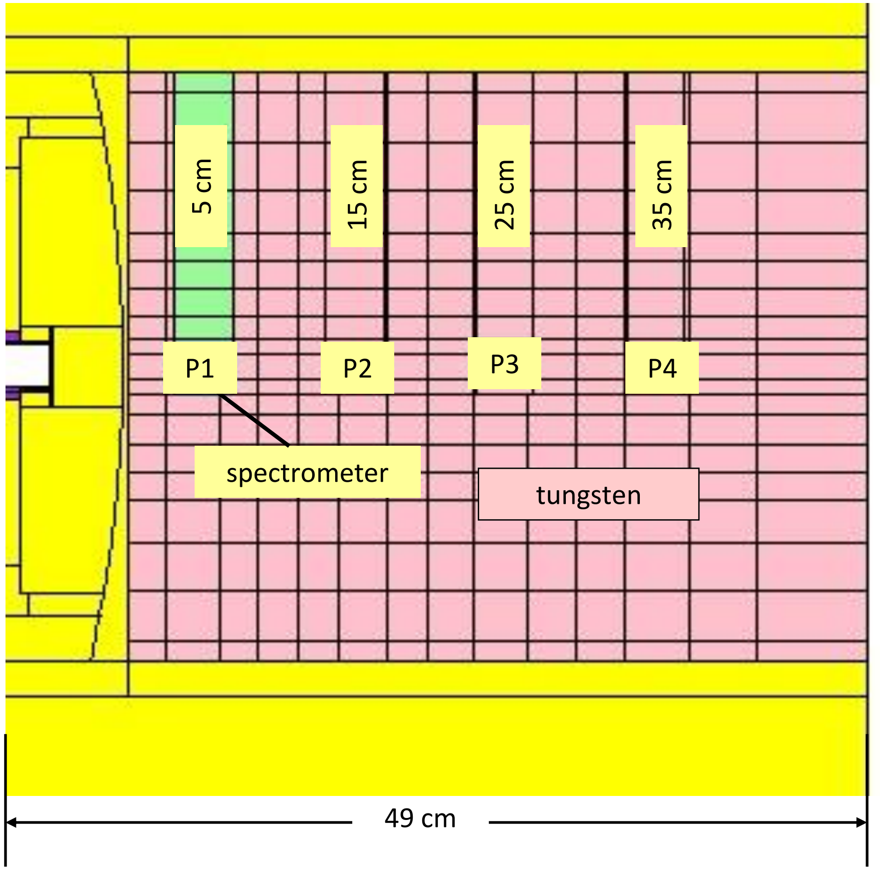
C/E for integrated neutron / photon flux (ITER bulk shield expt.)



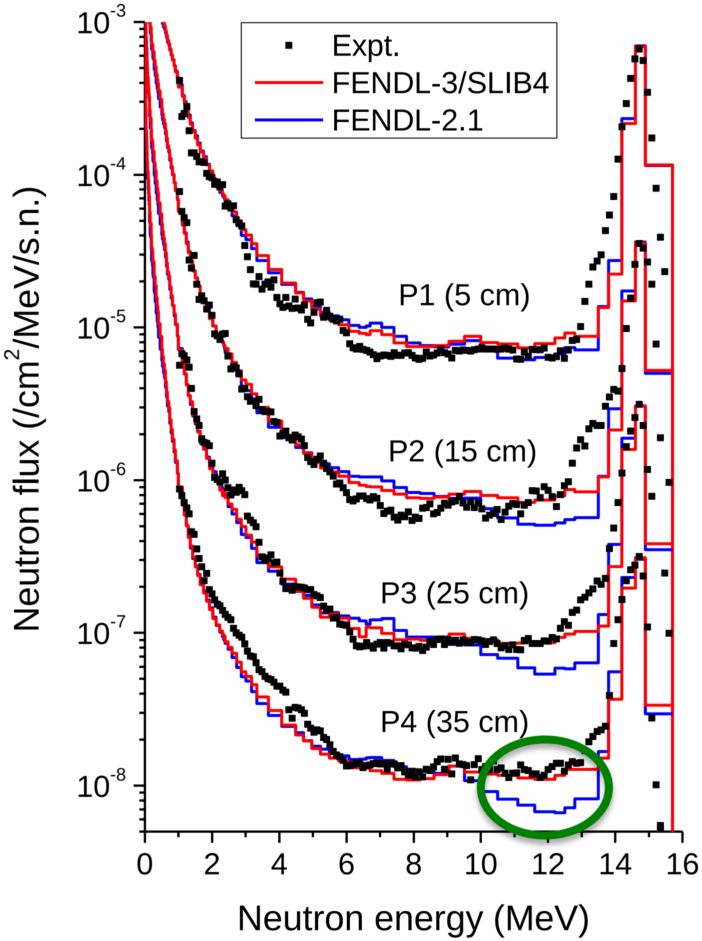
FNG Tungsten Benchmark Experiment

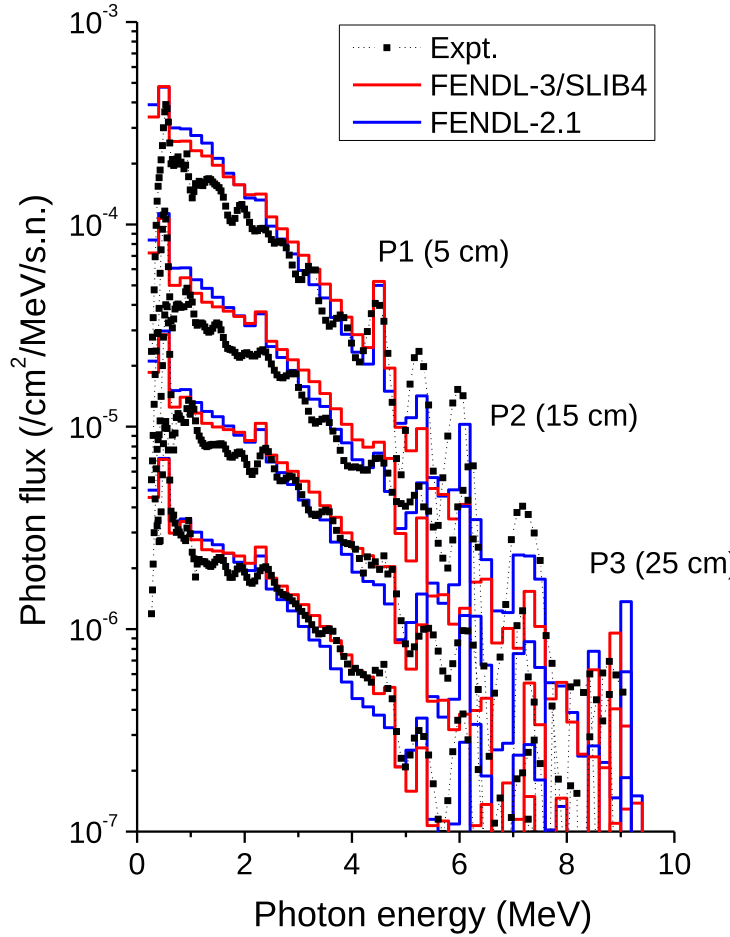
Measurements of neutron/photon flux spectra by TUD (K. Seidel et al.)

- Spectra measured in four positions in W (tungsten) assembly
- MCNP4C calculations for 3D model of W assembly & rack, spectrometer, neutron generator and experimental hall (FNG)



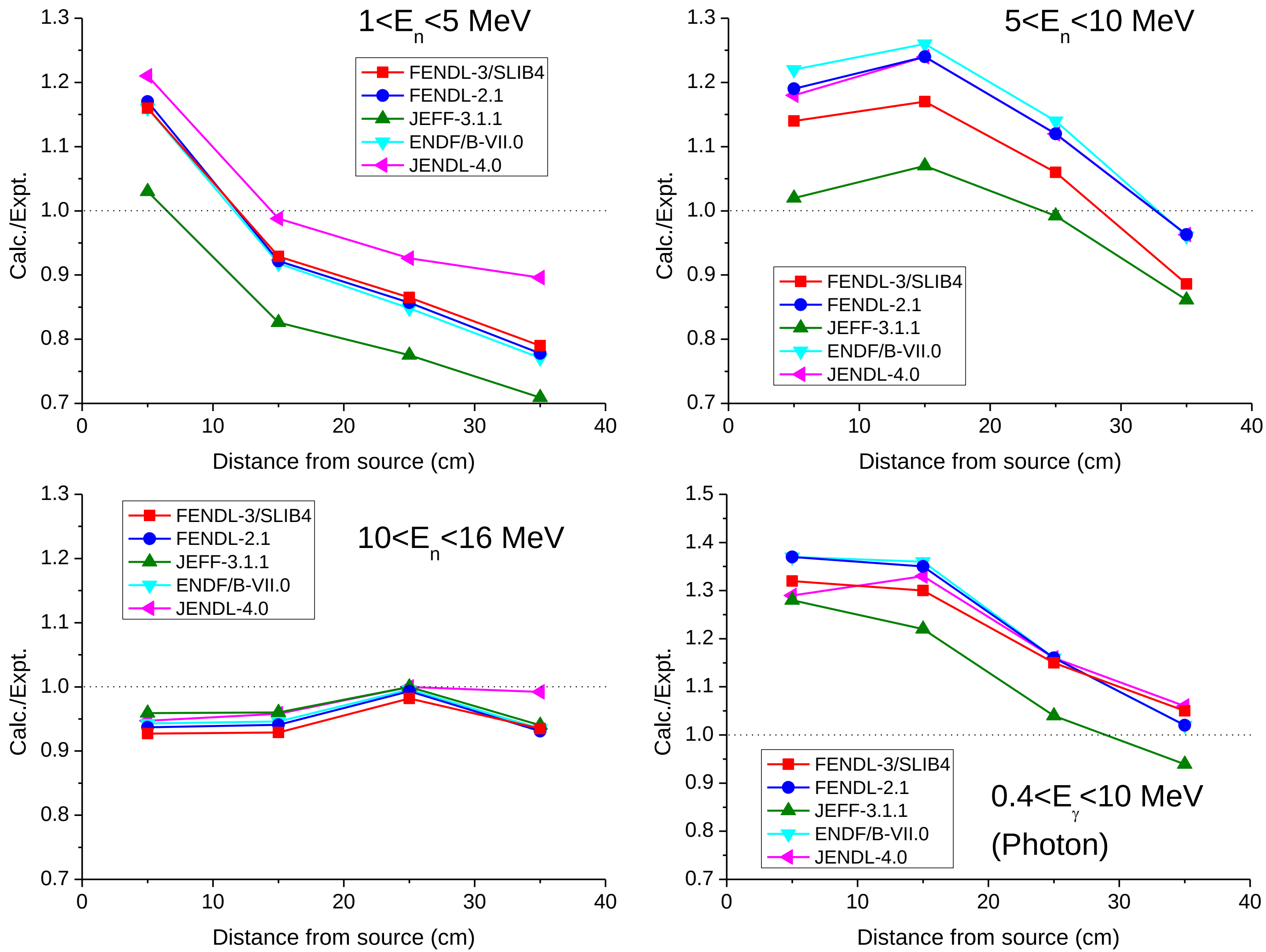
Neutron/Photon spectra (W expt.)





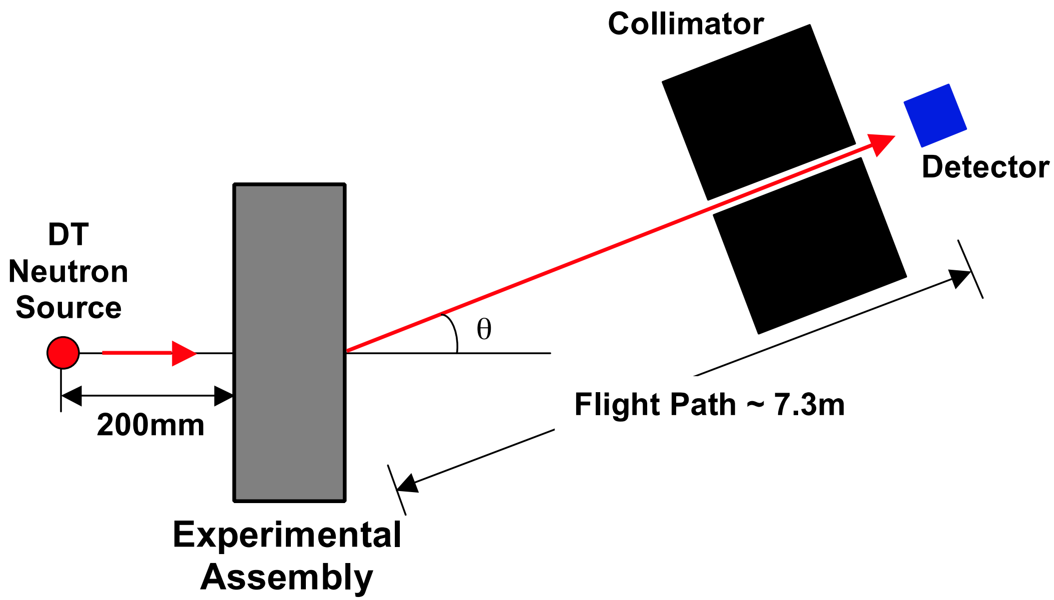
➢ FENDL-3.0 reproduces well the neutron spectra, in general better than FENDL-2.1

C/E for integrated neutron / photon flux (W benchmark expt.)



FNS experiments

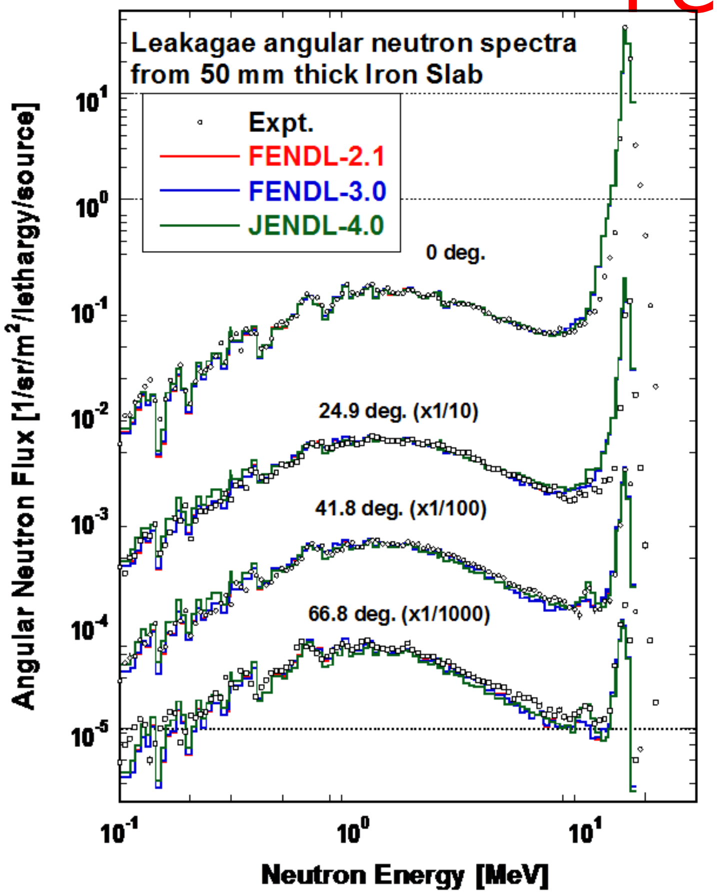
Experimental setup for TOF experiments.

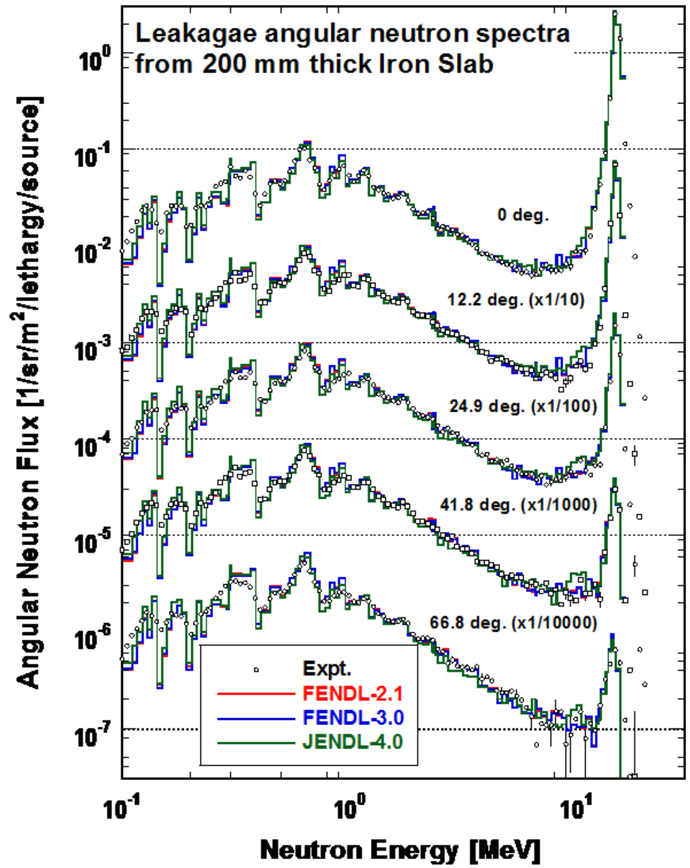


Time-Of-Flight (TOF) experiments

- Angular neutron leakage spectra above 100 keV from the simple geometry slab were measured for lithium oxide, beryllium, graphite, nitrogen, oxygen, iron, copper, lead, etc. by using a collimator system
- Size of experimental assemblies is different for each experiment depending on material amounts which we have

Angular neutron leakage spectra from Fe slabs



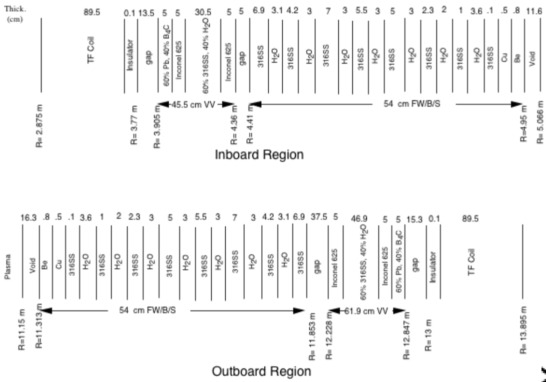


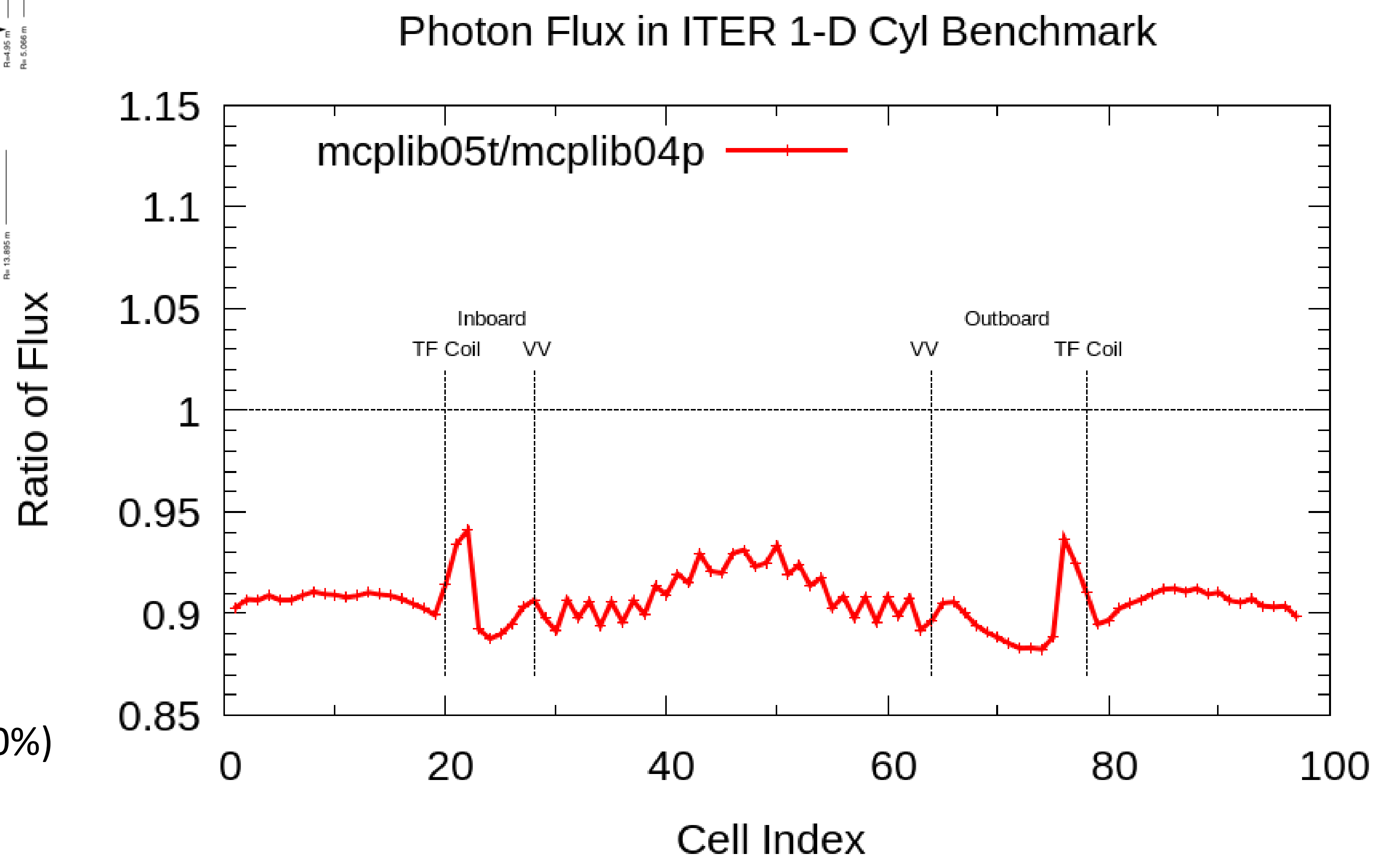
Calculations with FENDL-3.0 and 2.1 data in general agree well and also reproduce well the experimental spectra

Testing of Photon Data for Fusion Application

- Photon (gamma) transport is important in fusion neutronics analysis because photons dominate the contribution to nuclear heating/absorbed dose for most of materials used in fusion (e.g. Copper, steel, magnet insulators, etc)
- Photon transport is also important for activation (shutdown dose) analysis
- Fusion nuclear analysis with MCNP has been utilizing the mcplib04p photon library
- A new version (mcplib05t) of photon cross section library has recently 2011 been made available for testing with MCNP
  - *J.S. Hendricks, B.J. Quiter, "MCNP/X Form Factor Upgrade for Improved Photon Transport", Nuclear Technology, Volume 175, p150-161, July, 2011*
- We found switching to this library results in ~10% lower gamma flux in the ITER computational benchmark
- We plan to perform benchmark calculations for nuclear heating and shutdown dose to assess impact on fusion nuclear analysis

Relative Change in Photon Flux for ITER Computational Benchmark





(statistical uncertainty <0.50%)

- Photon flux calculated with the new photon library is 5-10% lower than the flux calculated with the currently used library

Results Presented at ITER Neutronics Meeting in July 2013 and Following Recommendations Made

- **FENDL 3**
  - *Test FENDL 3 and compare results to those obtained with FENDL2.1*
  - *Report difference*
  - *Use Covariance data*
- **Use new photon library**

Summary

- FENDL-3 benchmark analyses were performed on a computational ITER benchmark and a series of available 14 MeV neutron benchmark experiments
- The comparison to experimental results showed that in general, FENDL-3, as compared to FENDL-2.1, shows an improved performance for fusion neutronics applications
- The computational benchmark revealed a modest increase of neutron flux, nuclear heating, and damage levels in deep penetration regions shielded by water-cooled SS with expected small impact on ITER nuclear analysis by switching to FENDL-3.0
- FENDL-3.0 yields only ~2% increase in magnet heating which is the primary magnet shielding design driver in ITER and switching to FENDL-3.0 is not urgently needed for ITER nuclear analysis except when materials not present in FENDL-2.1 are needed
- Caution should be observed when calculating gas production due to missing D, T, He-3 reactions for several materials. These need to be added in future releases
- We need to assess the impact of the new release of photon data for MCNP on heating and shutdown dose calculations