Current FENDL Activities at the University of Wisconsin-Madison

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FENDL Consultants Meeting
30 October-2 November, 2023
Vienna, Austria (hybrid)

Outline

1) Impact of INDEN Fe-56 XS in ITER 1-D
2) Impact of INDEN Fe-56 XS in FNSF 1-D
3) Impact of INDEN F-19 XS in flibe blanket 1-D
4) WW generation to speed 1-D calculational benchmarks
5) Future Work

Goal of this work

- Look at the neutronics impact of using the updated neutron libraries in a **realistic model of fusion systems** using MCNP
- Libraries examined:

standard MCNP id

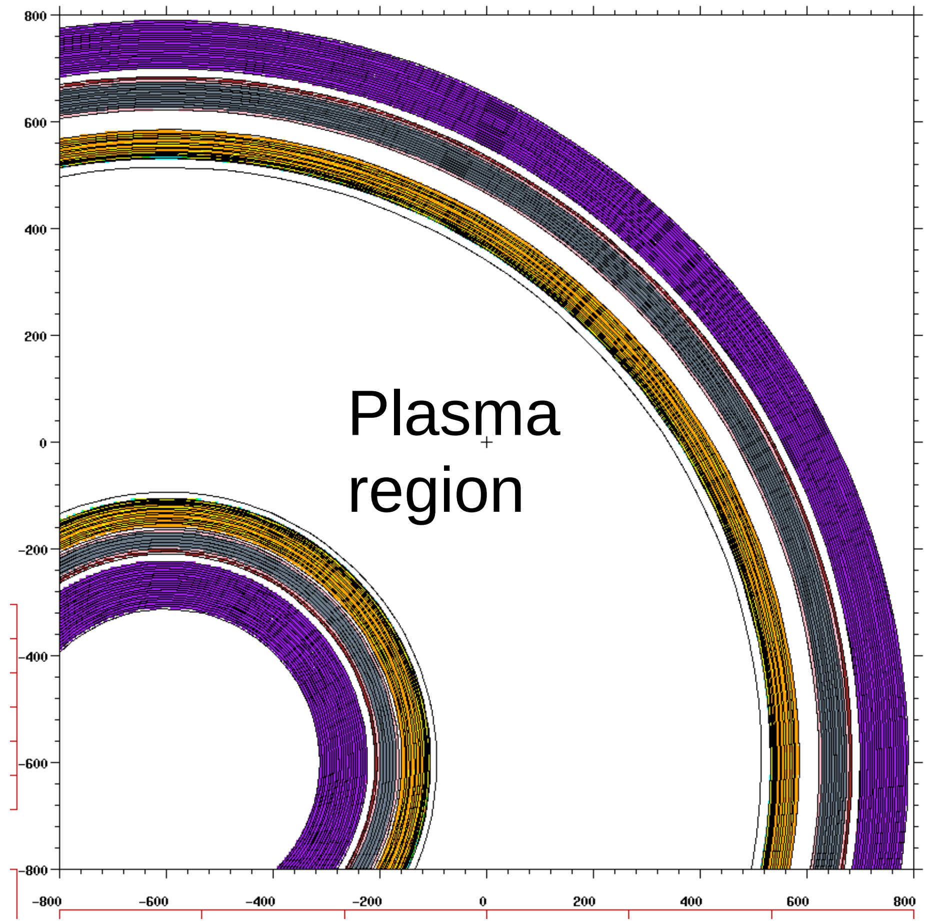
- *Neutron:*
  1. FENDL-2.1 (21c)
  2. FENDL-3.1d (31c)
  3. FENDL-3.2b (32c)
  4. ENDF/B-VIII.0 (00c)
  5. New INDEN evaluations for Fe-56, F-19 ← New work
- *Photon:*
  1. mcplib84 (84p)**

- *Previous work has shown that mcplib84 produces results similar to the newer MCNP eprdata12 library, the latest MCNP photon library (eprdata14) has not been tested yet*

** Bohm T.D, Sawan M.E. "Neutronics calculations to support the Fusion Evaluated Nuclear Data Library (FENDL)", Fusion Science and Technology, on-line early access August 2021.*
***Bohm T.D, Sawan M.E. "The impact of updated cross section libraries on ITER neutronics calculations", Fusion Science and Technology, Vol 68, p. 331-335, 2015.*

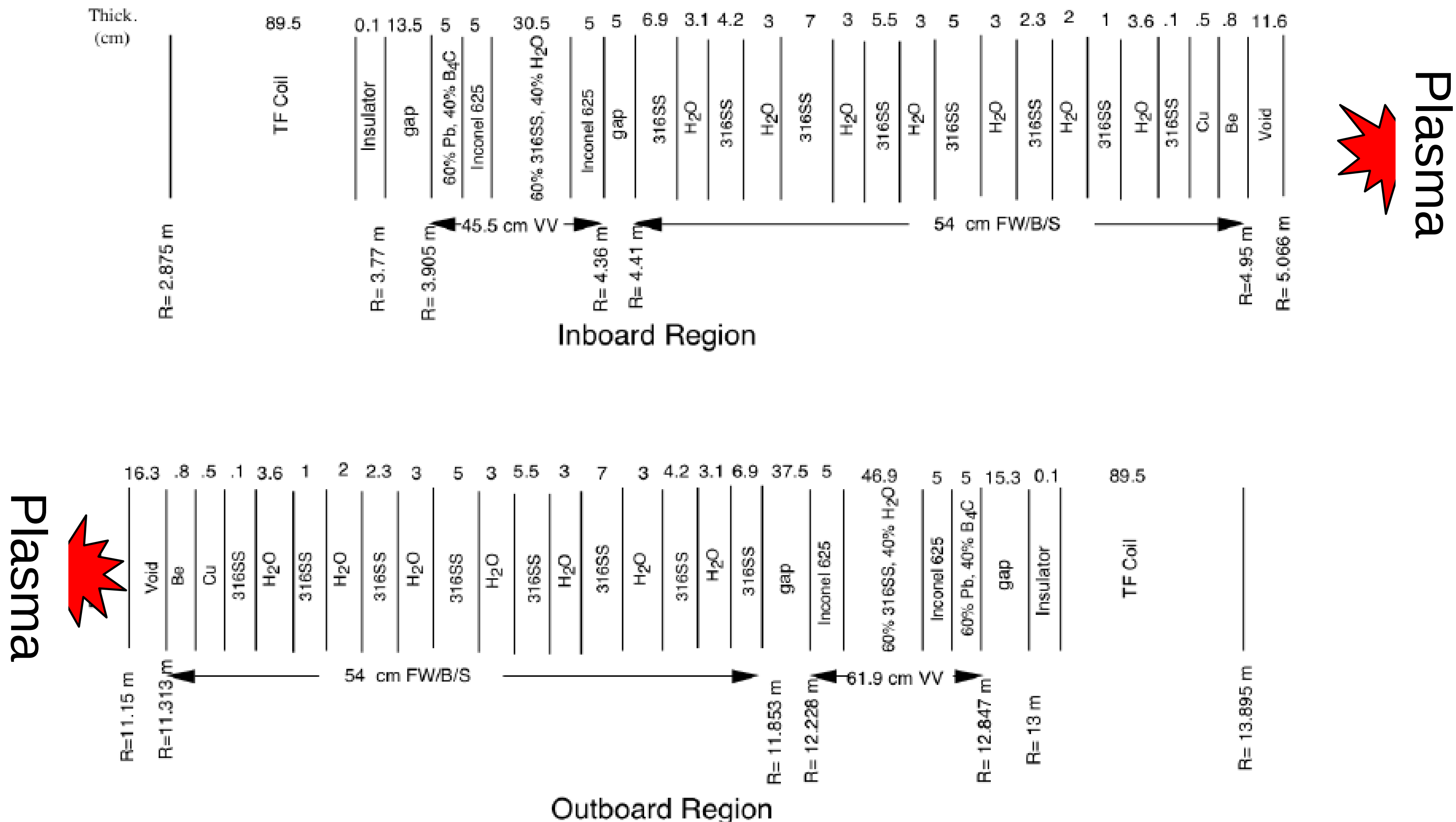
ITER 1-D Cylindrical Calculation Benchmark

- 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

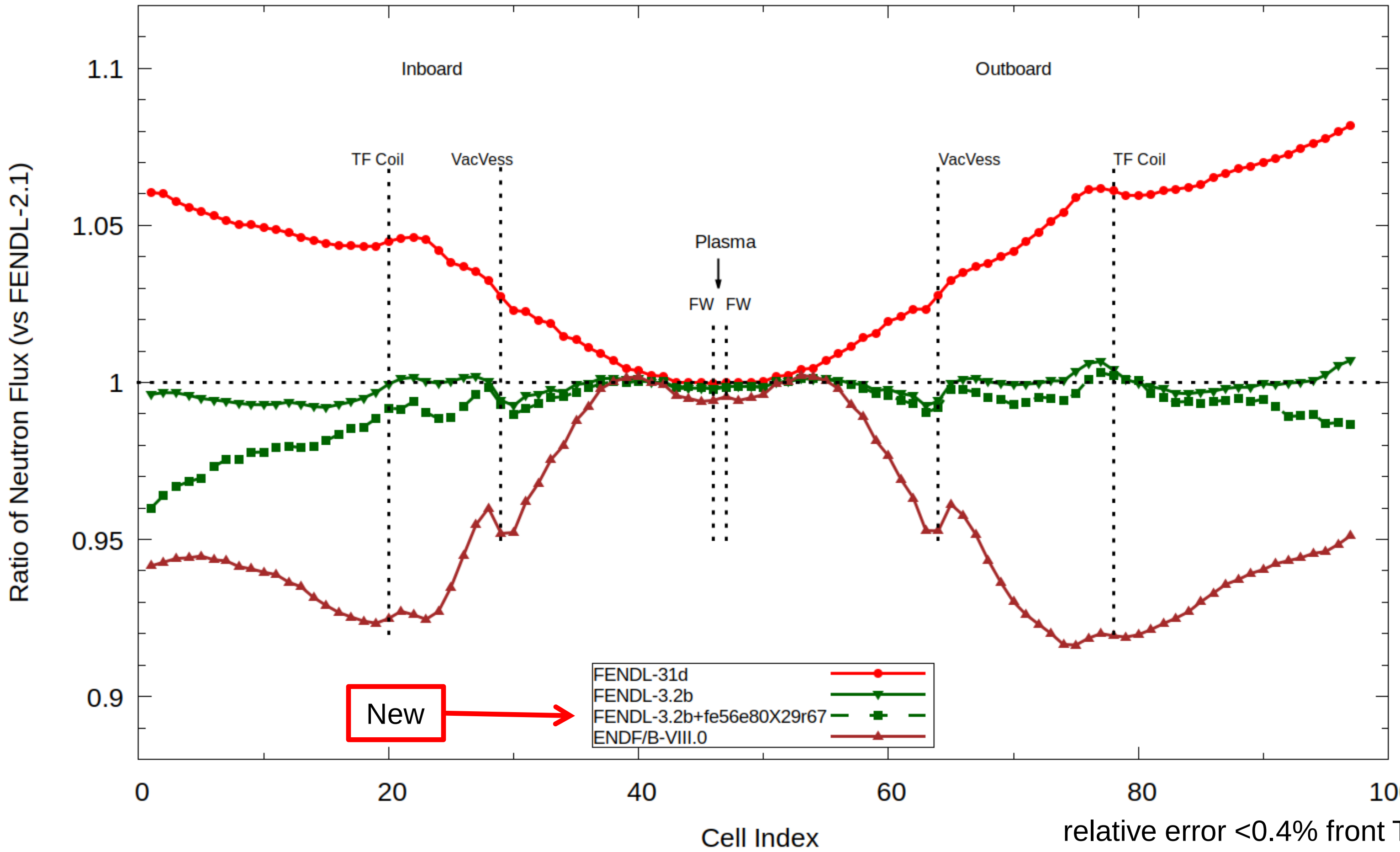


M. Sawan, FENDL Neutronics Benchmark: Specifications for the calculational and shielding benchmark, INDC(NDS)-316, December 1994

ITER 1-D Cylindrical Benchmark continued



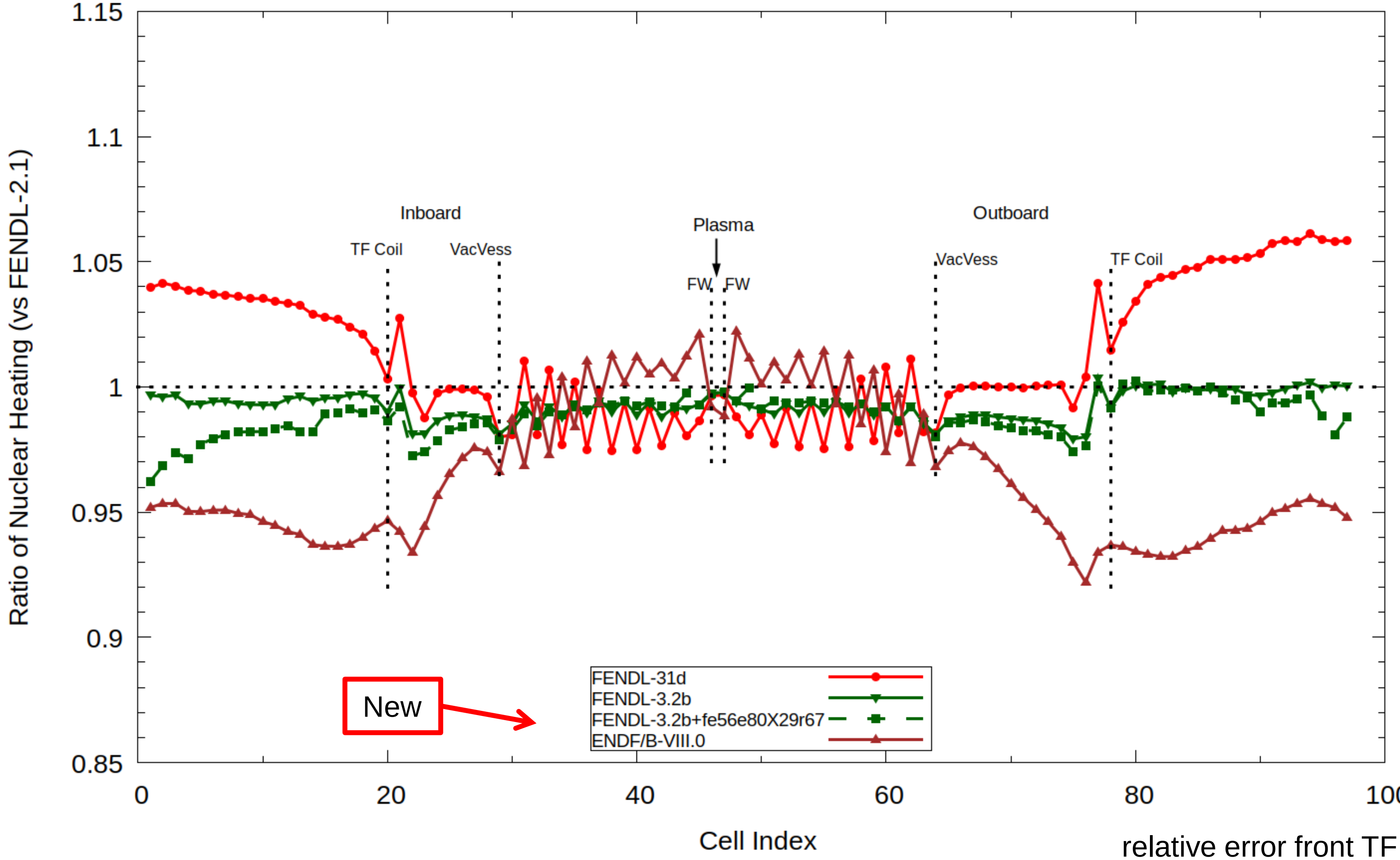
Preliminary Results: Neutron Flux ITER



relative error <0.4% front TF coil

- FENDL-3.2b and FENDL-3.2b+fe56e80X29r67 quite close

Preliminary Results: Total Nuclear Heating ITER

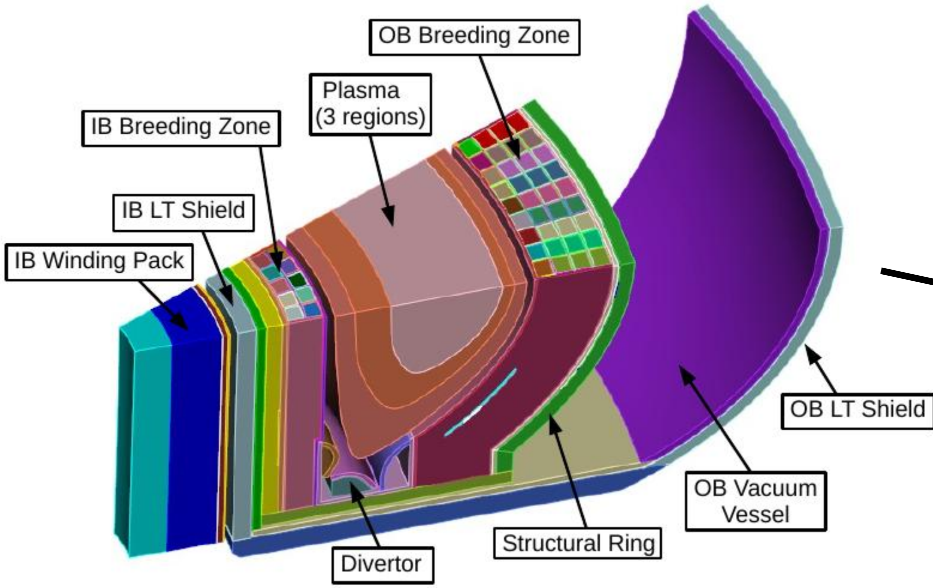


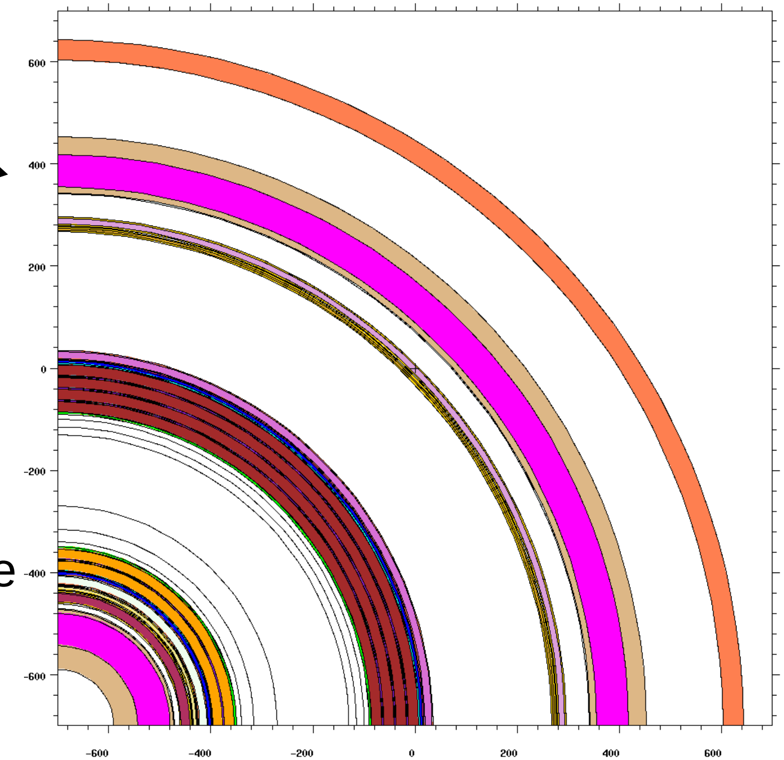
relative error front TF coil <0.4%

- FENDL-3.2b and FENDL-3.2b+f56e80X29r67 quite close

FNSF 1-D Cylindrical Computational Benchmark

- Fusion Energy Systems Studies Fusion Nuclear Science Facility (FESS-FNSF)
- Breeding Zone: He cooled steel structure (90 w/o Fe, 7.5 w/o Cr, 2 w/o W, 0.2 w/o V), PbLi breeder (Dual Coolant Lithium Lead-DCLL)

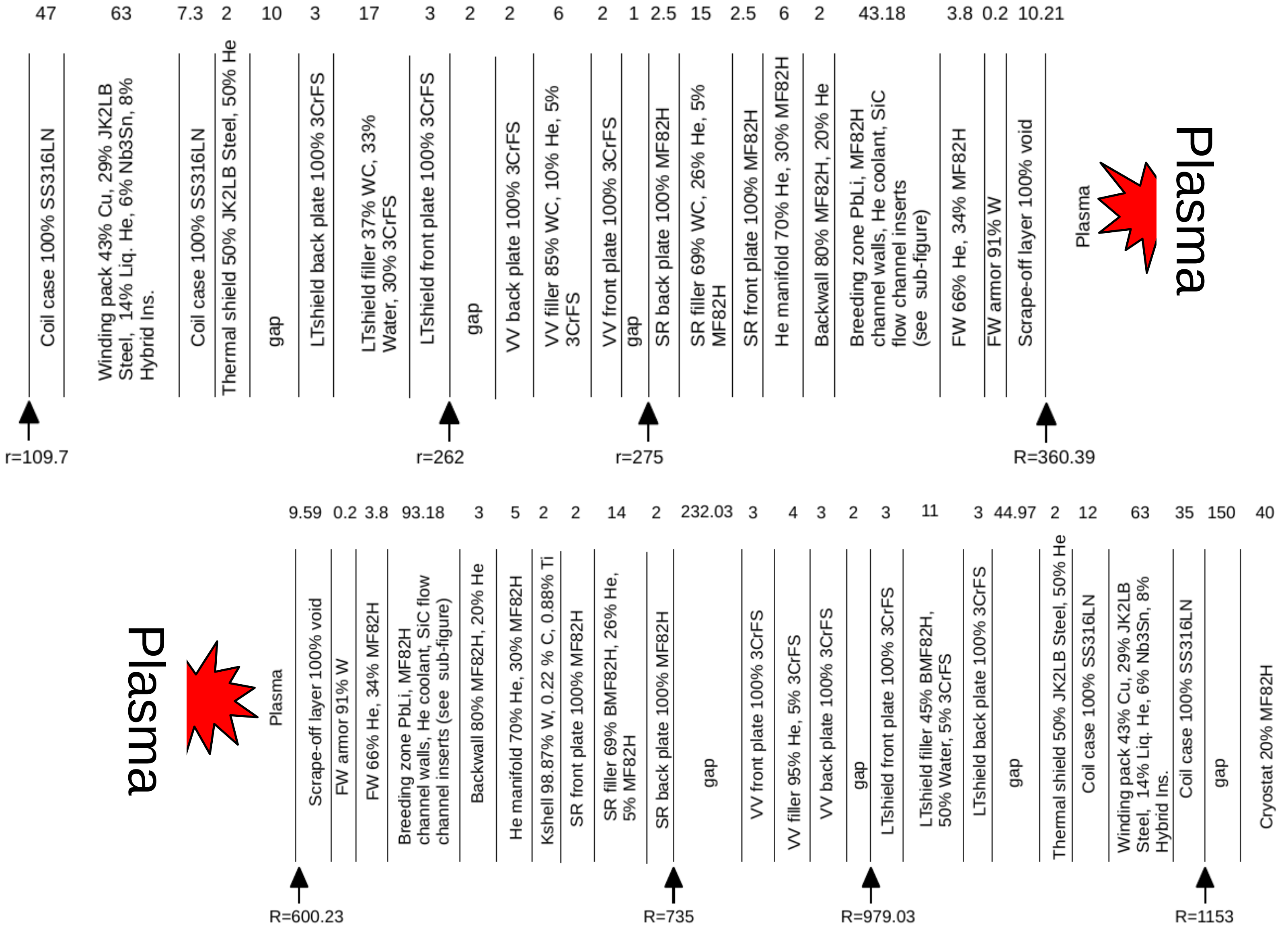




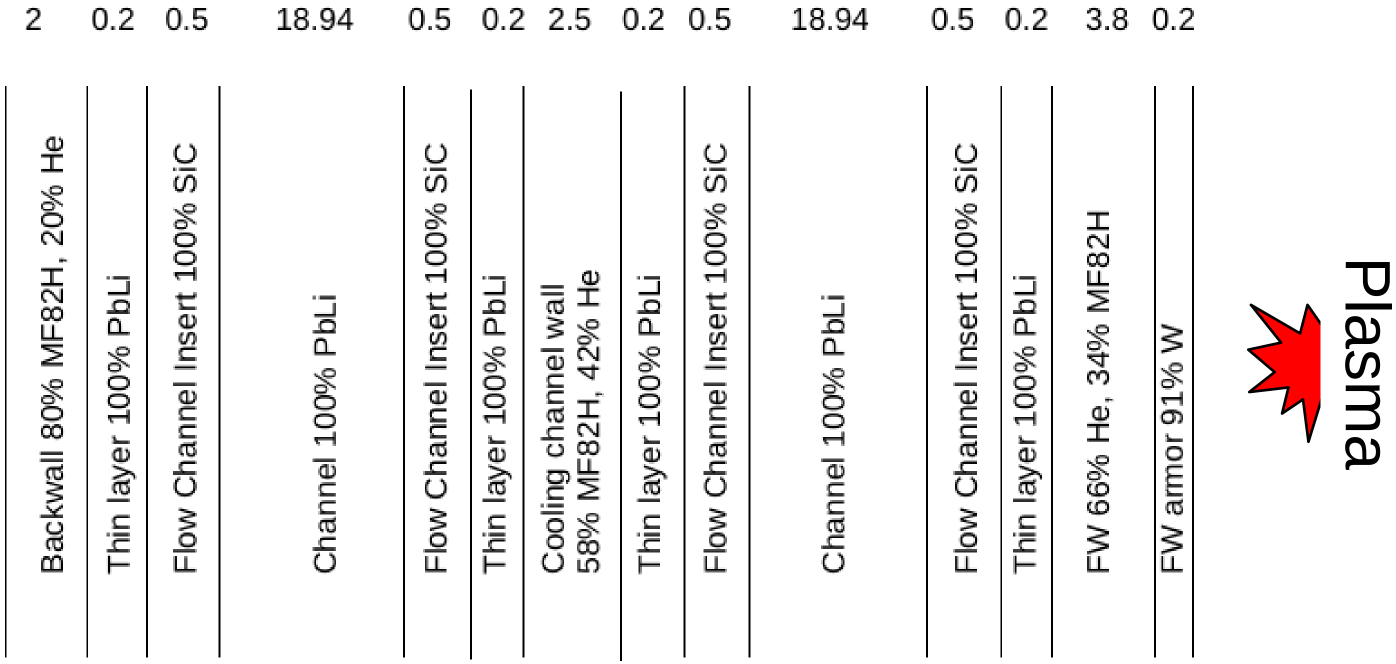
- 85 radial zones
- Includes SiC flow channel inserts in breeding zone
- Includes face plates and filler for SR, VV, LTshield
- Includes IB, OB magnet and cryostat
- MCNP materials created with PyNE

T. Bohm et al. "Initial Neutronics Investigation of a Liquid Metal Plasma Facing Fusion Nuclear Science Facility, *Fusion Science and Technology*, 2019.

FNSF 1-D Cylindrical Computational Benchmark

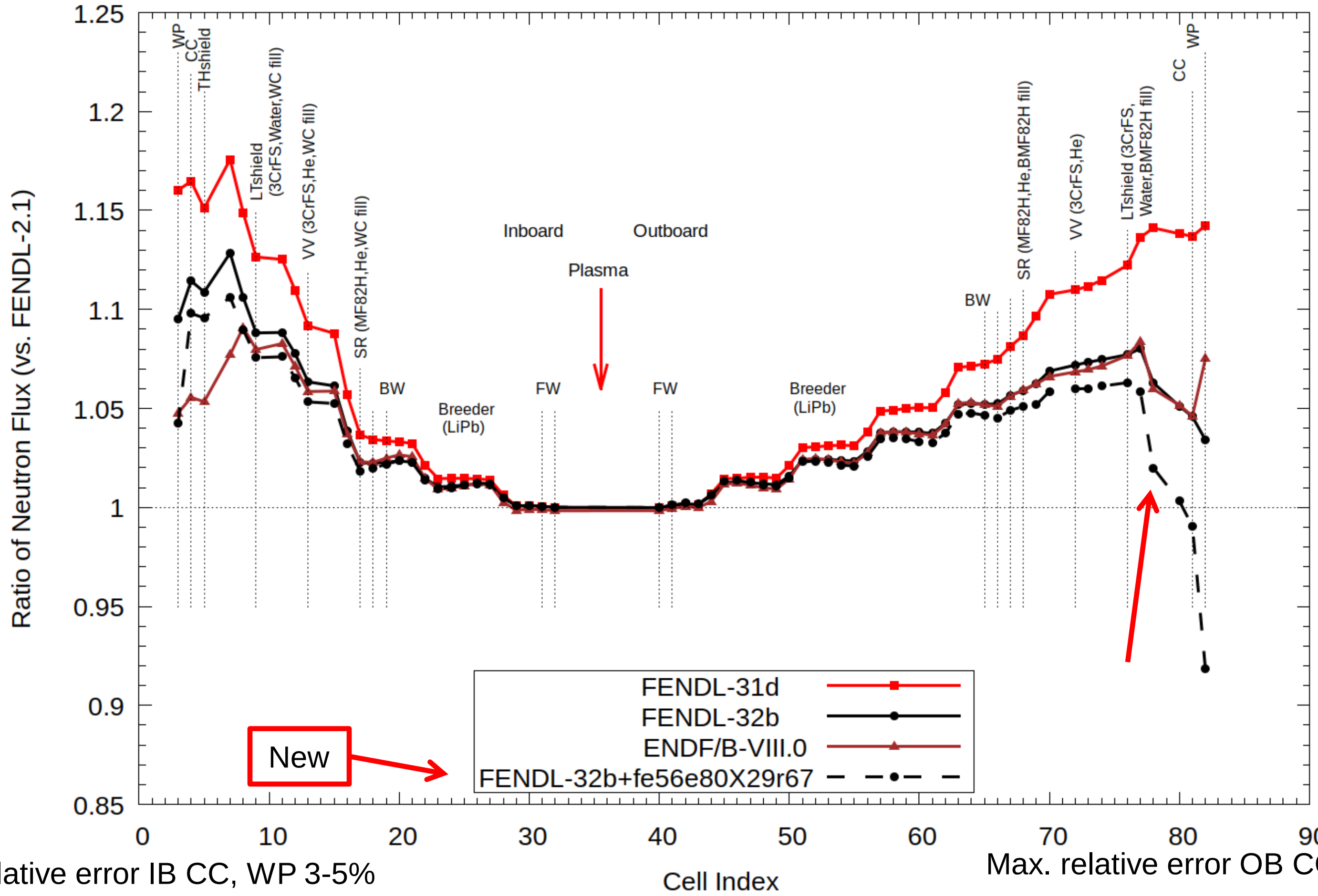


FNSF 1-D Benchmark- Details of IB Breeder Zone



- OB Breeder zone similar but has 4 PbLi channels

Preliminary Results: Neutron Flux FNSF

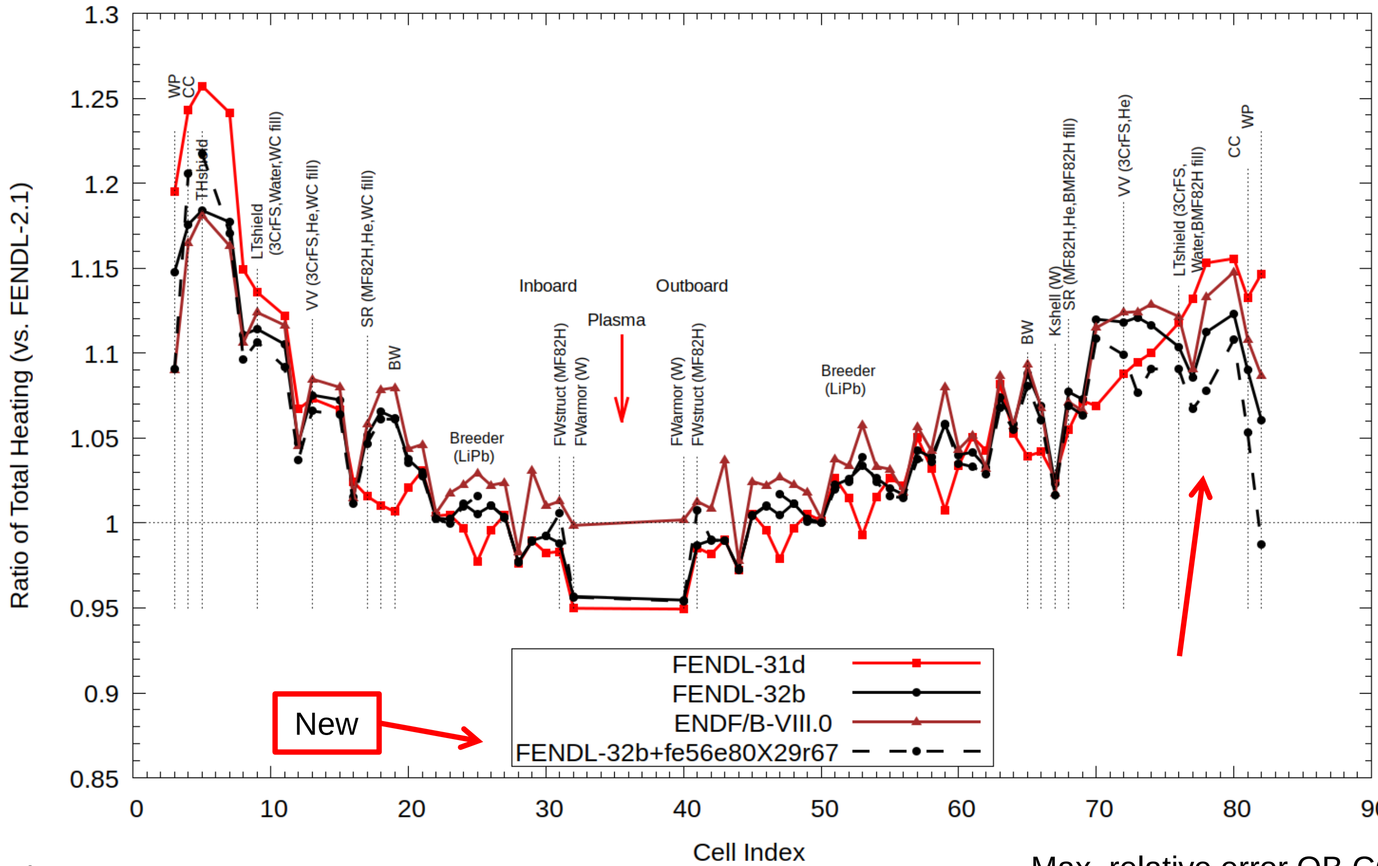


Max. relative error IB CC, WP 3-5%

Max. relative error OB CC, WP 1-2%

- FENDL-3.2b vs. FENDL-3.2b+fe56e80X29r67 generally good agreement *except deviation at OB LTshield*
    - OB LTshield uses water cooled borated steel filler

Preliminary Results: Total Nuclear Heating FNSF



Max. relative error IB CC, WP 3-5%

Max. relative error OB CC, WP 1-2%

- FENDL-3.2b vs. FENDL-3.2b+fe56e80X29r67 generally good agreement in heating
- Not seeing deviation at OB LTshield as observed with neutron flux
  - need to refine statistics at deep locations

➢ Generally good agreement observed for TBR, dpa, and helium production

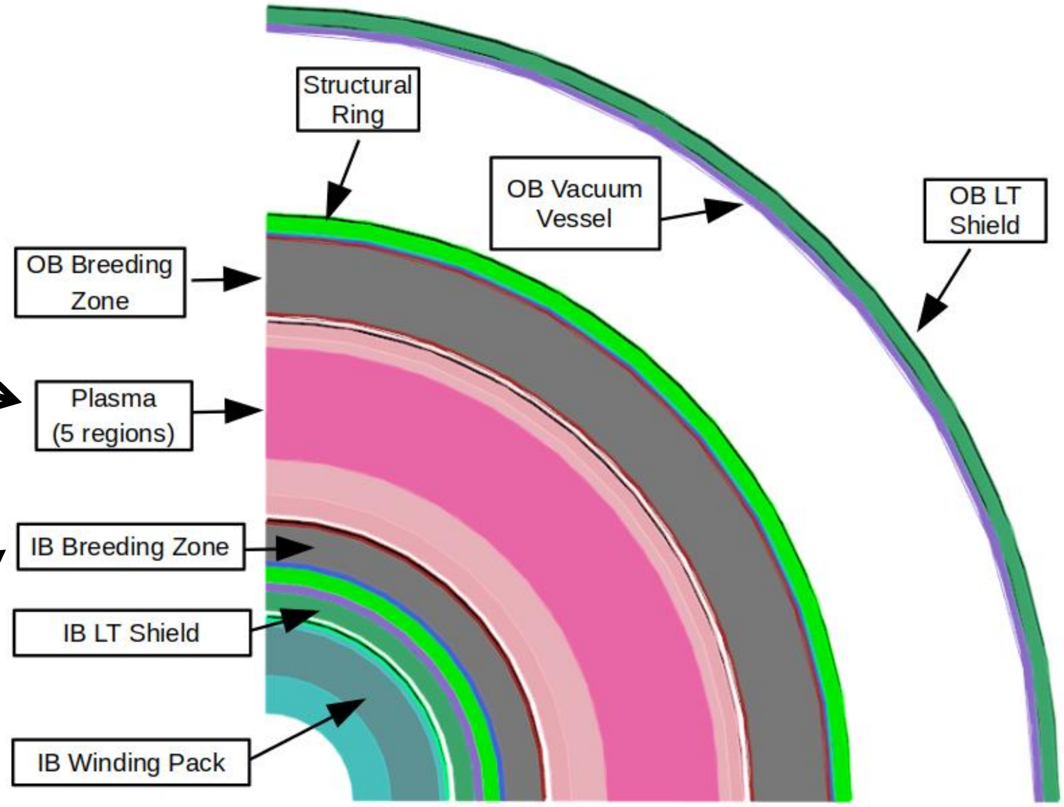
1-D Cylindrical Computational Benchmark (flibe blanket)

- Molten salt 2(LiF)-1(BeF_2) sometimes proposed as a liquid blanket
  - Commonwealth Fusion Systems reactor design
- INDEN provides a new XS for ^{19}F: *https://www-nds.iaea.org/INDEN/*
- Created 1-D model based on FESS-FNSF but modified the blanket:
  - Breeding Zone: 2 cm Be multiplier layer, flibe breeder tank

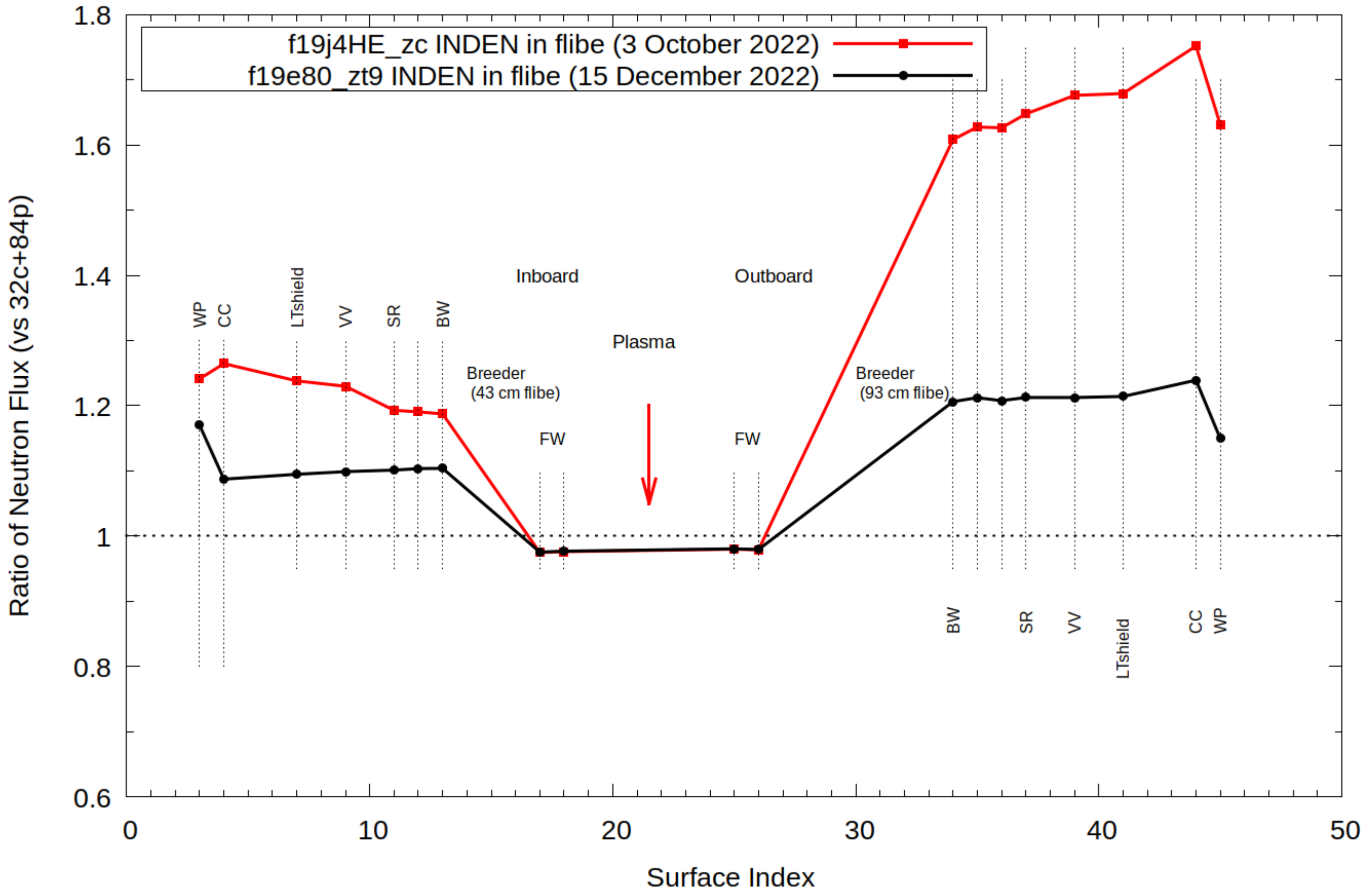
OB flibe thickness 91 cm

D-T plasma (14.1 MeV n)

IB flibe thickness 41 cm



Results: Neutron Flux (impact of INDEN ^{19}F XS)



Max. relative error <0.6% except CC <2.5% and WP 3.6%

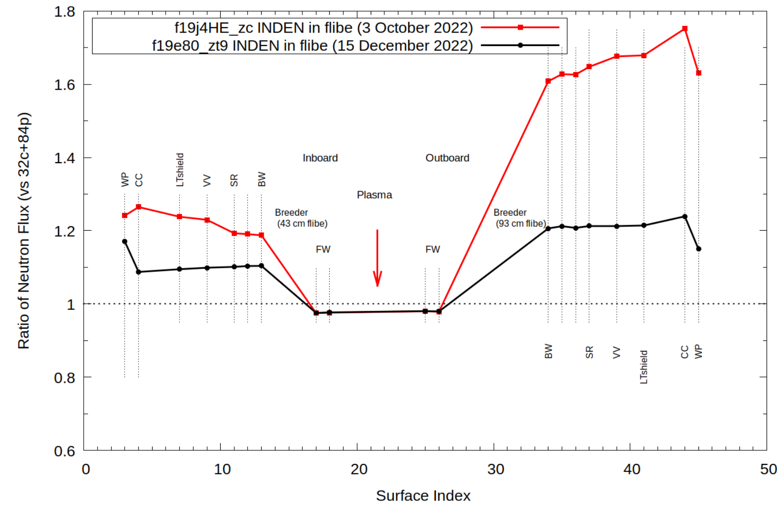
- **Neutron flux:** higher neutron fluxes behind the flibe breeder regions
  - ➢ 10-20% higher flux behind the IB flibe breeder zone
  - ➢ 20-70% higher flux behind the OB flibe breeder zone

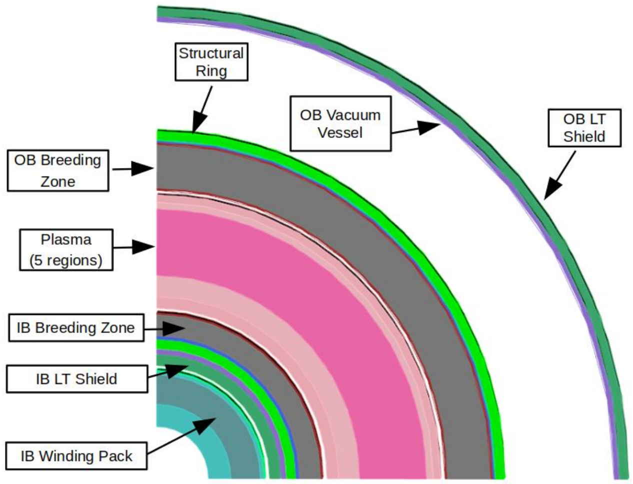
Possible Impact on Reactor Design: (due to change in ^{19}F XS in flibe blanket)

- For this 1-D model, the e-fold attenuation distance for neutron flux in the SR shield (MF82H face plates + He cooled WC filler) was 14 cm

➢ **Added shielding required to compensate for f19j4HE_zc:**

  - **IB: 3 cm**
  - **OB: 17 cm**





Note: a candidate Commonwealth Fusion Systems flibe immersion blanket design has ~25 cm thick IB blanket and 110 cm thick OB blanket

Results: TBR (impact of INDEN F-19 XS)

Region	FENDL-3.2b	FENDL-3.2b +INDEN f19j4HE_zc	Ratio	FENDL-3.2b +INDEN f19e80_zt9	Ratio
IB	0.39594	0.39861	1.007	0.39769	1.004
OB	0.90622	0.92137	1.017	0.91543	1.010
Total	1.3022	1.3200	1.014	1.31312	1.008

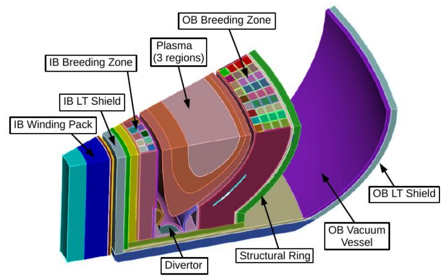
- **Total TBR:**
  - increases by 1.4% for f19j4HE_zc in flibe blanket
  - increases by 0.8% for f19e80_zt9 in flibe blanket

➢ while small, this is good for reactor design since flibe designs tend to need more margin to be tritium self-sufficient

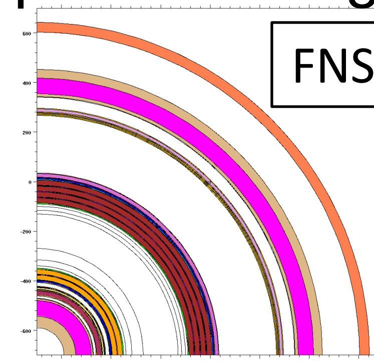
Other work on 1-D Benchmark Models: Variance Reduction

The cylindrical 1-D models are more computationally efficient than the detailed 3-D CAD models but can be improved using variance reduction:

FNSF 3-D CAD



FNSF 1-D



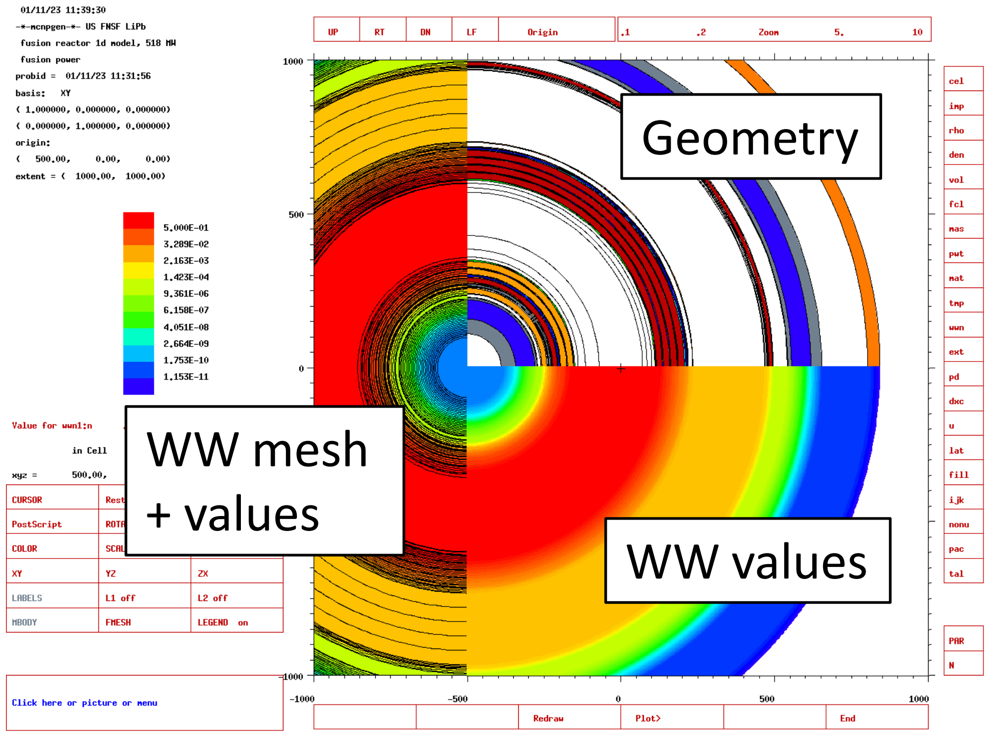
Weight windows are a good option:

- but potentially need many sets of WWs since many different neutronics responses of interest (thresholds at different energies, neutrons & photons)

- WW Generation options (for global VR):
  1. ADVANTG (FW-CADIS)
     - rigorous method uses discrete ordinates transport (forward and adjoint)
     - requires additional code package
  2. MAGIC
     - uses MC responses (flux) from previous run to “guess” WWs (essentially splitting to keep the particle population up through highly attenuating regions)
     - generally a few iterations needed
     - no additional code package needed

WW Generation: start simple

- ➢ MAGIC
  - FNSF 1-D model
  - fmesh neutron flux tally from r=0 to the cryostat
  - single energy group
  - 5 cm mesh in thick components
  - run a few iterations to generate neutron WWs through deep depths

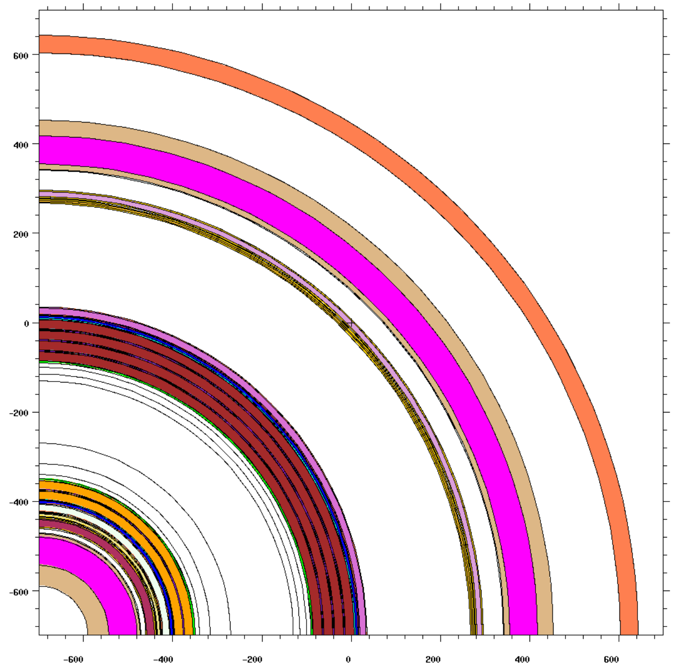


Results:

- Neutrons tracks now easily making it to deep regions in model
- Many more tallies pass the 10 statistical checks (for the same nps value)
- The FOM is much higher for neutron responses in deep locations:
  - Cu dpa at IB winding pack: FOM ratio=207
  - Total neutron flux at IB coil case 2: FOM ratio=8800
- The FOM is typically a bit **lower** at shallow locations

WW Generation: Next Steps

- MAGIC
  - Repeat with a few neutron energy groups:
    (e.g. Eupper=0.25, 1.25, 5, 20 MeV)
  - Consider adding photon WWs
  - Consider adding other tallies as “drivers”
- ADVANTG
  - use FW-CADIS



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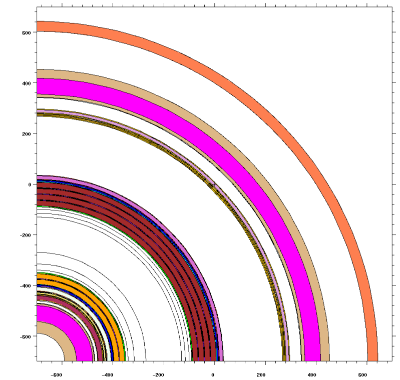
Future Work

- ➢ Refine WW Generation method for 1-D benchmarks
- ➢ Develop more 1-D benchmarks (e.g.):
  - Updated ITER design
  - EU-DEMO HCPB, WCLL
  - UK-STEP
  - General Atomics GAMBL (SiC, PbLi waterfall blanket)
  - CFS flibe immersion blanket
  - Inertial Confinement designs



- ➢ Perform Sensitivity/Uncertainty analysis of important neutronics responses for variety of 1-D models
- ➢ Look at activation responses with various activation libraries

Questions?

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