The Impact of Neutron and Photon Cross Section Libraries on ITER Neutronics Calculations

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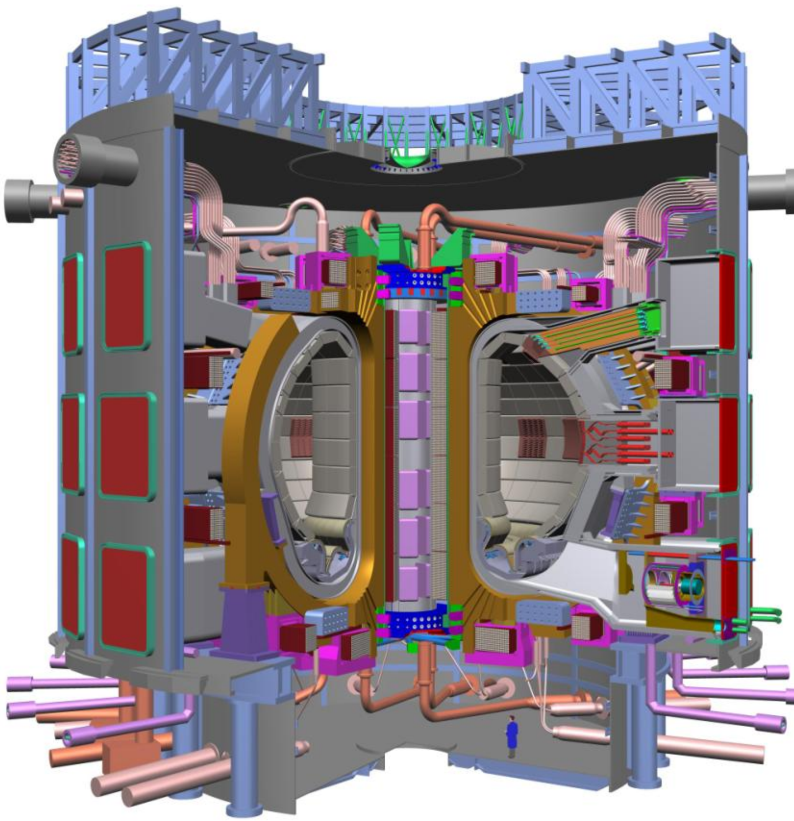
Outline

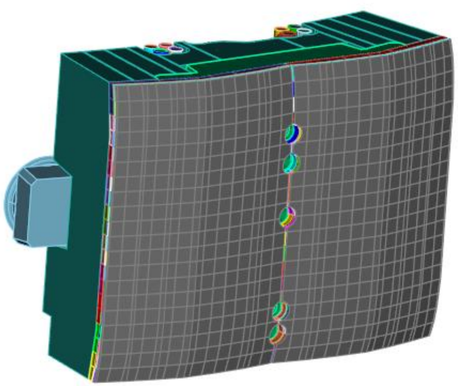
1) Introduction
2) Nuclear data libraries examined
3) Benchmark calculations considered
4) Results
5) Conclusion/Future Work

Introduction

- In the design of fusion reactors, radiation transport calculations are very important
- Both deterministic (Discrete Ordinates) and stochastic (Monte Carlo) methods are used
- These transport codes need to have accurate cross section libraries



ITER

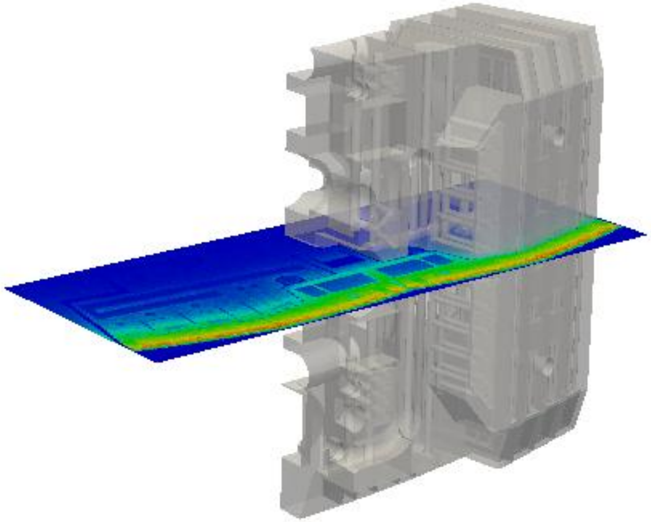


ITER Blanket (shield) Module

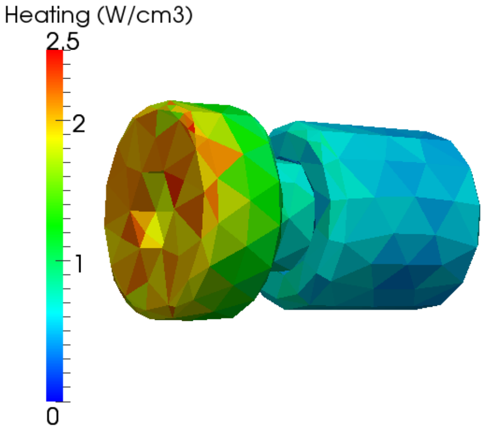
Fusion Neutronics Calculations

- Neutron flux/fluence (**neutron**)
  - magnet
- Radiation damage/dpa (**neutron**)
  - structural material degradation
- He production (**neutron**)
  - reweldability
- T production (**neutron**)
  - breeding, environmental
- Radiation dose (**neutron+photon**)
  - insulator
- Total nuclear heating (**neutron+photon**)
  - coolant system design, thermal stress, magnets

➢ Need accurate neutron **and** photon libraries



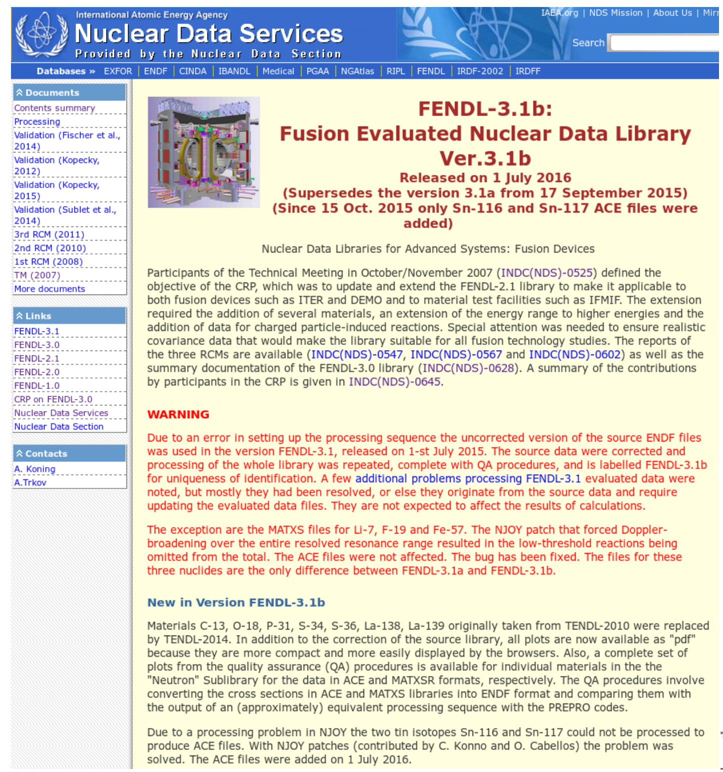
Shield Block



Central Bolt

FENDL

- The Fusion Evaluated Nuclear Data Library (FENDL) is an international effort coordinated by the IAEA Nuclear Data Section
- Assembles a collection of the best nuclear data from national cross section data libraries for fusion applications
  - ENDF/B (US), JENDL (Japan), JEFF (Europe), BROND (Russia)
- Process uses fusion specific experimental and calculational benchmarks to evaluate the data



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FENDL continued

- FENDL-2.1 (71 isotopes, 2003) is reference library for ITER
- FENDL-3.1b has recently been released with 180 isotopes and energies up to 150 MeV for neutrons, protons, and deuterons
- Libraries available on-line:
  - https://www-nds.iaea.org/fendl21/
  - https://www-nds.iaea.org/fendl3/

Source of FENDL-2.1 data:

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

Source of FENDL-3.1b Data

- 65/180 isotopes in FENDL-3.1b come from ENDF/B-VII.1
  - See Table 1 in INDC(NDS)-0628
- Some key isotopes for this work:

Isotope	FENDL-2.1	FENDL-3.1b
H-1	JENDL-3.3	ENDF/B-VII.1
0-16	ENDF/B-VI.8	ENDF/B-VII.1
Cr-52	ENDF/B-VI.8	ENDF/B-VII.1
Fe-56	JEFF-3	JEFF-3.1.1
Ni-58	JEFF-3	ENDF/B-VII.0
Cu-63,65	ENDF/B-VI.8	ENDF/B-VII.0

Photon Data Libraries in FENDL/MCNP

- Significant efforts performed evaluating neutron data for FENDL
  - FENDL provides ACE formatted neutron data libraries for use with MCNP
- Less effort examining photon cross section data in the FENDL evaluation process
  - No MCNP (ACE formatted) photon libraries provided with FENDL

➢ *But photon heating contributes 90% of the nuclear heating for important fusion materials (e.g. stainless steel, Cu, tungsten)*

MCNP Photon Data:

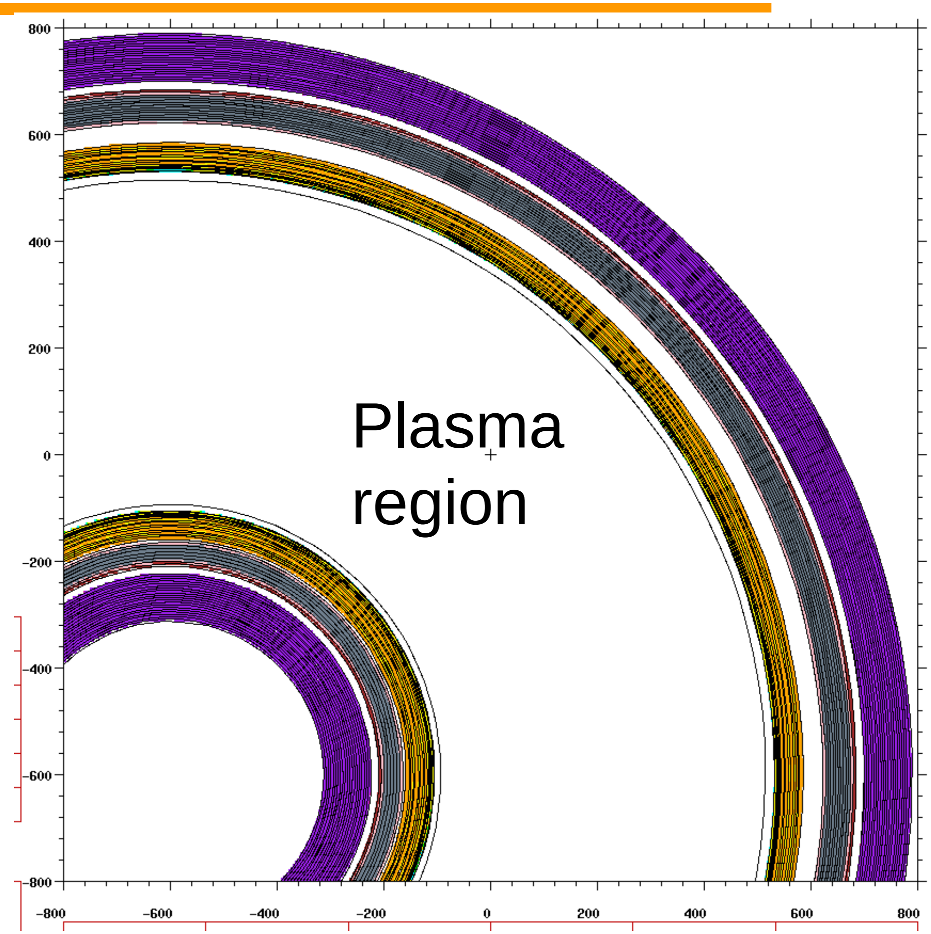
- Standard library: mcplib04/84 (note: mcplib84 corrects bug in mcplib04)
- New library: eprdata12 (for MCNP6)
  - includes low energy < 1keV data

Goal of this work

- Want to look at the impact of using the updated neutron and photon libraries in a realistic model of ITER
- Libraries examined:
  - *Neutron:*
    1. FENDL-2.1 (21c)
    2. FENDL-3.1b (31c)
    3. ENDF/B-VII.0 (70c)
    4. ENDF/B-VII.1 (80c)
  - *Photon:*
    1. mcplib84 (84p)
    2. eprdata12 (12p)

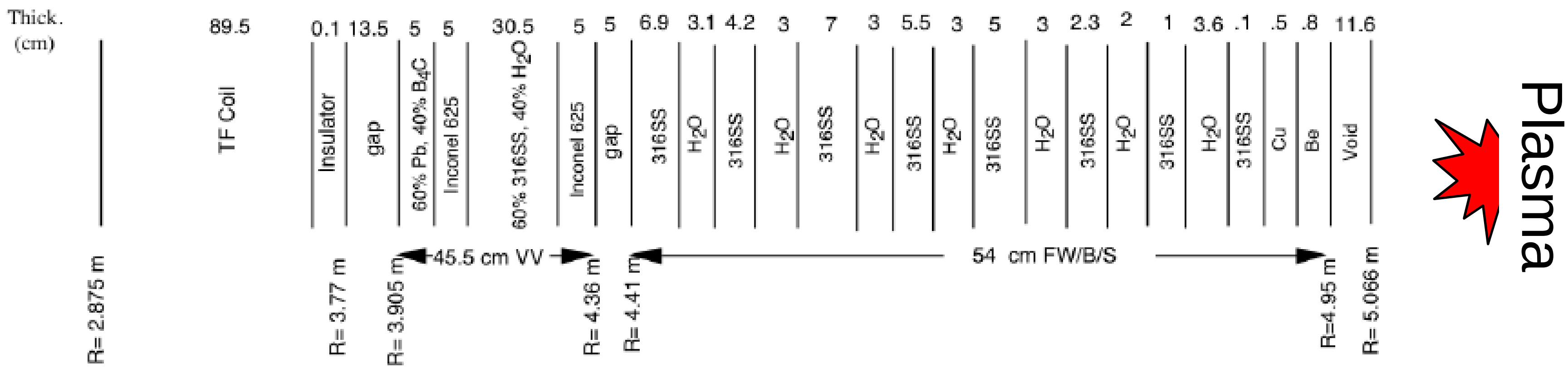
ITER 1-D Cylindrical Calculation Benchmark

- Based on an early ITER design
- Developed for the FENDL evaluation process
- Simple but realistic model of ITER with the Inboard and Outboard portions modeled with the plasma in between
- D-T fusion (14.1 MeV neutrons)
- Flux (neutron and photon), heating, dpa, and gas production calculated

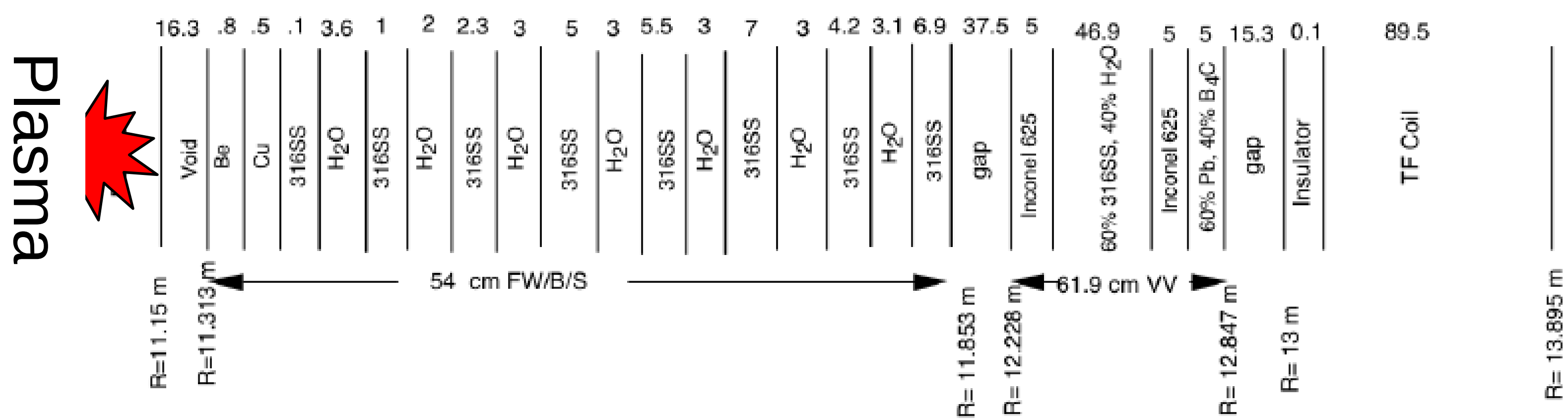


M. Sawan, FENDL Neutronics Benchmark: Specifications for the calculational and shielding benchmark, INDC(NDS)-316, December 1994

ITER 1-D Cylindrical Benchmark continued



Inboard Region



Outboard Region

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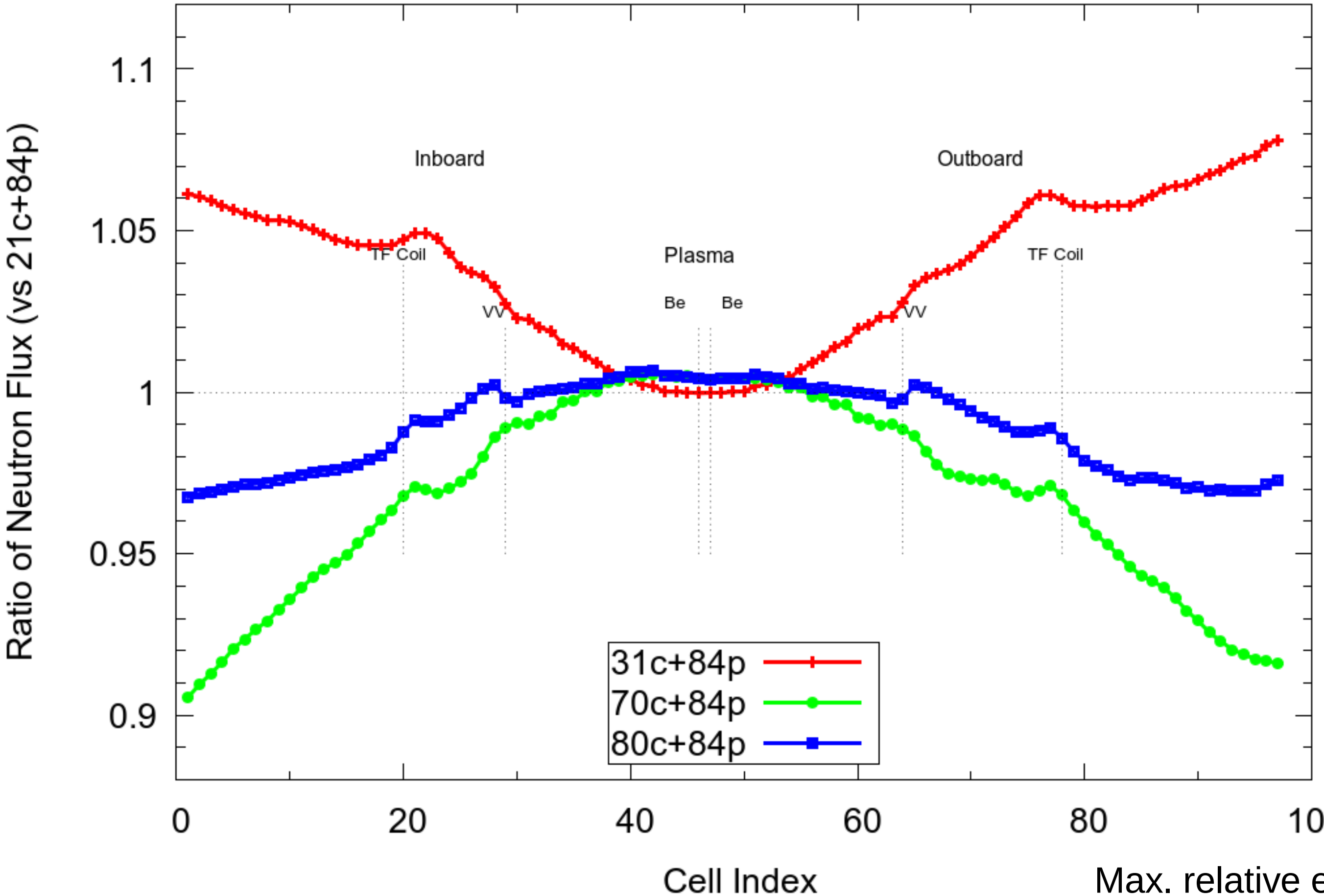
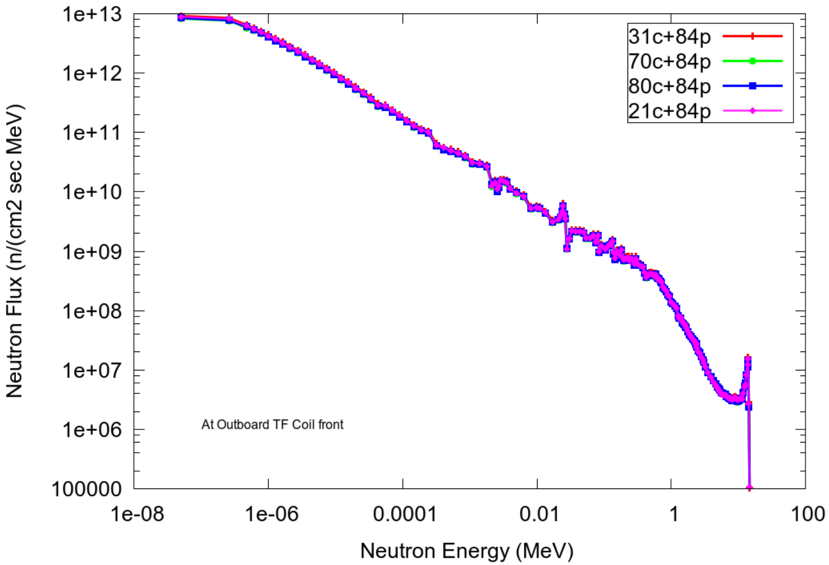
Results: Neutron Flux

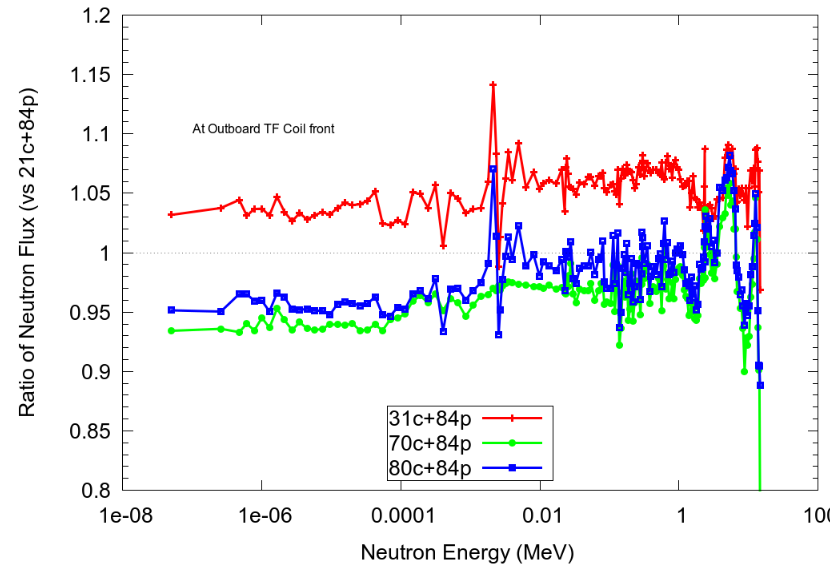


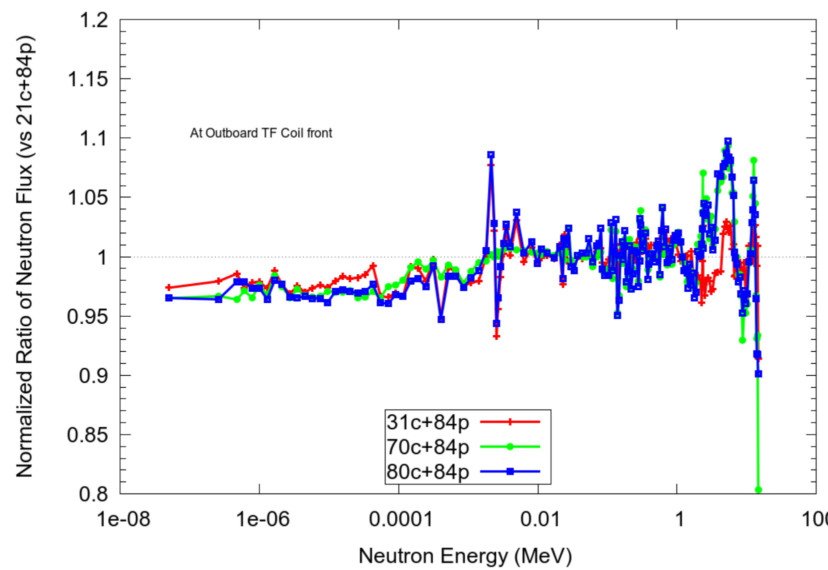
Max. relative error <0.26%

- With updated FENDL-3.1b neutron library (31c) see neutron fluxes up to 8% higher than FENDL-2.1 (21c) at deep depths in TF coil
- With ENDF/B-VII.1 (80c) see neutron fluxes up to 3% lower
- In FENDL-3.1b, Fe-56 and Cu data come from JEFF-3.1.1 and ENDF/B-VII.0

Results: Neutron Spectrum at OB TF coil

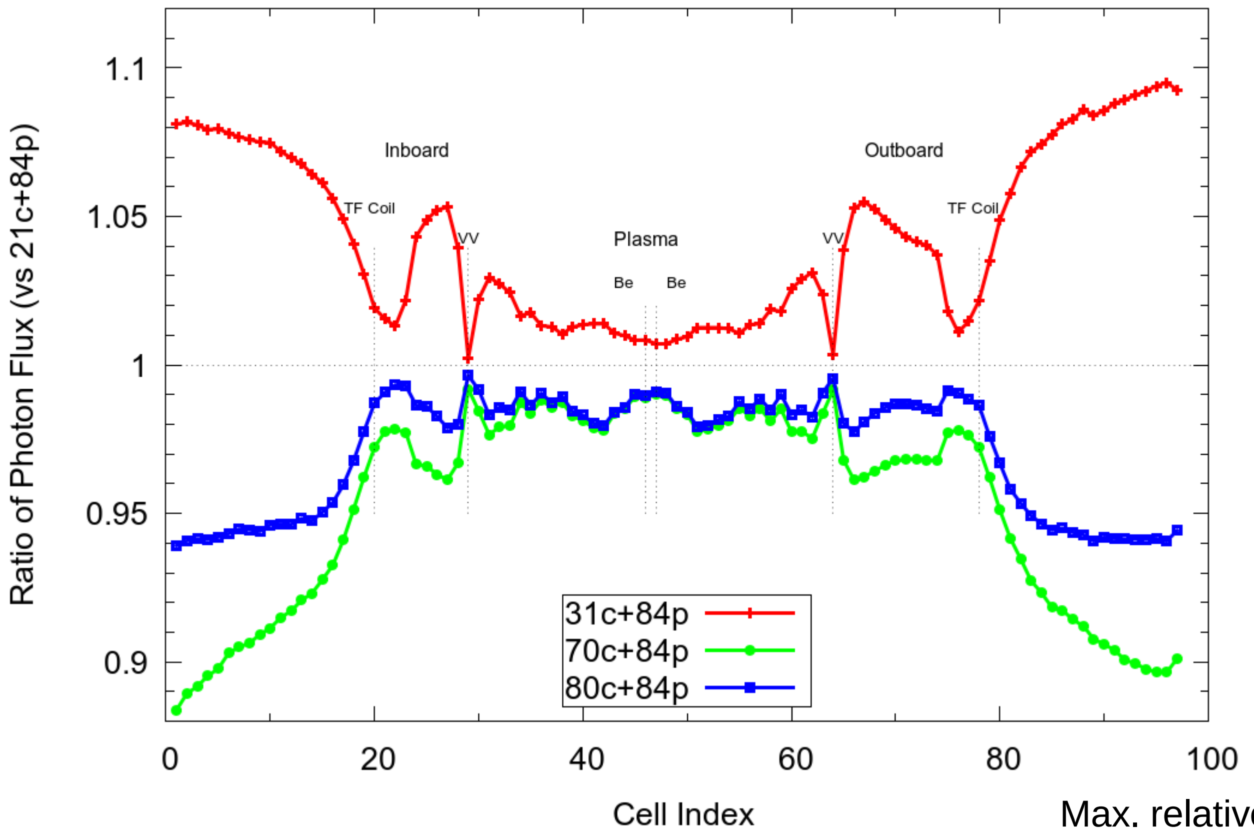






- With ENDF/B-VII.0-1 (70c, 80c) see lower flux at TF coil
- With updated FENDL-3.1b neutron library (31c) see a harder spectrum than FENDL-2.1 (21c) at TF coil
- With ENDF/B-VII.0-1 (70c, 80c) also see a harder spectrum at TF coil

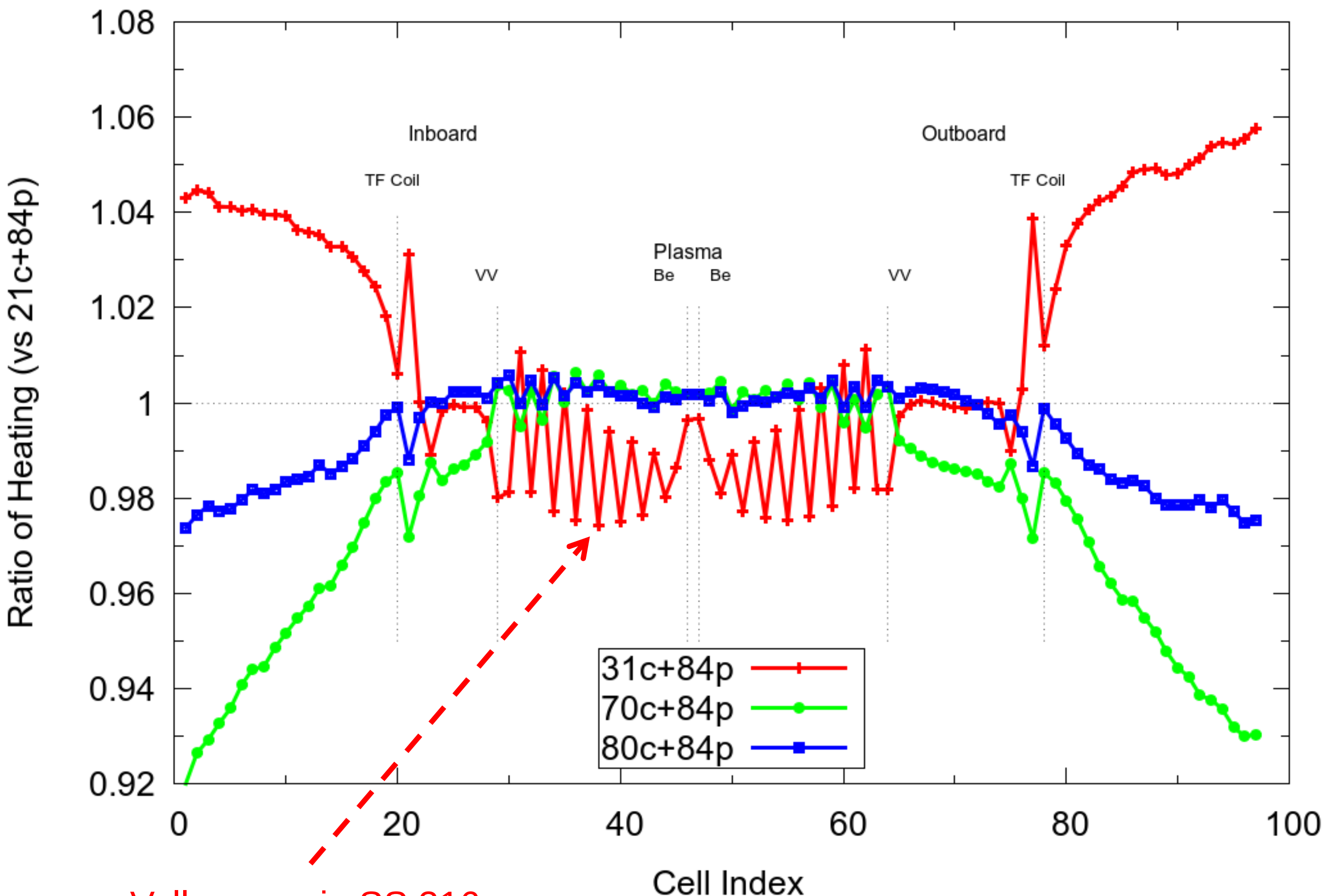
Results: Photon Flux



Max. relative error <0.25%

- Photon fluxes roughly follow neutron fluxes (see structure at VV shell)
- With updated FENDL-3.1b neutron library (31c) see photon fluxes up to 9% higher than FENDL-2.1 (21c) at deep depths in TF coil
- With ENDF/B-VII.1 (80c) see neutron fluxes up to 6% lower

Results: Total nuclear heating

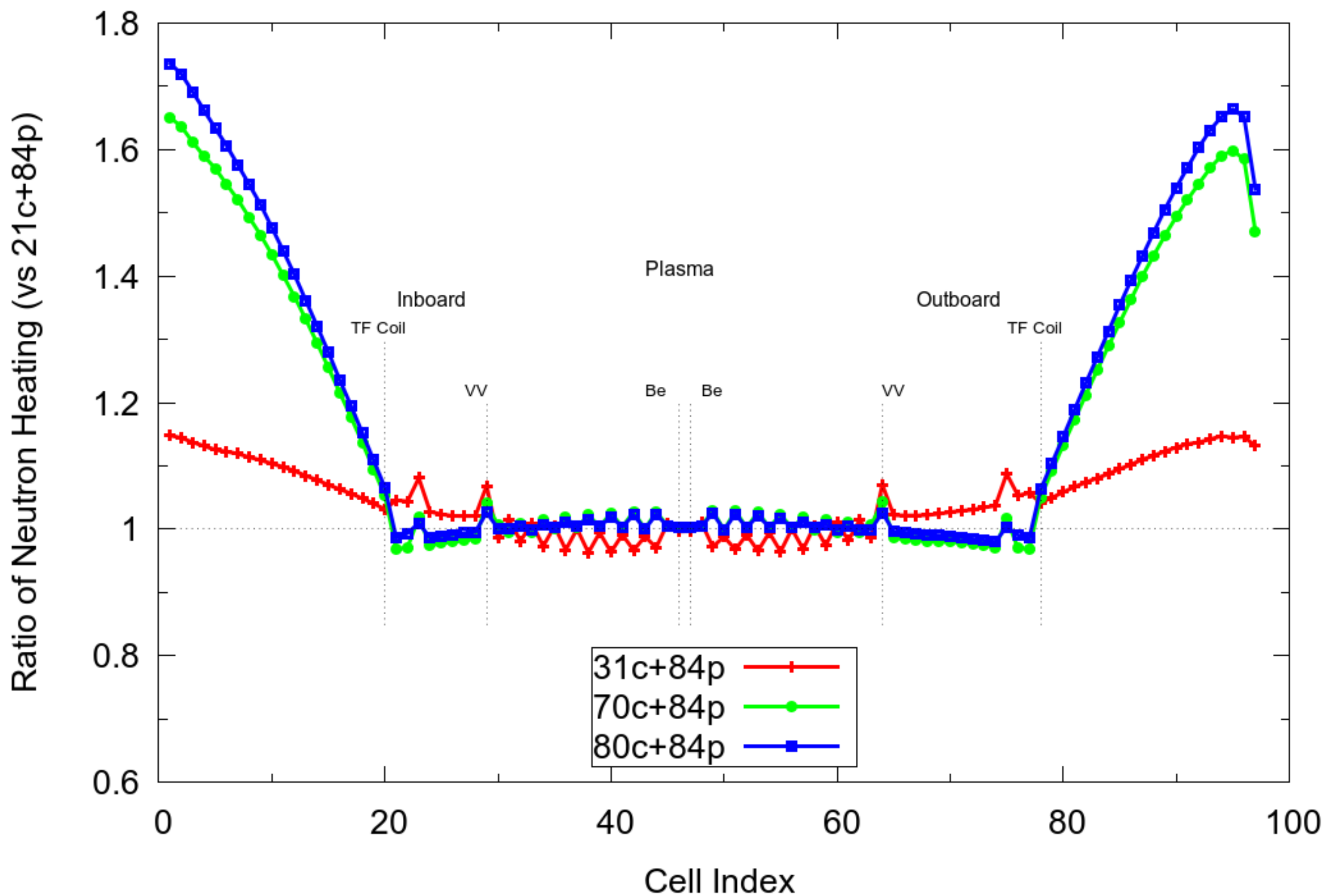


Valleys are in SS 316

Max. relative error <0.27%

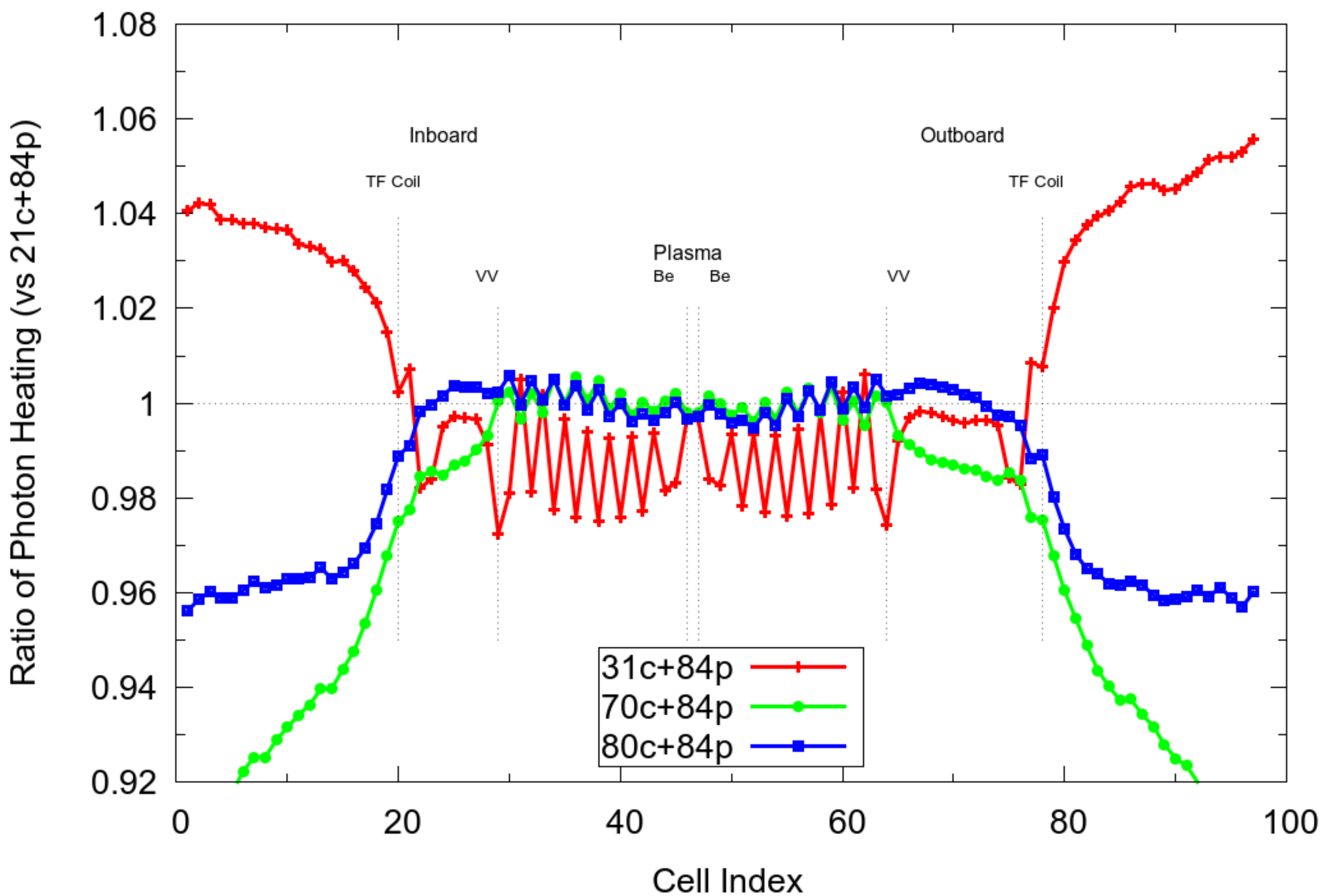
- With updated FENDL-3.1b neutron library (31c) see total heating up to 6% higher than FENDL-2.1 (21c) at deep depths in TF coil
- With ENDF/B-VII.1 (80c) see total heating up to 3% lower

Results: neutron heating



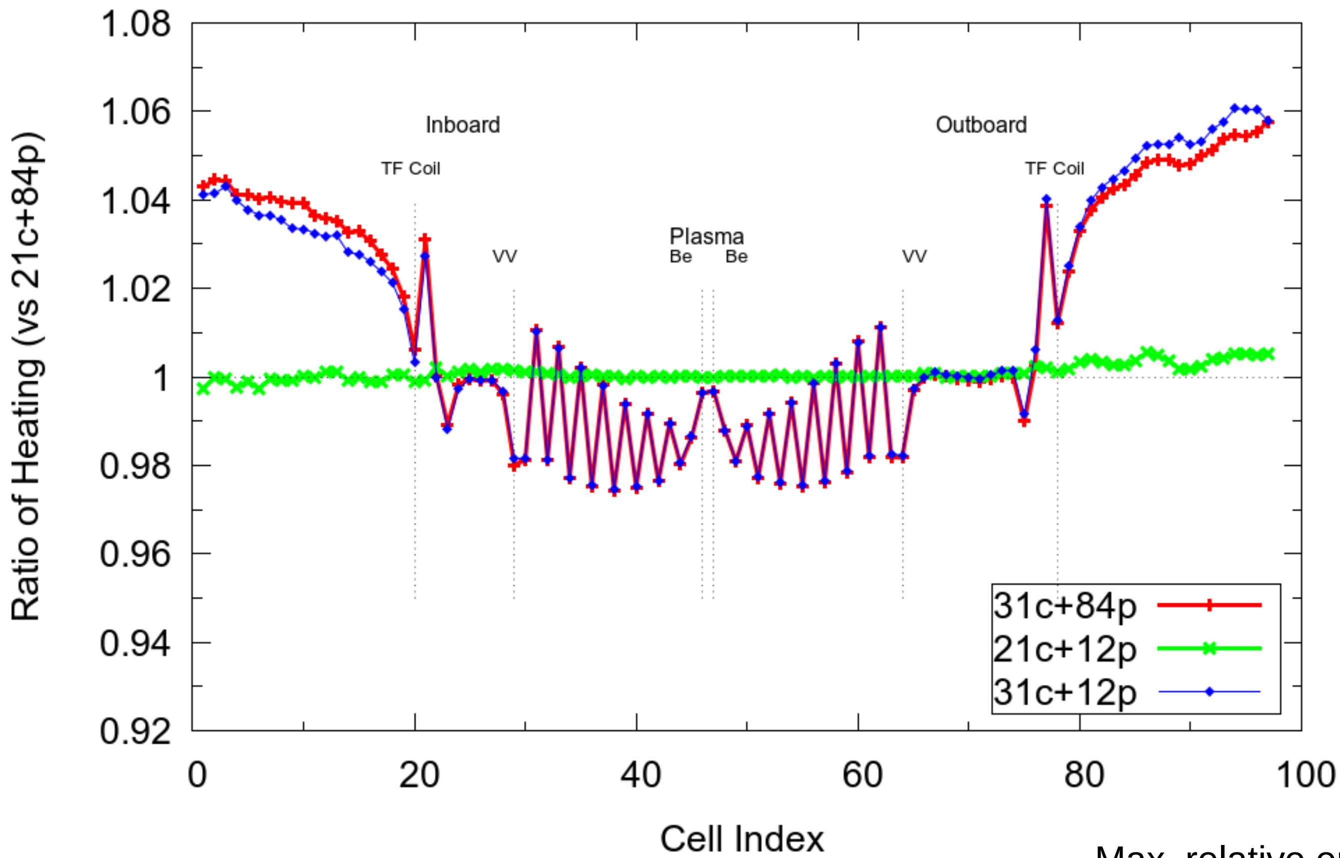
- With updated FENDL-3.1b neutron library (31c) see neutron heating up to 15% higher than FENDL-2.1 (21c) at deep depths in TF coil
- With ENDF/B-VII.1 (80c) see neutron heating up to 70% higher

Results: photon heating



- With updated FENDL-3.1b neutron library (31c) see photon heating up to 5% higher than FENDL-2.1 (21c) at deep depths in TF coil
- With ENDF/B-VII.1 (80c) see photon heating up to 4% lower

Results: Impact of Photon Library



Max. relative error <0.27%

- With the updated photon library (12p), we see good agreement with the standard photon library (84p)

Results: dpa

	21c+84p	31c+84p	% diff.	80c+84p	% diff.
IB					
FW Cu	9.16416E+00	9.13434E+00	-0.33	9.18390E+00	0.22
FW SS (Fe)	7.78771E+00	7.78131E+00	-0.08	8.22207E+00	5.58
VV Inconel (Ni)	1.01076E-02	1.04166E-02	3.06	1.01171E-02	0.09
VV SS (Fe)	3.35716E-03	3.45015E-03	2.77	3.46625E-03	3.25
Magnet Cu	3.88072E-05	4.06994E-05	4.88	3.84160E-05	-1.01
OB					
FW Cu	1.37635E+01	1.37245E+01	-0.28	1.37831E+01	0.14
FW SS (Fe)	1.18140E+01	1.18099E+01	-0.03	1.24828E+01	5.66
VV Inconel (Ni)	1.38127E-02	1.42400E-02	3.09	1.38188E-02	0.04
VV SS (Fe)	5.02005E-03	5.16308E-03	2.85	5.18489E-03	3.28
Magnet Cu	5.61928E-06	5.95996E-06	6.06	5.55328E-06	-1.17

Max. relative error <0.15%

- different neutron flux and spectrum at FWSS, VV, magnet

Results: He production

	21c+84p	31c+84p	% diff.	80c+84p	% diff.
IB					
FW Be	4.09900E+03	4.10018E+03	0.03	4.12365E+03	0.60
FW CuBeNi	2.10289E+02	2.11113E+02	0.39	2.12205E+02	0.91
FW SS316	1.77311E+02	1.84877E+02	4.27	1.88600E+02	6.37
VV Inconel	6.76921E-02	7.98705E-02	17.99	7.68869E-02	13.58
VV SS316	7.62989E-02	8.24488E-02	8.06	7.97493E-02	4.52
Magnet Cu	3.80472E-04	4.01679E-04	5.57	3.79698E-04	-0.20
OB					
FW Be	5.98127E+03	5.98538E+03	0.07	6.01139E+03	0.50
FW CuBeNi	3.23240E+02	3.24749E+02	0.47	3.26056E+02	0.87
FW SS316	2.45343E+02	2.56222E+02	4.43	2.62737E+02	7.09
VV Inconel	9.04495E-02	1.06787E-01	18.06	1.02669E-01	13.51
VV SS316	1.07582E-01	1.16363E-01	8.16	1.12537E-01	4.61
Magnet Cu	5.56782E-05	5.93275E-05	6.55	5.53346E-05	-0.62

Max. relative error <0.19%

- different neutron flux and spectrum at FWSS, VV, magnet

Results: Tritium production

	21c+84p	31c+84p	% diff.	80c+84p	% diff.
IB					
FW Be	6.10392E+01	6.10362E+01	0.00	6.11245E+01	0.14
FW CuBeNi	1.56402E+00	1.56365E+00	-0.02	1.56666E+00	0.17
FW SS316	1.19527E-01	1.19116E-01	-0.34	2.22290E-01	85.97
VV Inconel	2.92231E-06	6.92198E-06	136.87	6.86316E-06	134.85
VV SS316	2.47763E-05	2.53464E-05	2.30	4.19001E-05	69.11
Magnet (Cu)	1.34326E-06	1.42722E-06	6.25	1.30178E-06	-3.09
OB					
FW Be	8.96548E+01	8.96782E+01	0.03	8.97799E+01	0.14
FW CuBeNi	2.44711E+00	2.44778E+00	0.03	2.45166E+00	0.19
FW SS316	1.86724E-01	1.86228E-01	-0.27	3.49079E-01	86.95
VV Inconel	3.78742E-06	9.02266E-06	138.23	8.95916E-06	136.55
VV SS316	3.57871E-05	3.66218E-05	2.33	6.04256E-05	68.85
Magnet (Cu)	1.82708E-07	1.95836E-07	7.19	1.76016E-07	-3.66

Max. relative error <0.27%

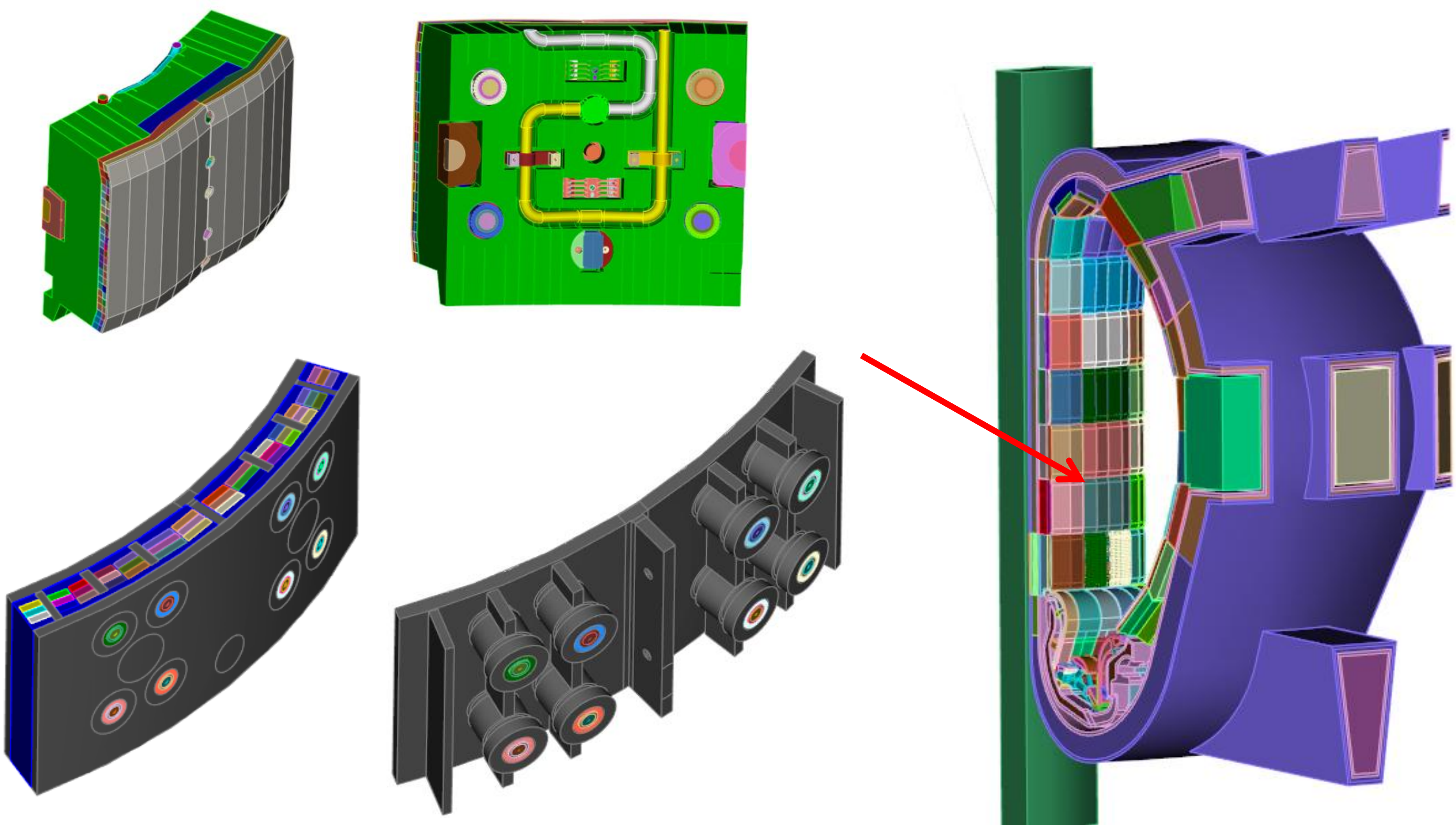
- different neutron flux and spectrum at FWSS, VV, magnet
- T production substantially different in SS 316 for 31c versus 80c
- FENDL-3.1b (31c) and ENDF/B-VII.1 (80c) still missing rxn mt=205 for tungsten isotopes

Conclusions

- For realistic ITER calculations, use of updated photon and neutron libraries produces neutron fluxes from 3% lower to 8% higher than the reference libraries
- For realistic ITER calculations, use of updated photon and neutron libraries produces photon fluxes from 6% lower to 9% higher than the reference libraries
- For realistic ITER calculations, use of updated photon and neutron libraries produces total nuclear heating from 3% lower to 6% higher than the reference libraries

Future Work

• Repeat with FENDL-3.2 and ENDF/B-VIII when released
• Repeat comparisons with a detailed 3-D model of ITER using DAG-MCNP (CAD based version of MCNP developed at UW)



Questions/Acknowledgements

Questions?

ACKNOWLEDGMENTS

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The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.