Karlsruhe Institute of Technology

Neutronics Benchmark of EuropeanDEMO and VNS using MCNP and OpenMC for the Eurofusion Programme

INR – NK

Overview

- Objectives
- Tools
- European DEMO and VNS
- Workflow
- Benchmark studies (Plasma source, lattice, TBR, Neutron flux, Heating etc,)
- Summary

Objectives

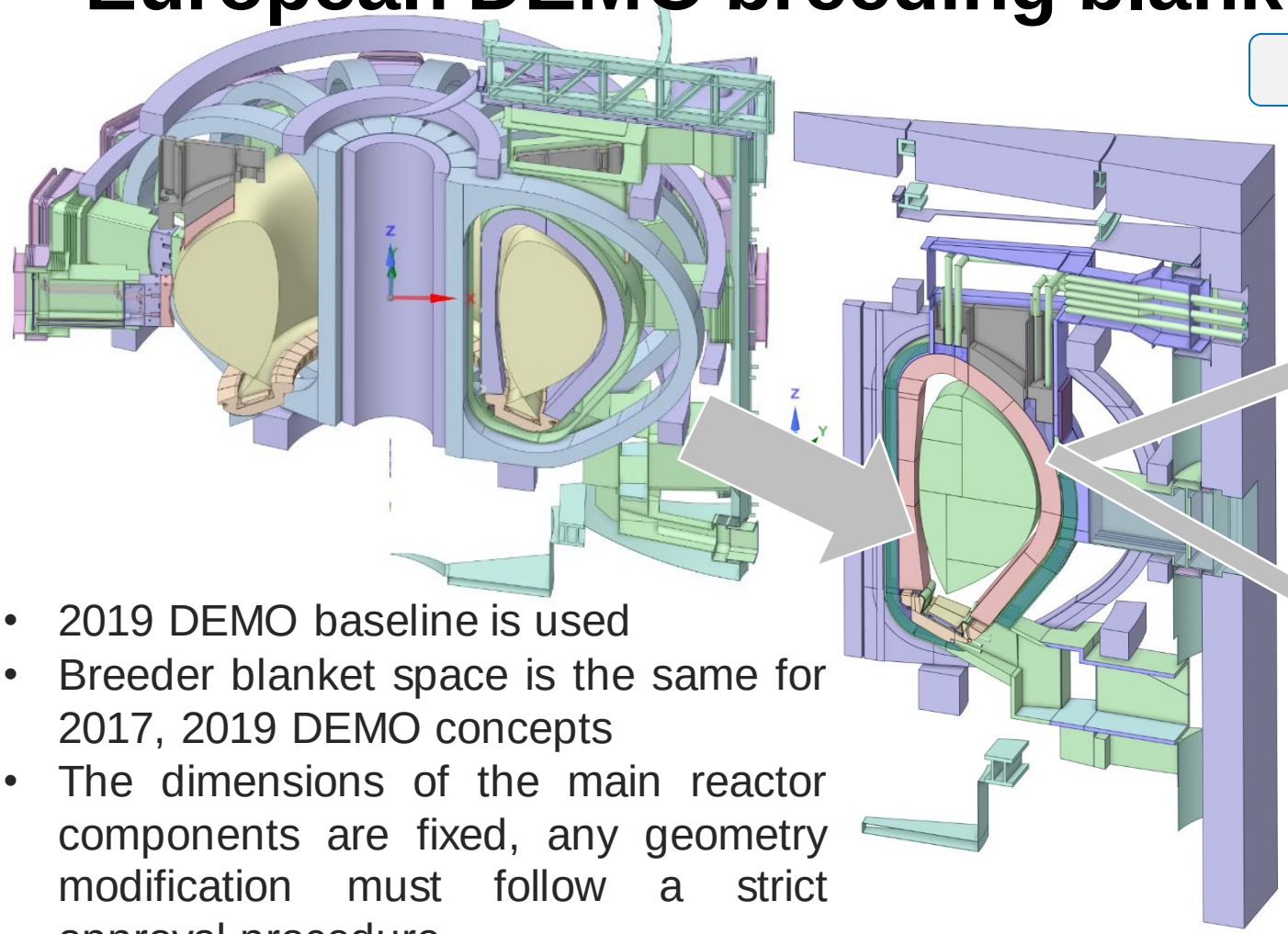
- Benchmark MCNP and OpenMC performance for the European DEMO and VNS.
- Compare and analyze simulation performance and results using identical models and tallies.
- Identify issues discovered during benchmarking

- Highlight desired OpenMC capabilities
  - direct CAD file import
  - GPU-accelerated Monte Carlo calculations.

Tools

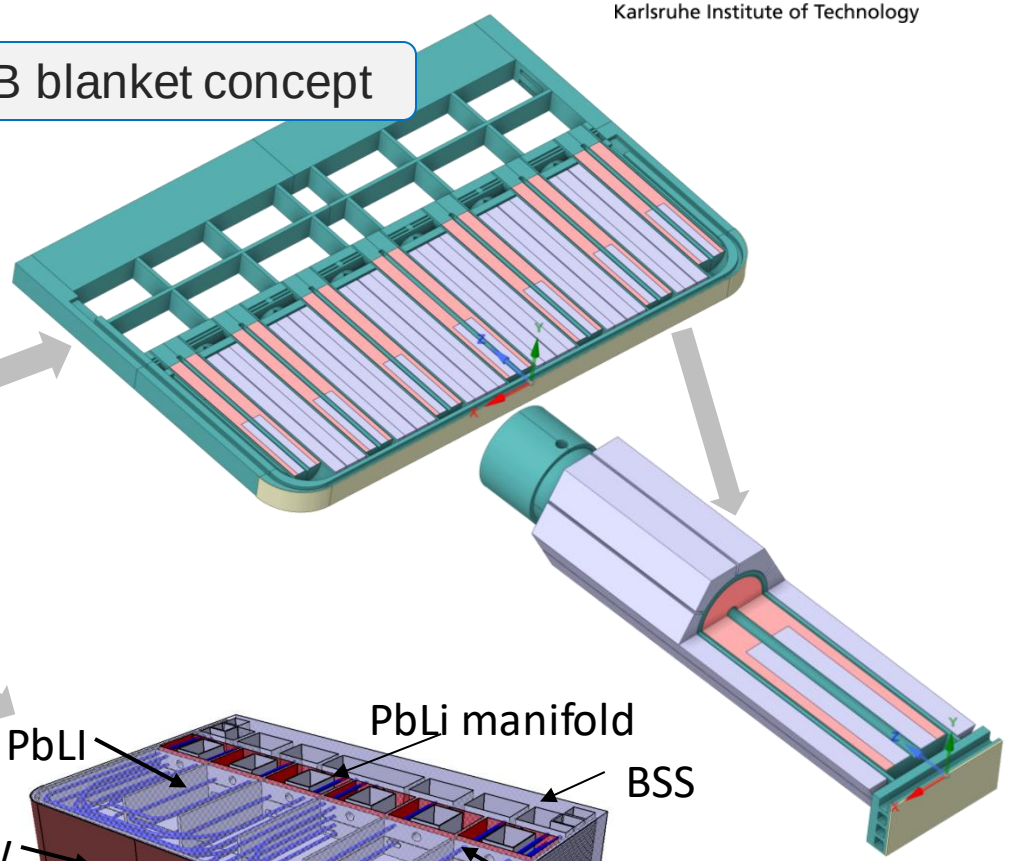
- Monte-Carlo simulation
  - MCNP(6.3) and OpenMC (0.15.1-dev1, 0.15.3-dev5 and dev9)
- Modelling and preparing inputs
  - ANSYS SpaceClaim, MCNP-to-OpenMC converter, SDEF converter, etc,.
- Weight window generation
  - ADVANTG
- Data processing and analysis
  - Coreform cubit, Radiant, Origin, Paraview, etc,.

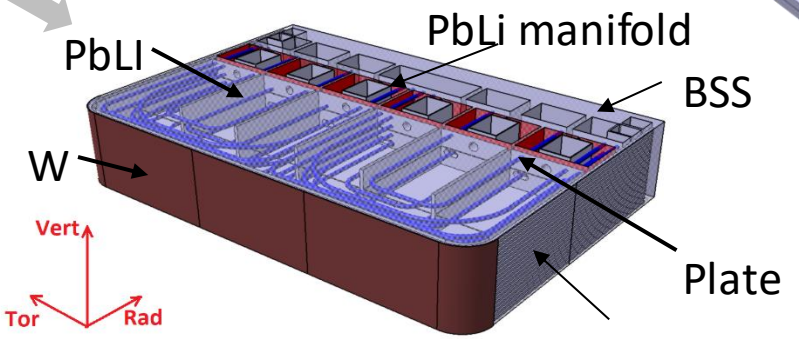
European DEMO breeding blanket



- 2019 DEMO baseline is used
- Breeder blanket space is the same for 2017, 2019 DEMO concepts
- The dimensions of the main reactor components are fixed, any geometry modification must follow a strict approval procedure

HCPB blanket concept

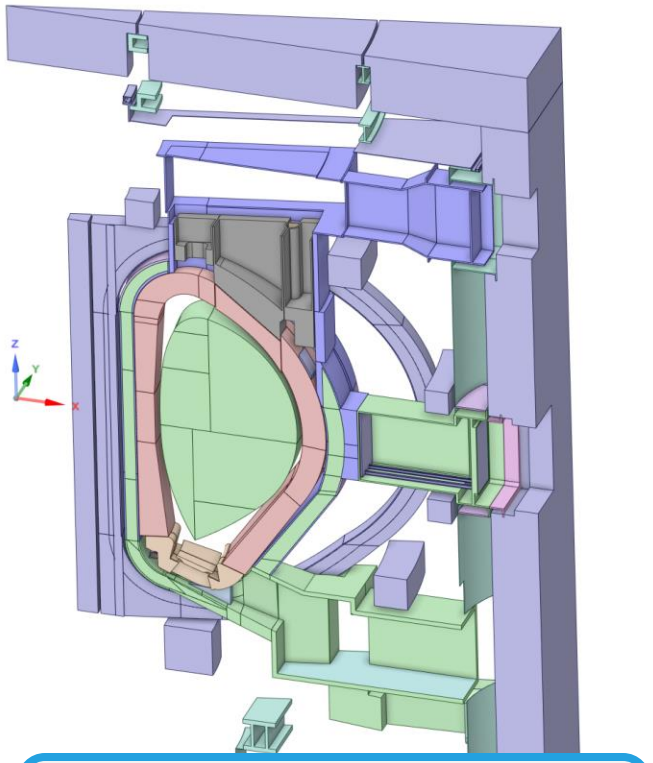




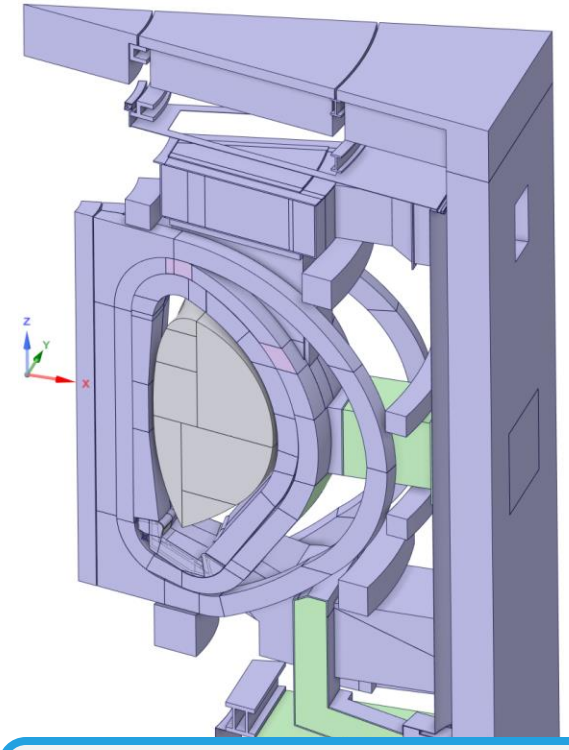
WCLL blanket concept

European DEMO facility

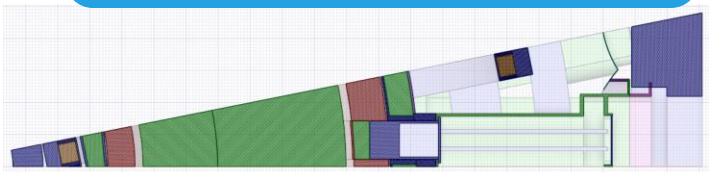
- 11.25° and 22.5° sector DEMO model
- The envelope structure with fill card with heterogeneous geometry
- HCPB breeding blanket was tested
- Fusion power – 2000 MW
- At least 300MW supply to the grid

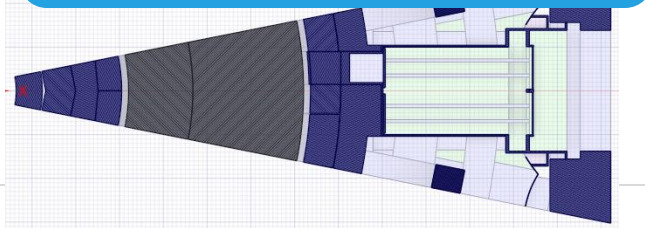


11.25° DEMO 2019
CAD generic model



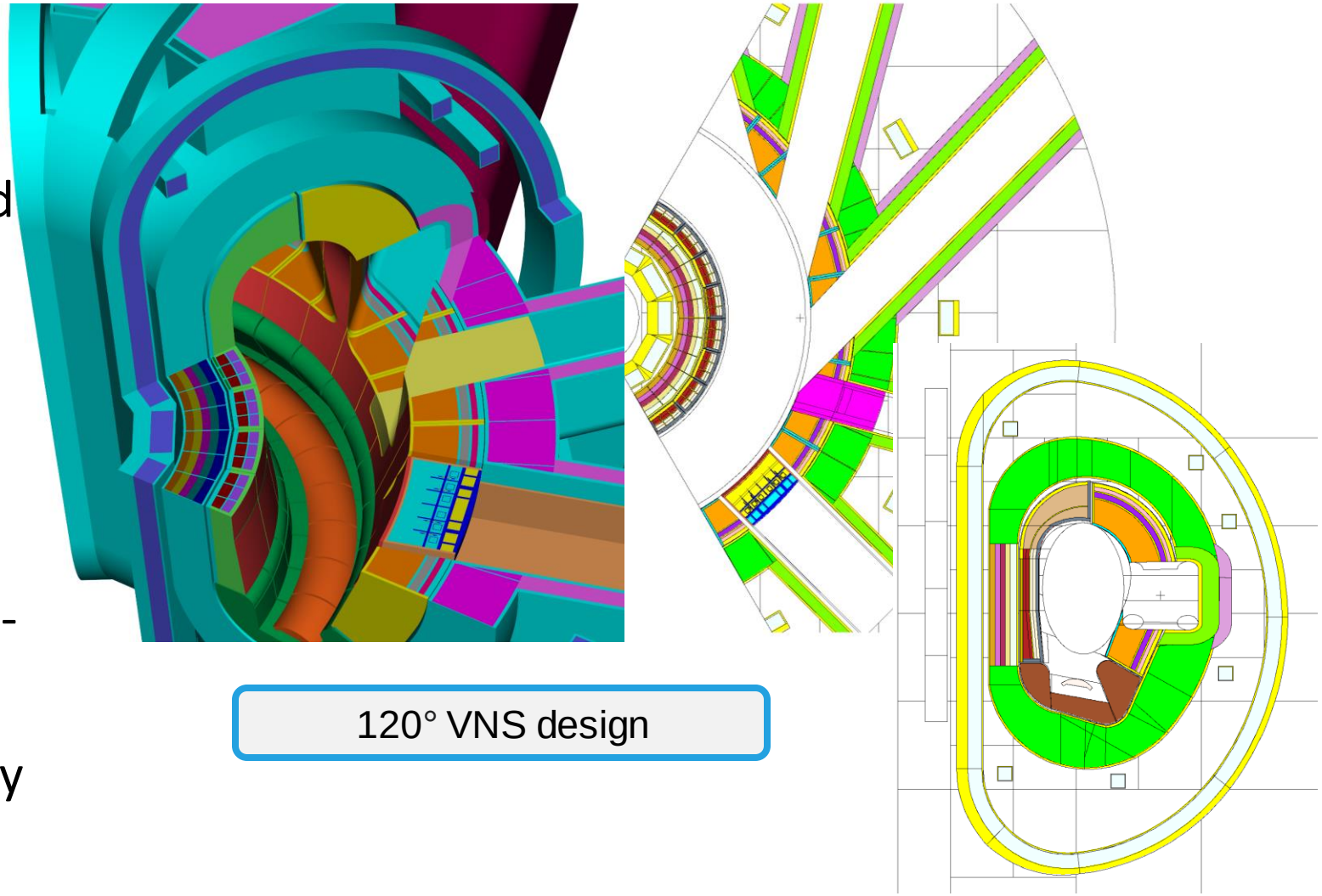
22.5° DEMO 2019
CAD generic model





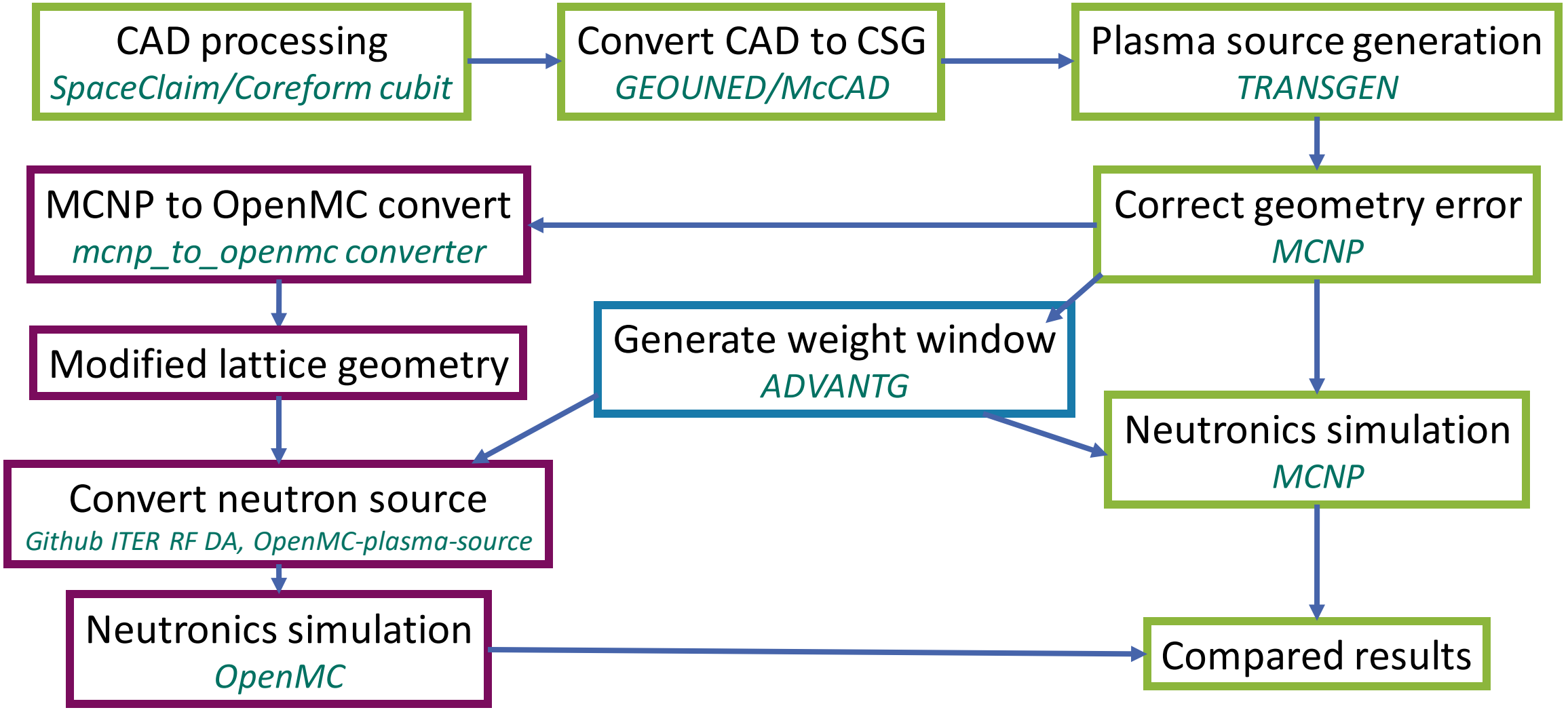
VNS

- 120° model of the VNS
- The envelope structure with fill card with heterogeneous geometry
- Shield blanket on IB and homogeneous WCLL BB on OB
- Fusion power – 29 MW
- Aiming at nuclear qualification of in-vessel systems
- No requirement on T-self sufficiency

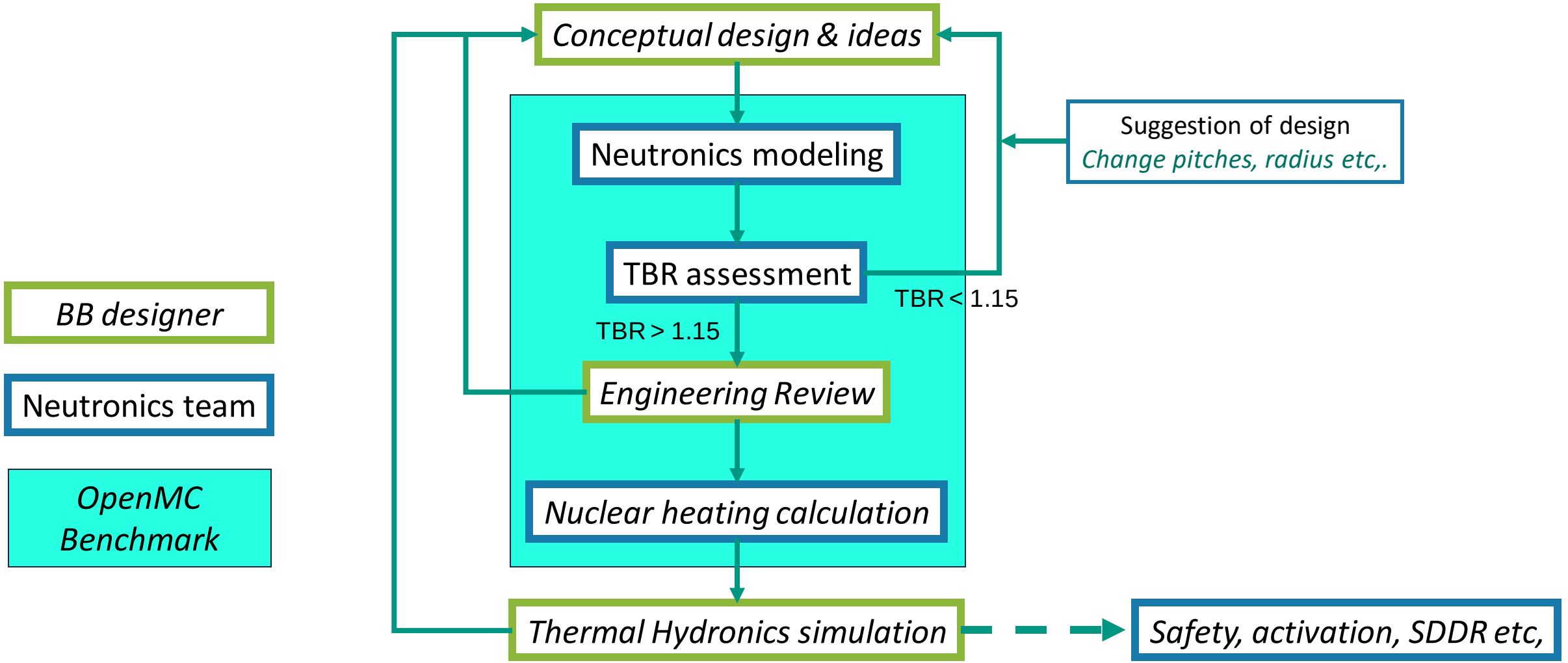


120° VNS design

Workflow


CAD processing
SpaceClaim/Coreform cubit
Convert CAD to CSG
GEOUNED/McCAD
Plasma source generation
TRANSGEN
MCNP to OpenMC convert
mcnp_to_openmc converter
Correct geometry error
MCNP
Modified lattice geometry
Generate weight window
ADVANTG
Neutronics simulation
MCNP
Convert neutron source
Github ITER RF DA, OpenMC-plasma-source
Neutronics simulation
OpenMC
Compared results

Blanket development



Plasma source

- MCNP SDEF card generated by TRANSGEN – Cylindrical definition

```
C **** CYLINDRICAL GEOMETRY ****
C
SDEF ERG=D1 WGT=0.062500 EFF=1e-4 CEL= 1 &
POS=0 0 -598.0360 AXS=0 0 1 RAD D2 EXT FRAD D3
C
C **** NEUTRON ENERGY DISTRIBUTION ****
C
SP1 -4 0.51677   14.1000
C
C **** NEUTRON EMISSION PROBABILITY - RADIAL ****
C
SI2 H
     553.0000  565.2800  577.5600  589.8400  602.1200  614.4000  626.6800
     638.9600  651.2400  663.5200  675.8000  688.0800  700.3600  712.6400
                                      •
                                      •
                                      •
C
SP2 D 0
    1.869E-13  6.414E-11  2.054E-09  2.263E-08  1.374E-07  5.751E-07
    4.056E-06  6.196E-04  2.754E-03  5.731E-03  9.047E-03  1.244E-02
                                      •
                                      •
                                      •
C
```

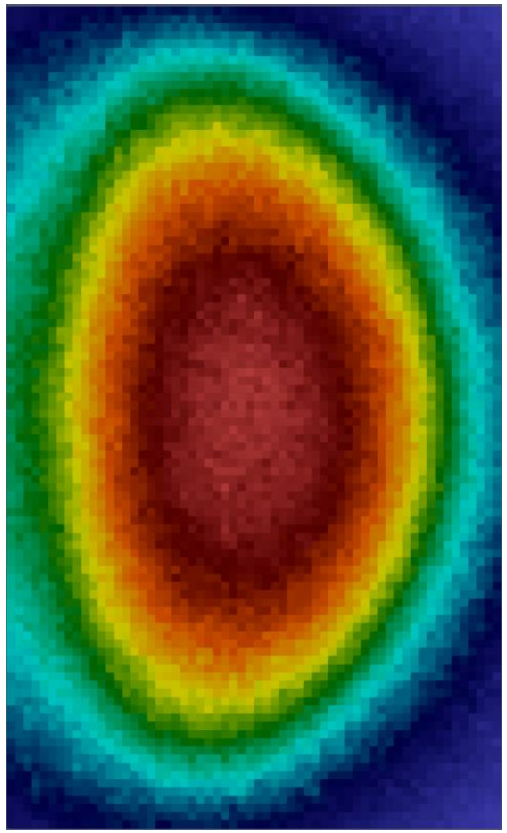
```
C **** NEUTRON EMISSION PROBABILITY - VERTICAL ****
C
DS3 Q
     553.0000   500      565.2800   501      577.5600   502
     589.8400   503      602.1200   504      614.4000   505
                                 •
                                 •
                                 •
C
SI500 H
      0.0000   11.3912   22.7823   34.1735   45.5646   56.9558
     68.3470   79.7381   91.1293  102.5205  113.9116  125.3028
                                 •
                                 •
                                 •
C
SP500 D 0
   1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

SI501
SP501
          •
          •
          •
```

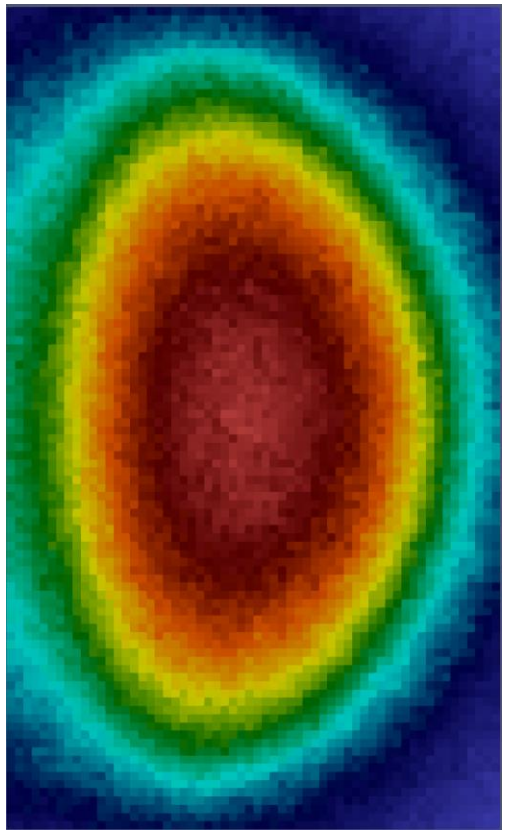
Plasma source – neutron emission probability

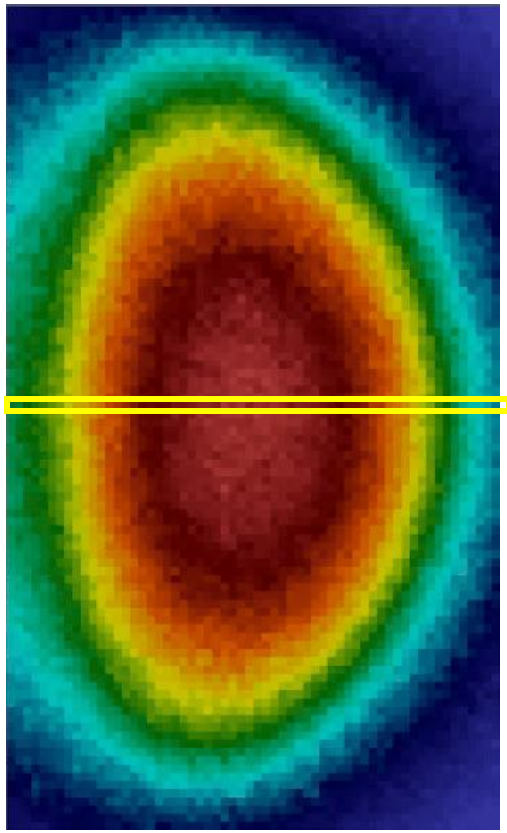
MCNP

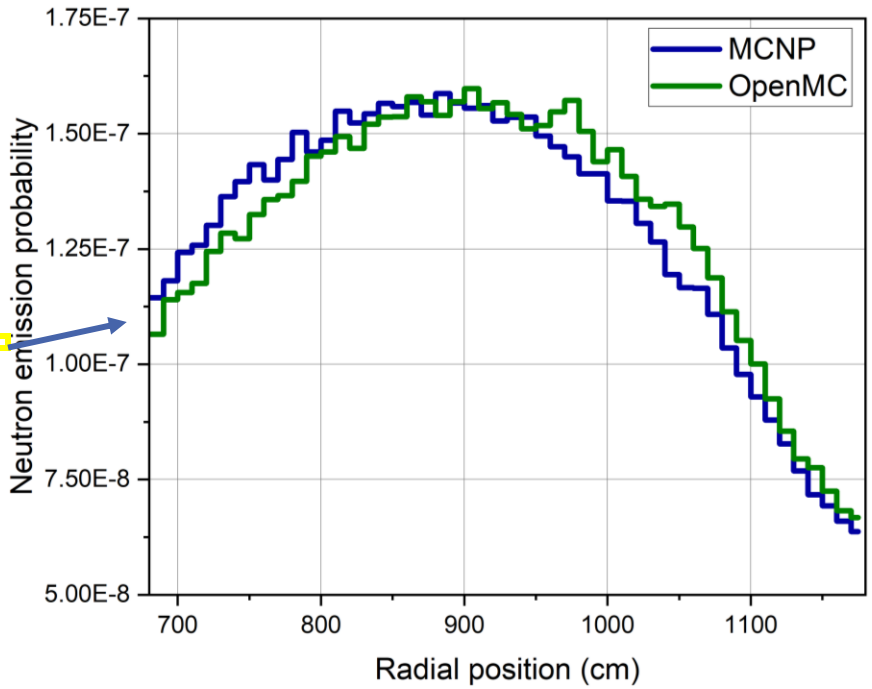
ITER RF DA

Compare

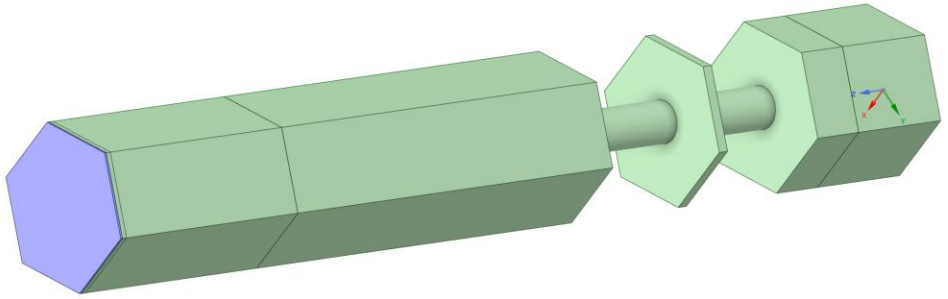


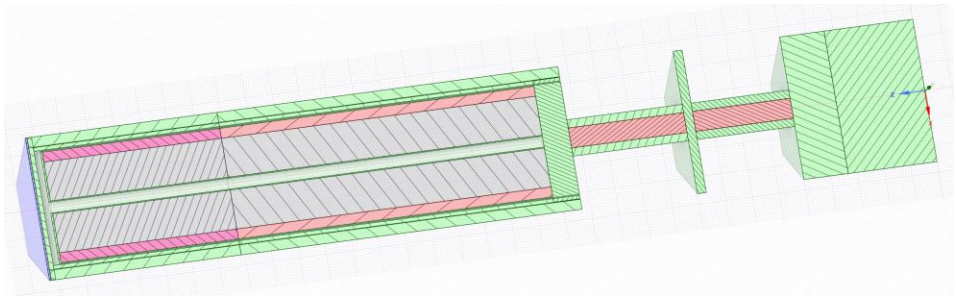


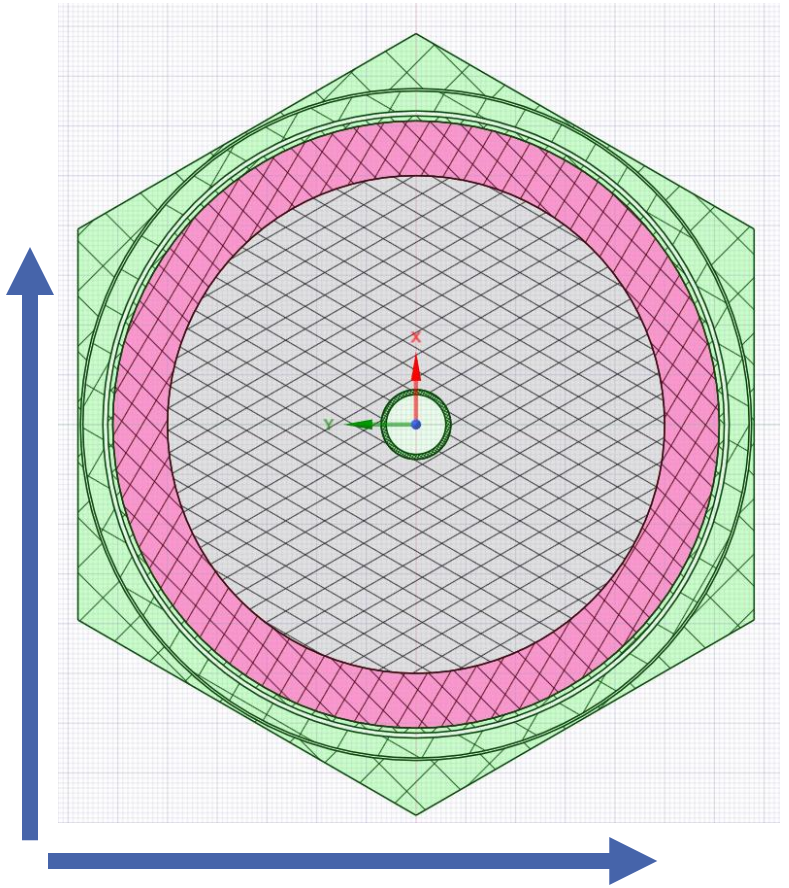




Hexagonal lattice



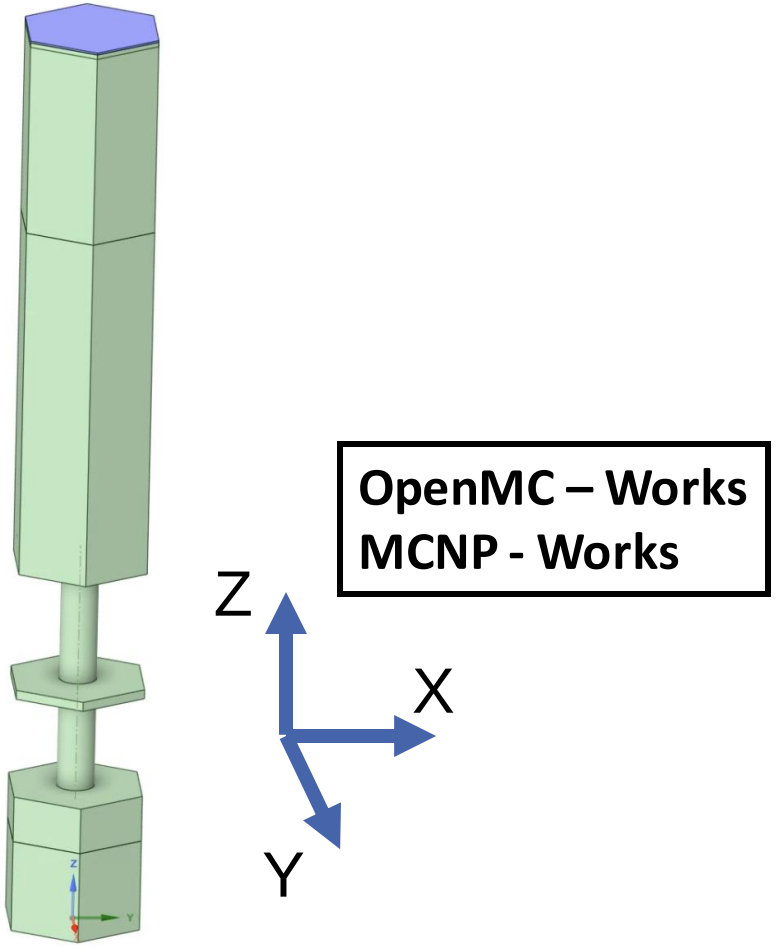




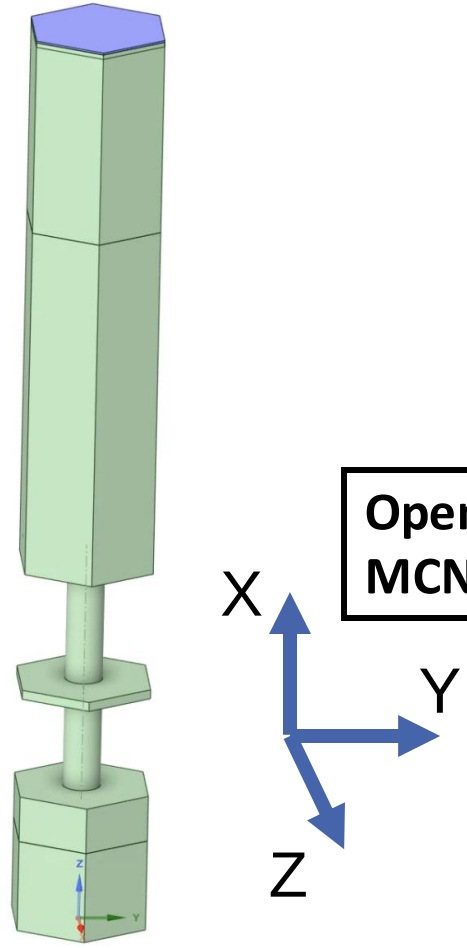
OpenMC hexagonal lattice

- Hexagon must located on XY plane

Hexagonal lattice



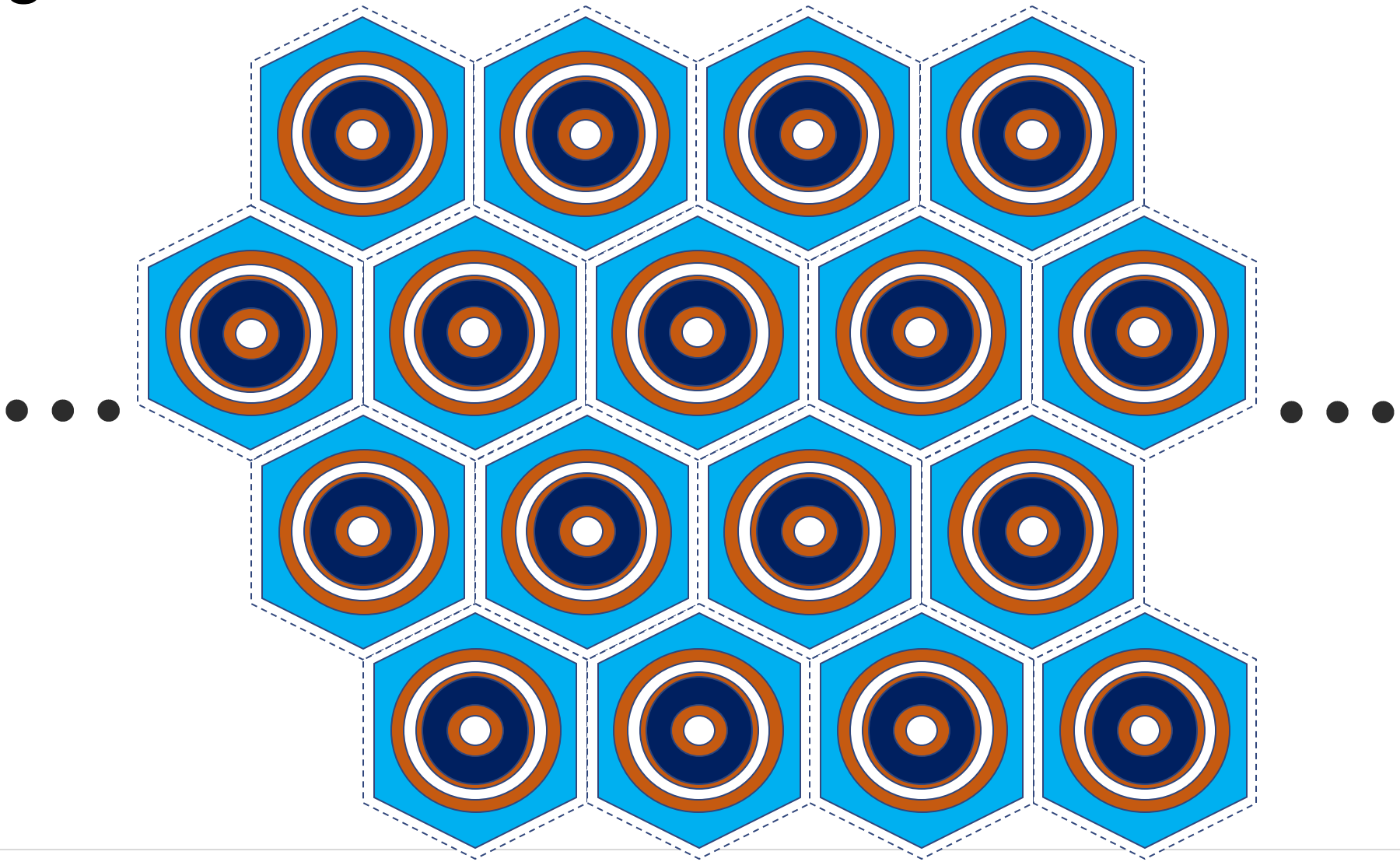
OpenMC – Works
MCNP - Works



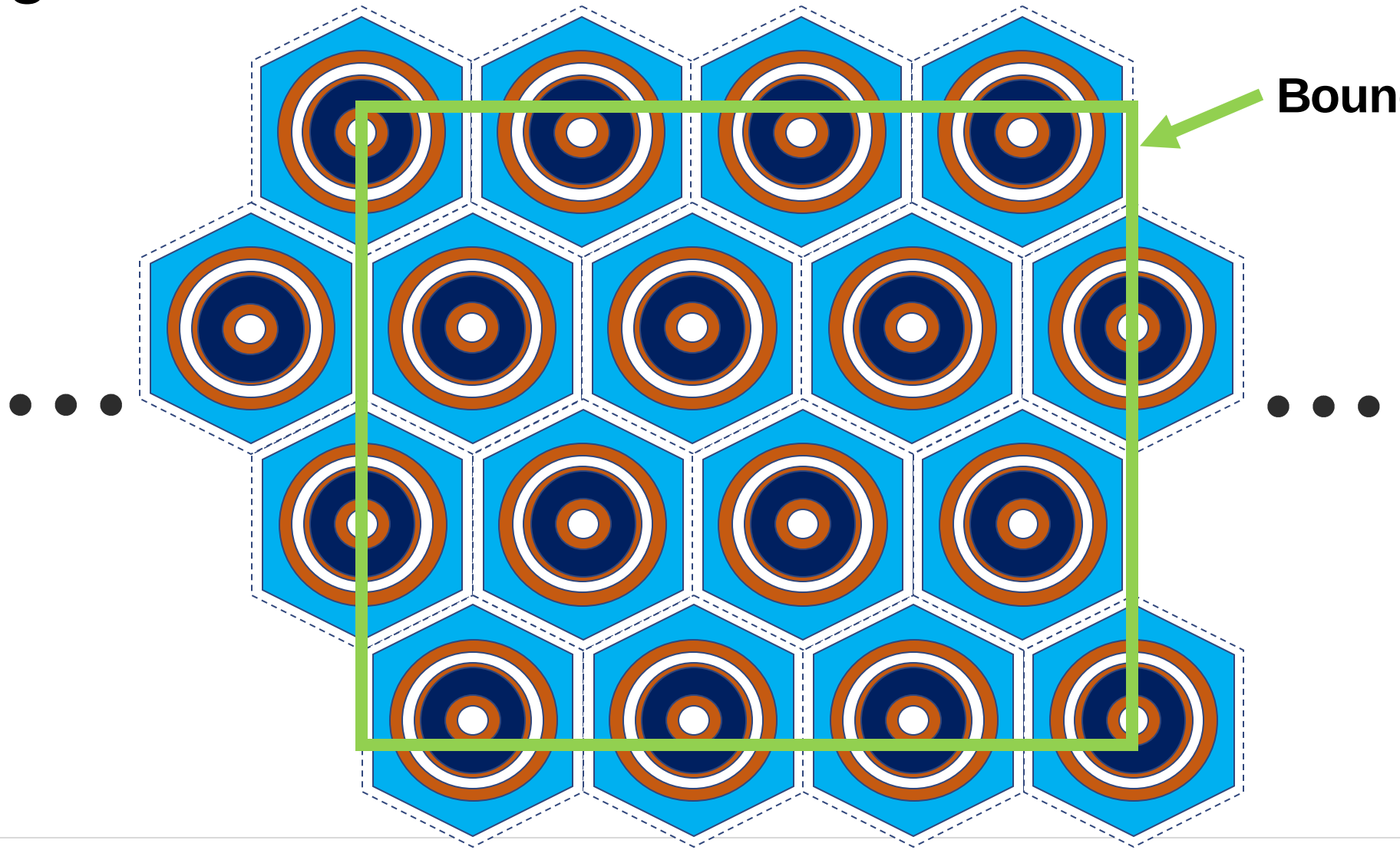
OpenMC – Not working
MCNP - Works

Hexagonal lattice

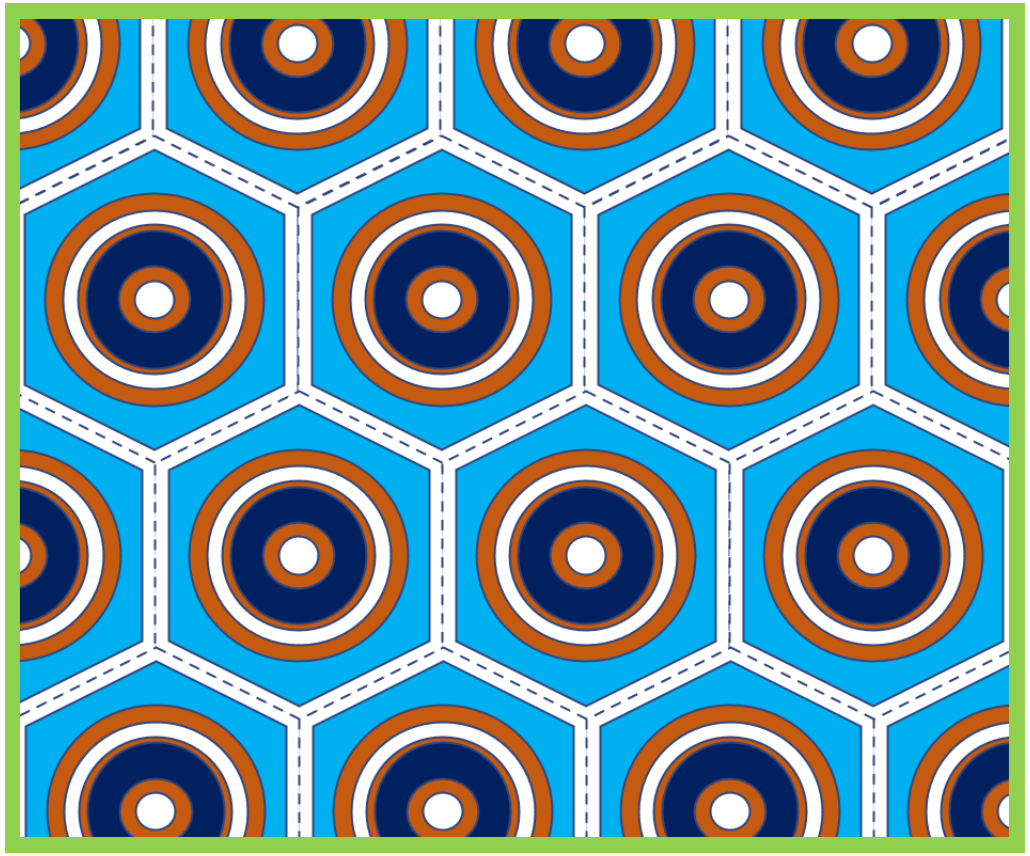
Hexagonal lattice



Hexagonal lattice



Hexagonal lattice



Lattice definition (MCNP-to-OpenMC)

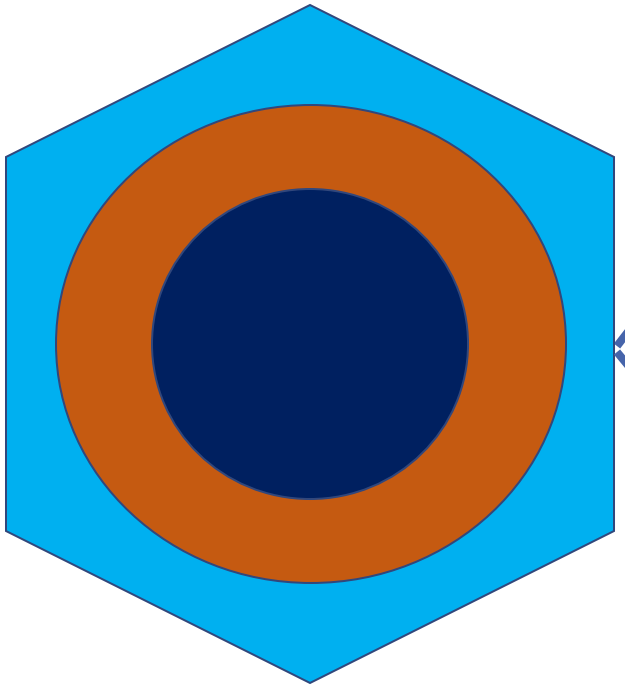
MCNP

```
c Armor layer -- 2mm
10001   0              -10001 10002 -10003 10004 -10005 10006
          U=101          FILL=102   IMP:N=1   IMP:P=1
```

OpenMC

```
<cell fill="102"   <hex_lattice id="101" n_rings="1"  orientation="y">                ="101"/>
          <center>0 0</center>
          <pitch> 13.5 </pitch>
          <universes> 102 </universes>
          <outer> 102 </outer>
  </hex_lattice>
<!--  <cell fill="102" id="10001" region="-10001 10002 -10003 10004 -10005 10006"
    universe="101"/> -->
```

Hexagonal lattice



OpenMC with geometry debugging
- detected overlapping cells

```
<cell id="10002" material="15" region="-10011" universe="102"/>
<cell id="10003" material="15" region="10011 -10010" universe="102"/>
<cell id="10004" material="15" region="10010" universe="102"/>
```

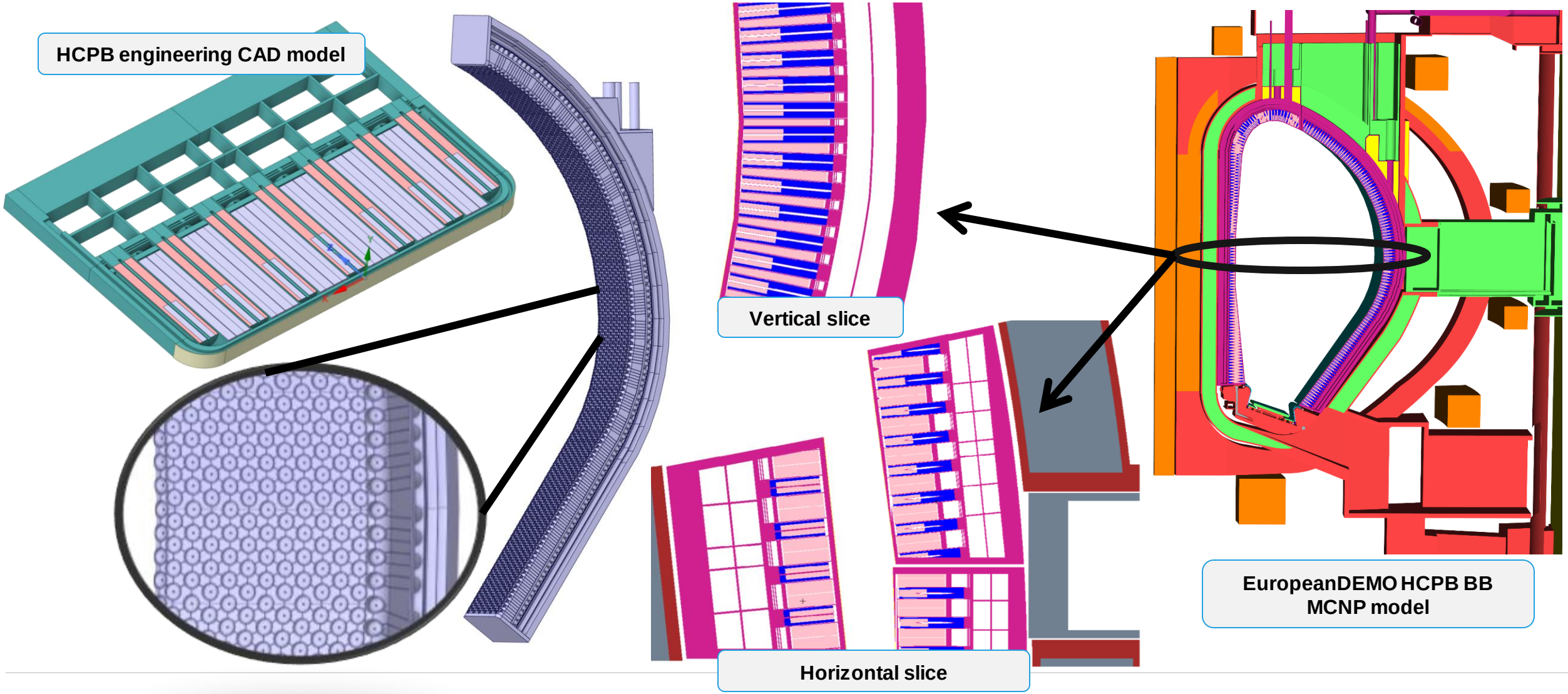
Cell 10002 = inside small circle
Cell 10003 = between two circle
Cell 10004 = outter big circle
Cannot be overlapped!!

If you add very big (bigger than universe envelope) Z boundary limit
- overlapping is disappeared

```
<cell id="10002" material="15" region="-10011 998 -999" universe="102"/>
<cell id="10003" material="15" region="10011 -10010 998 -999" universe="102"/>
<cell id="10004" material="15" region="10010 998 -999" universe="102"/>
```

```
<surface boundary="vacuum" coeffs="-150.0" id="998" type="z-plane"/>
<surface boundary="vacuum" coeffs="150.0" id="999" type="z-plane"/>
```

Lattice on DEMO HCPB design



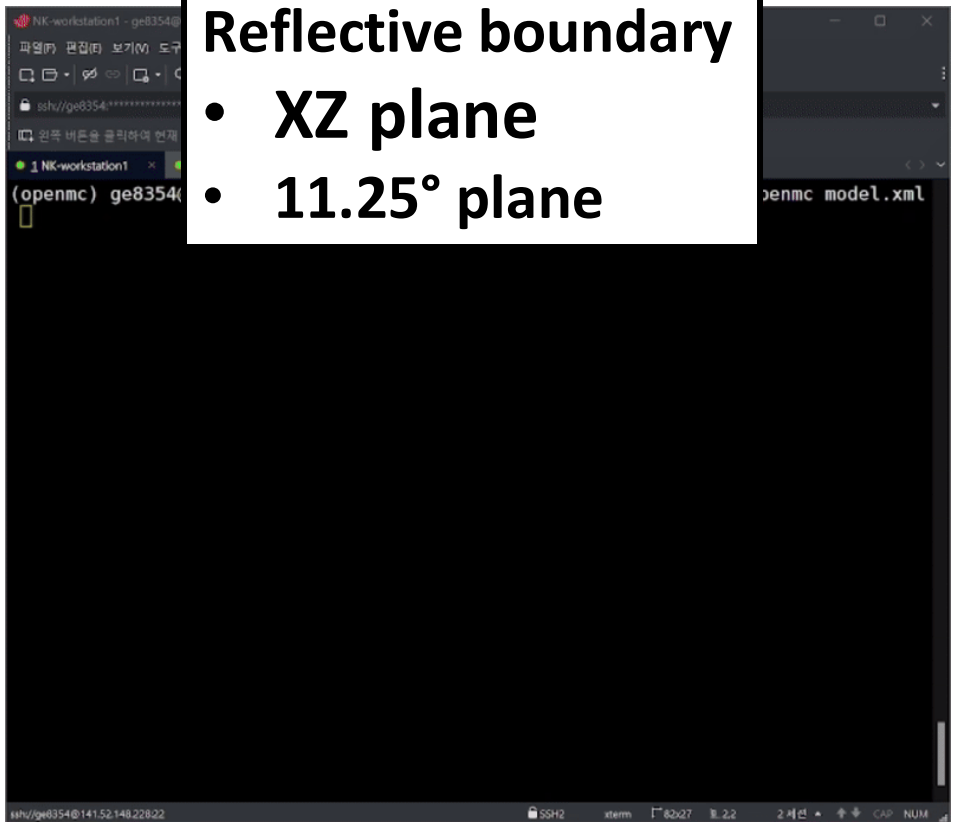
Tallies

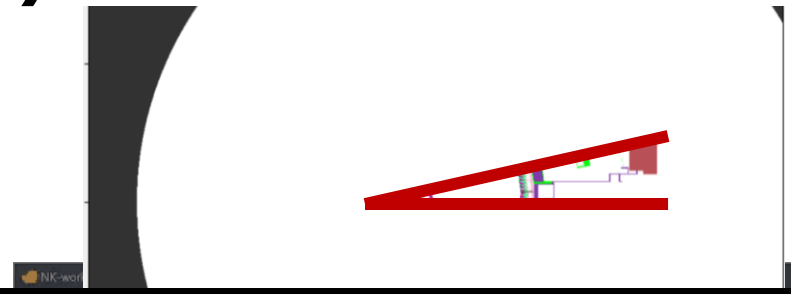
- MCNP
- Cell based tally with MT number
- FM card
  - Li6 – (n,t) [105]
  - Li7 – (n,xt) [205]

- OpenMC
- Nuclides based - Li6, Li7
- Scores
  - 1st T-production
  - 2nd MT number
    - Li6 – (n,t) [105]
    - Li7 – (n,xt) [205]

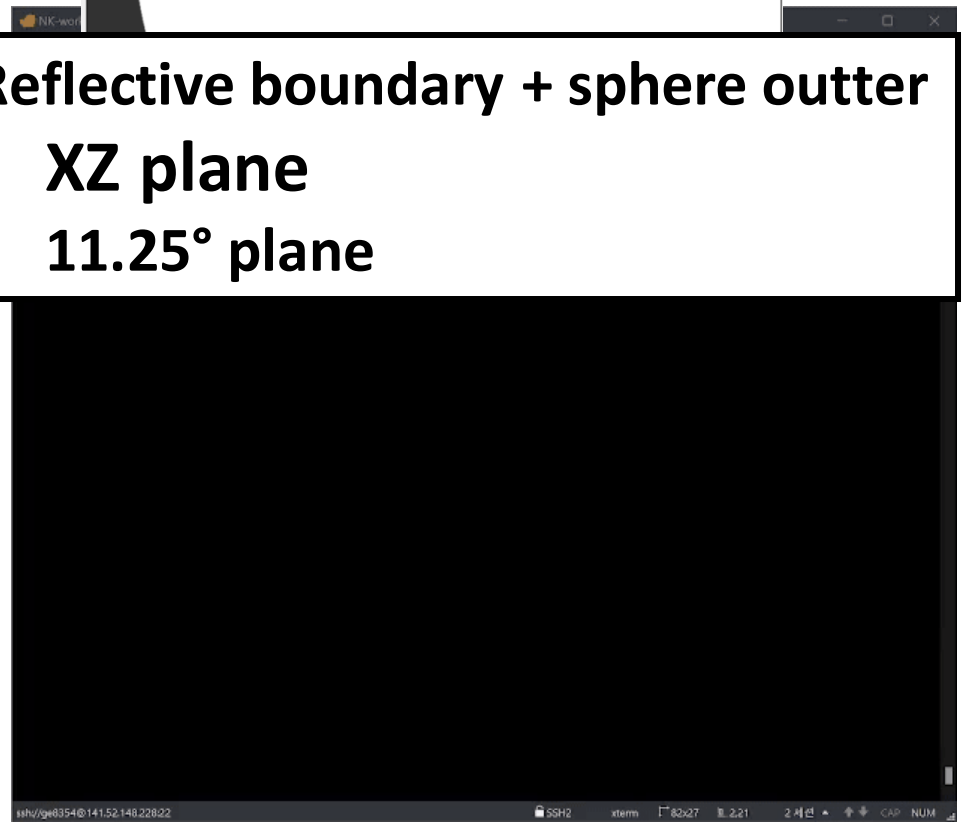
Boundary conditions (Y=0 plane)

Reflective boundary
- **XZ plane**
- **11.25° plane**

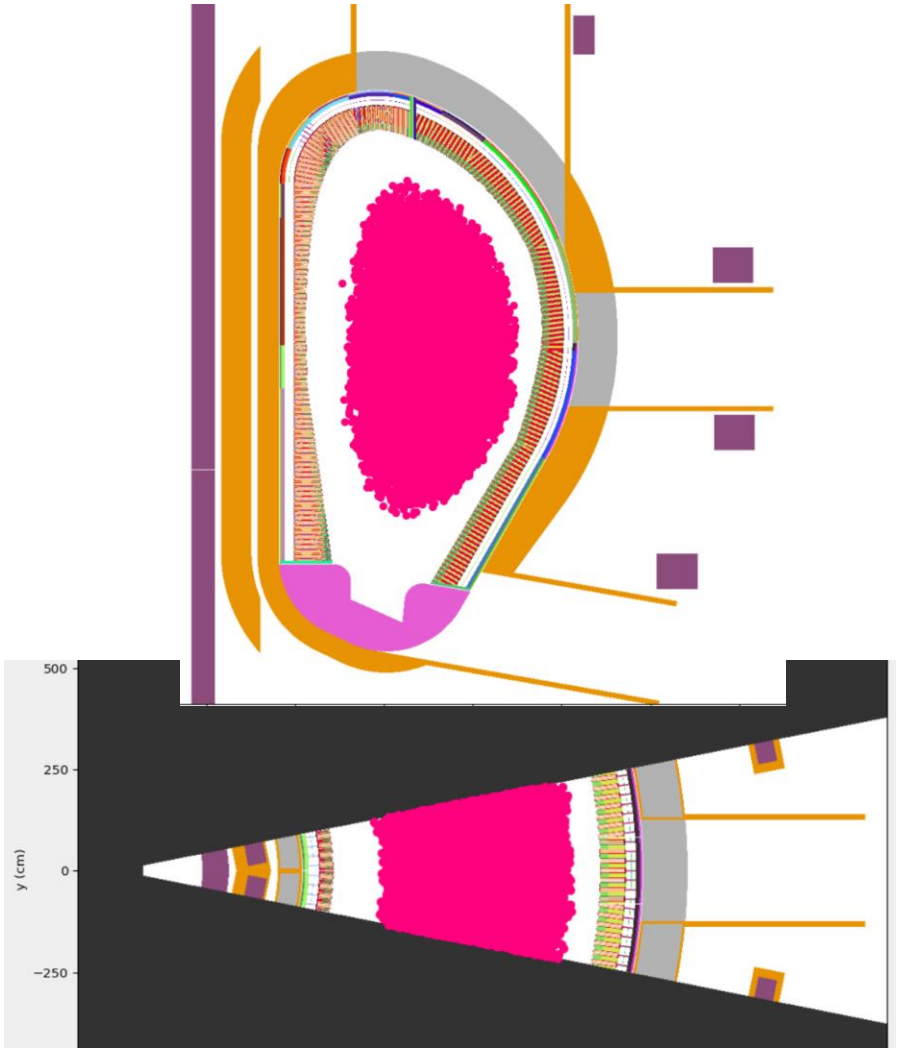


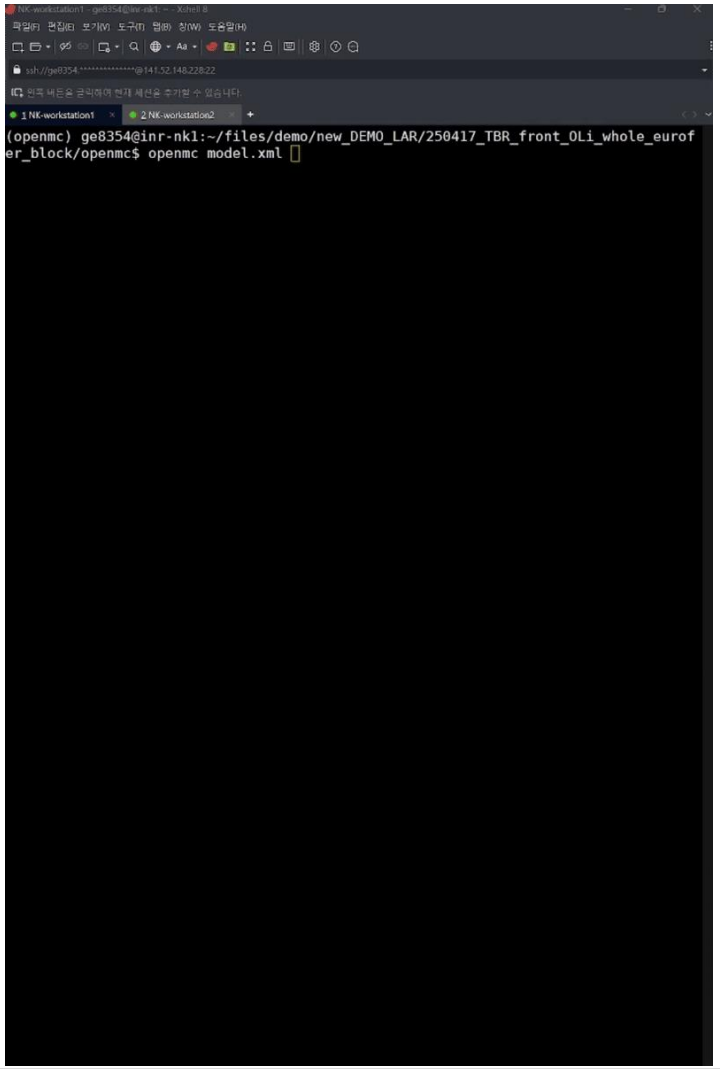


Reflective boundary + sphere outter
- **XZ plane**
- **11.25° plane**

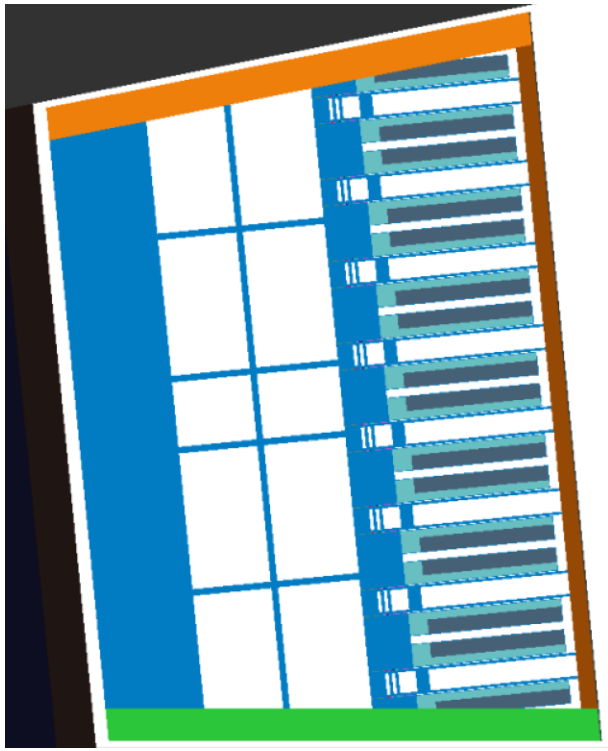


Tritium Breeding Ratio – 22.5° DEMO + HCPB

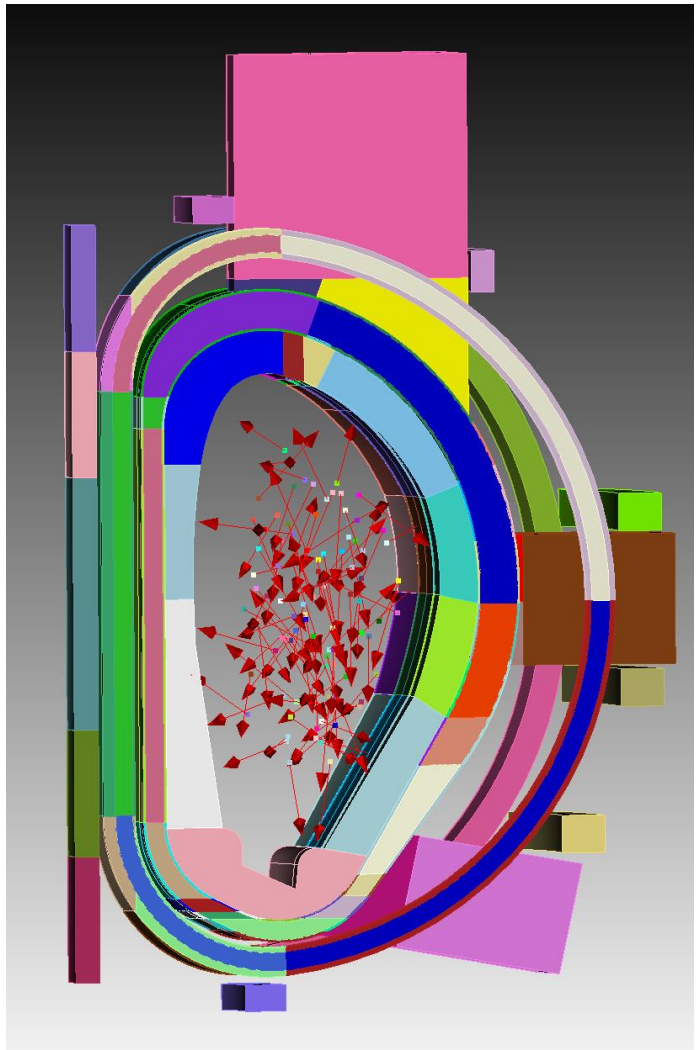




1E+7 nps	
MCNP:	1.171
OpenMC:	0.896



Tracking warning particles



Used coreform cubit
Tracking 100 warning particles

Most of warning particles located in plasma source cell (98 of 100 particles)

Tritium Breeding Ratio – 360° DEMO + HCPB

Sector universe with fill card + transformation matrix

1E+7 nps

22.5° sector model

MCNP: 1.171

OpenMC: 0.896

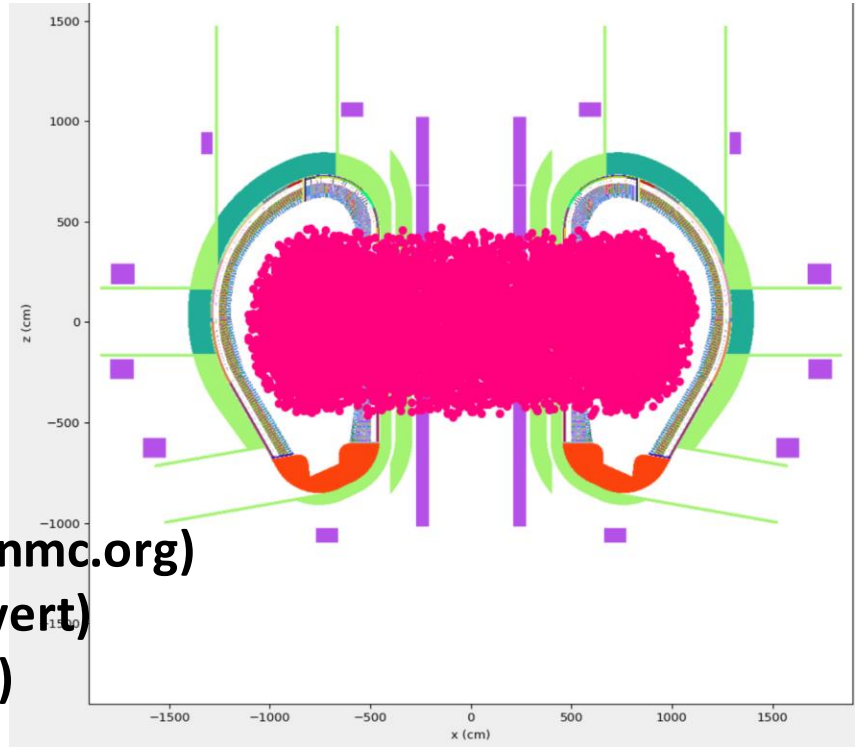
360 ° model

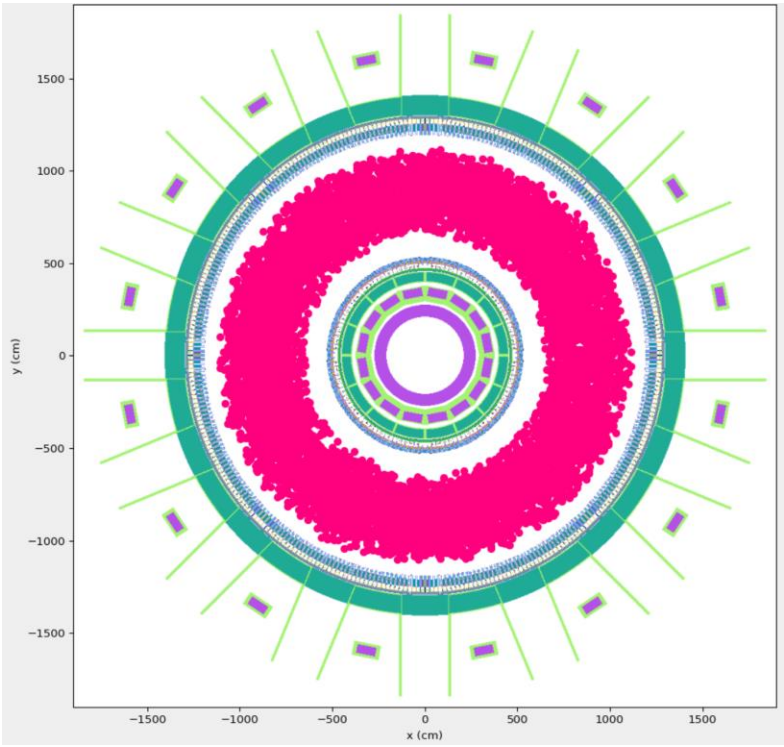
MCNP: 1.171

OpenMC: 0.917 (JEFF3.3 – openmc.org)

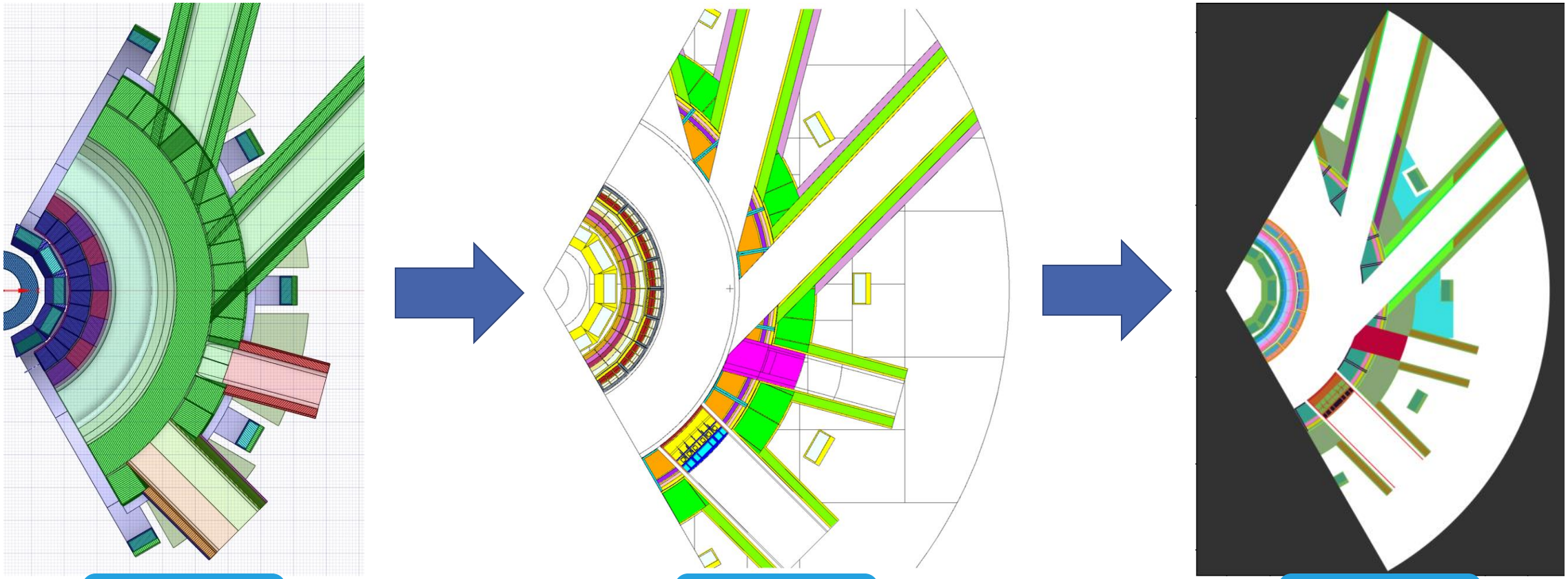
0.917 (JEFF3.3 – convert)

0.920 (ENDF/B-VIII.o)

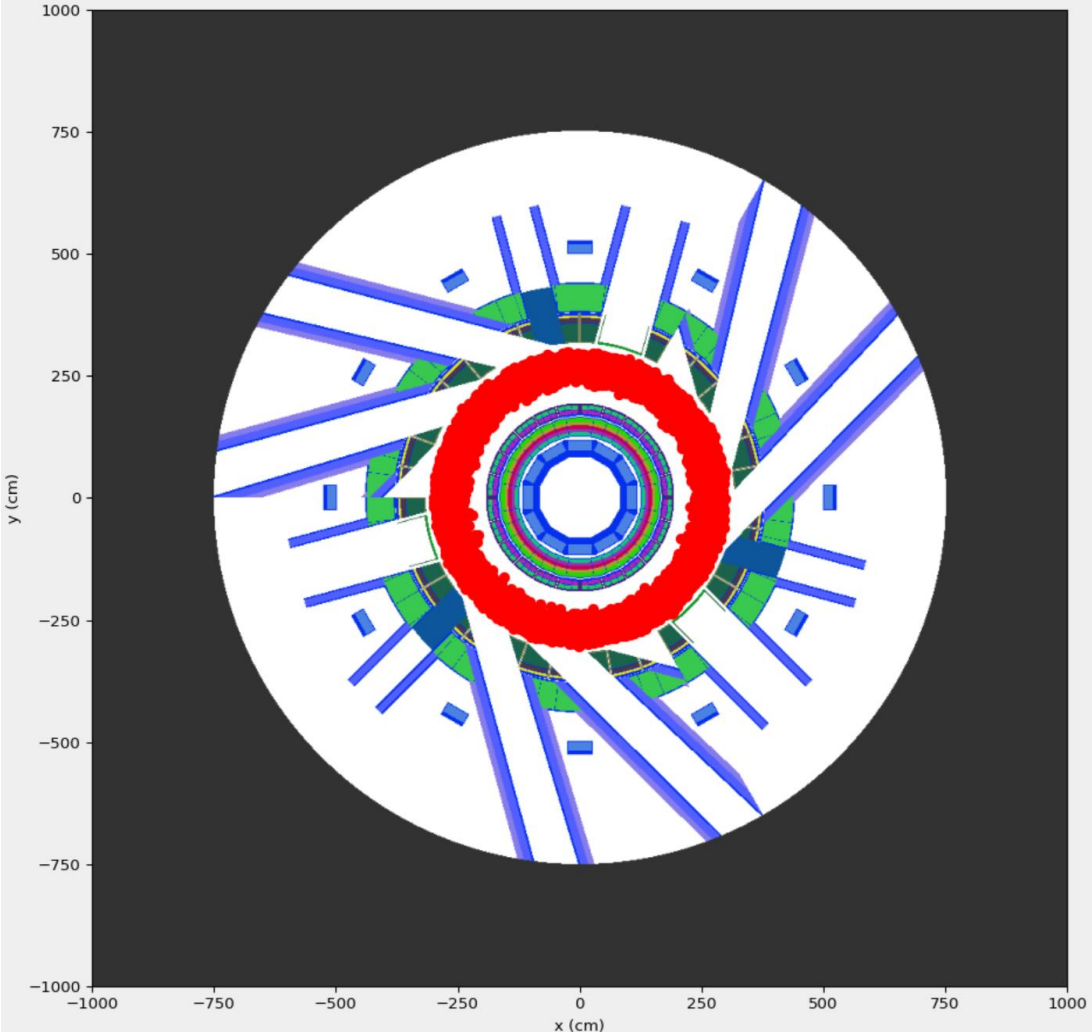




Geometry model conversion



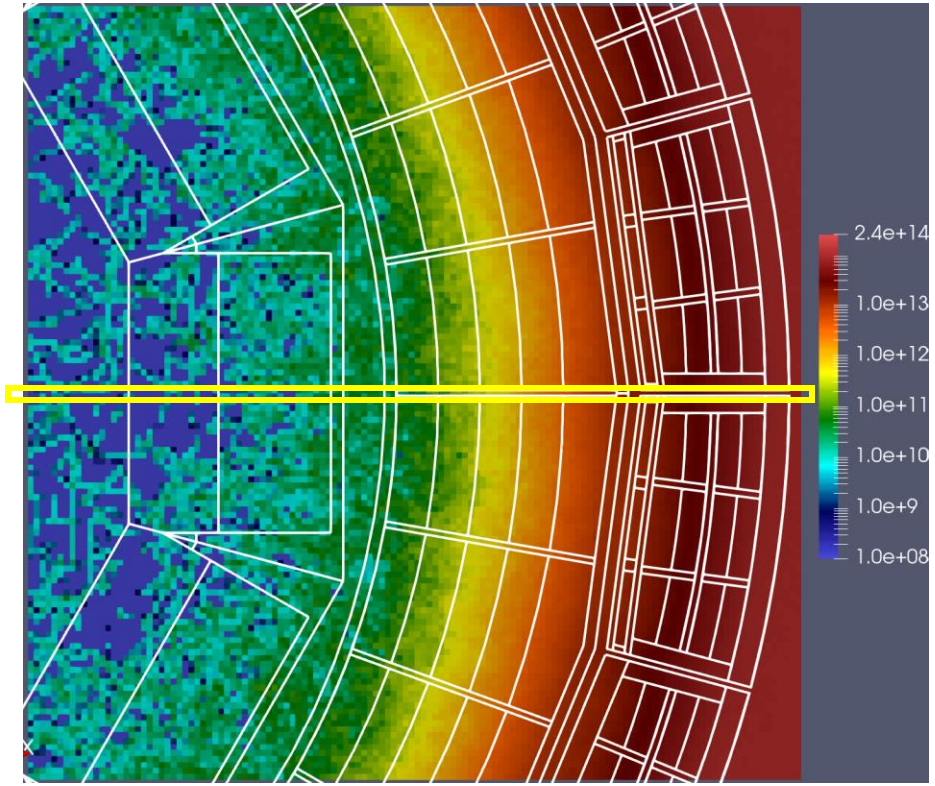
Boundary – 360° VNS (120 ° sector x3)



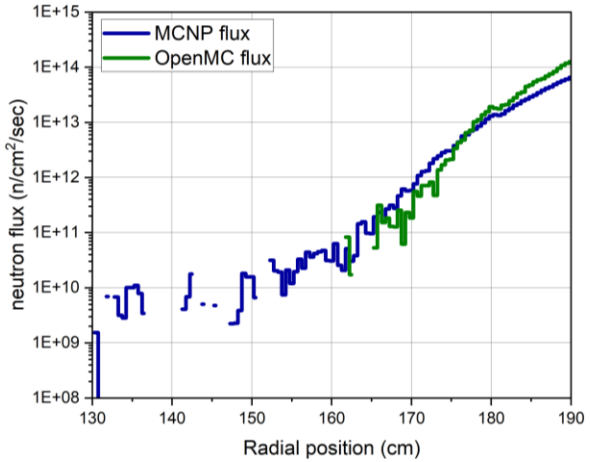

```
Simulating batch 1
Creating state point ./output/statepoint.01.h5...
Simulating batch 2
Creating state point ./output/statepoint.02.h5...
Simulating batch 3
Creating state point ./output/statepoint.03.h5...
Simulating batch 4
Creating state point ./output/statepoint.04.h5...
Simulating batch 5
Creating state point ./output/statepoint.05.h5...
Simulating batch 6
Creating state point ./output/statepoint.06.h5...
Simulating batch 7
Creating state point ./output/statepoint.07.h5...
Simulating batch 8
Creating state point ./output/statepoint.08.h5...
Simulating batch 9
Creating state point ./output/statepoint.09.h5...
Simulating batch 10
Creating state point ./output/statepoint.10.h5...
```

VNS – neutron flux

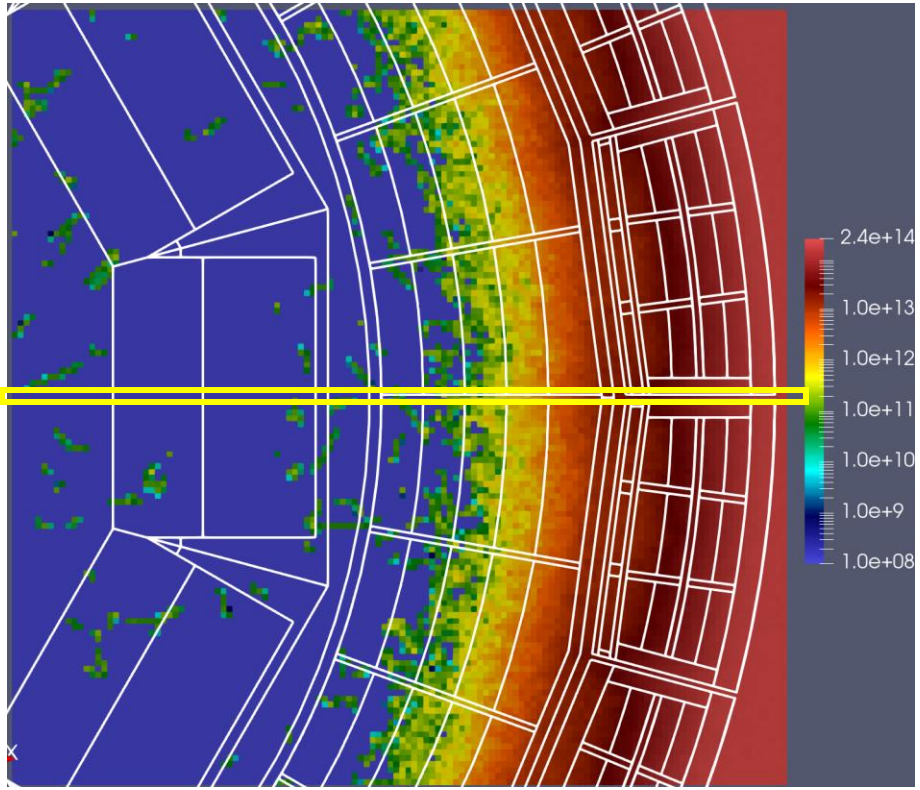
MCNP



5E+7 nps
without weight window

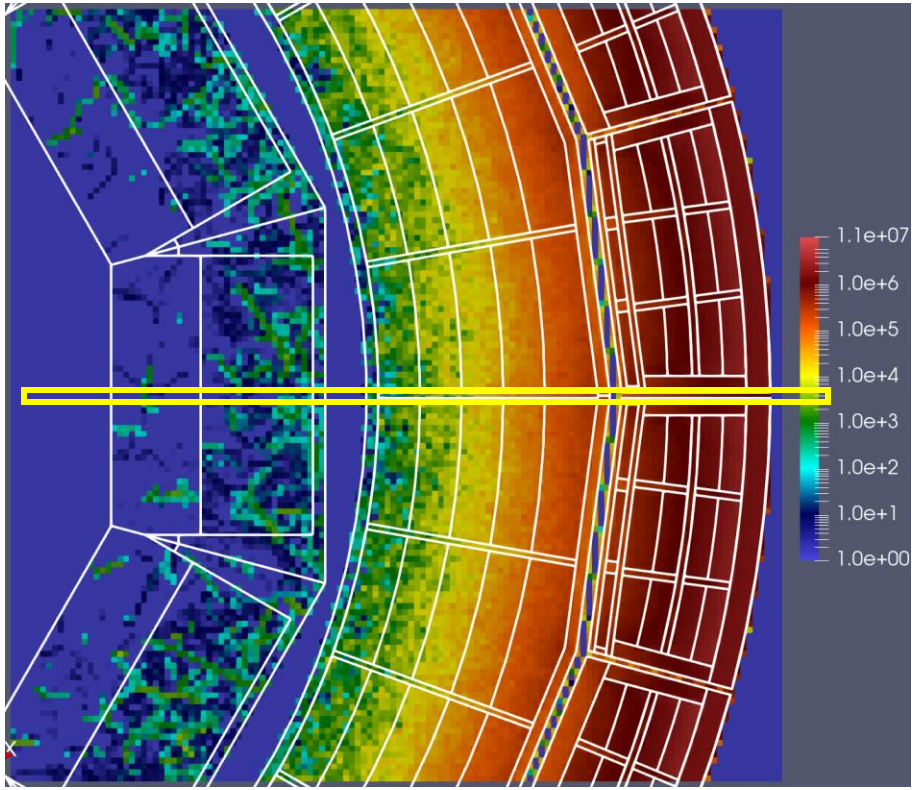


OpenMC

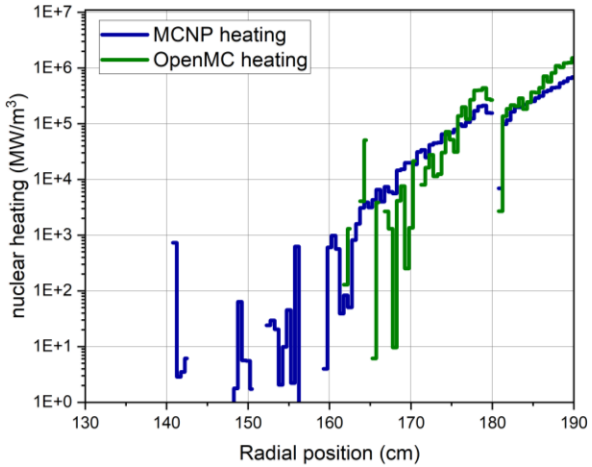


VNS – heating (n+p)

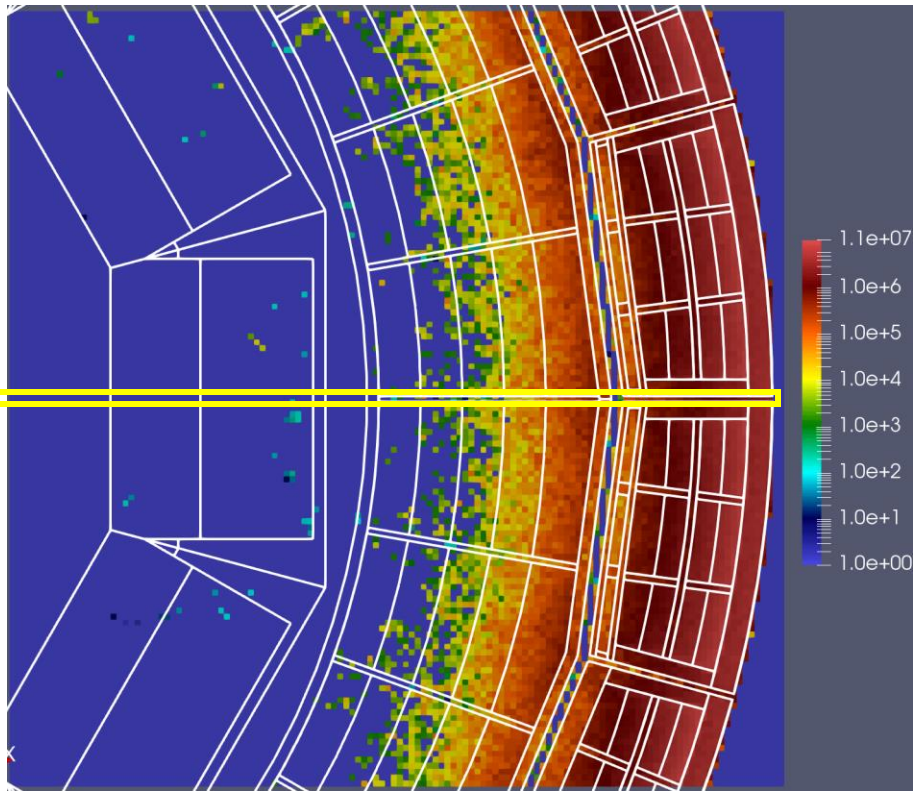
MCNP



5E+7 nps
without weight window

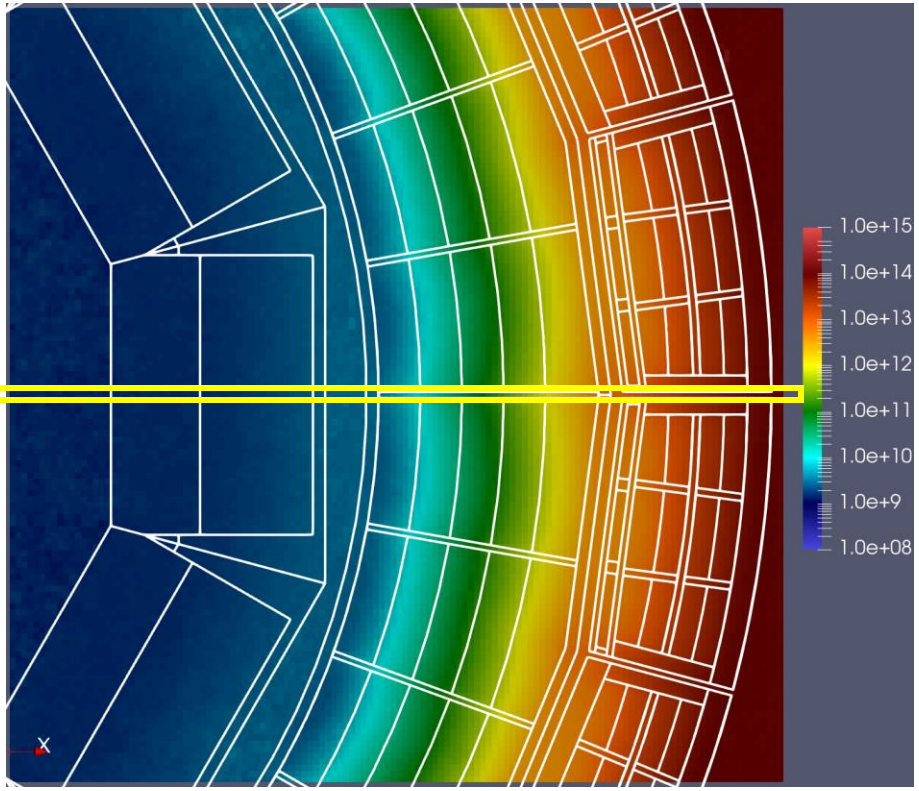


OpenMC

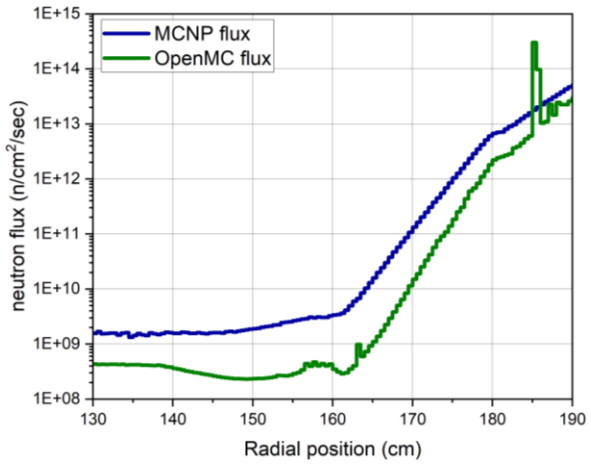


VNS + weight window – neutron flux

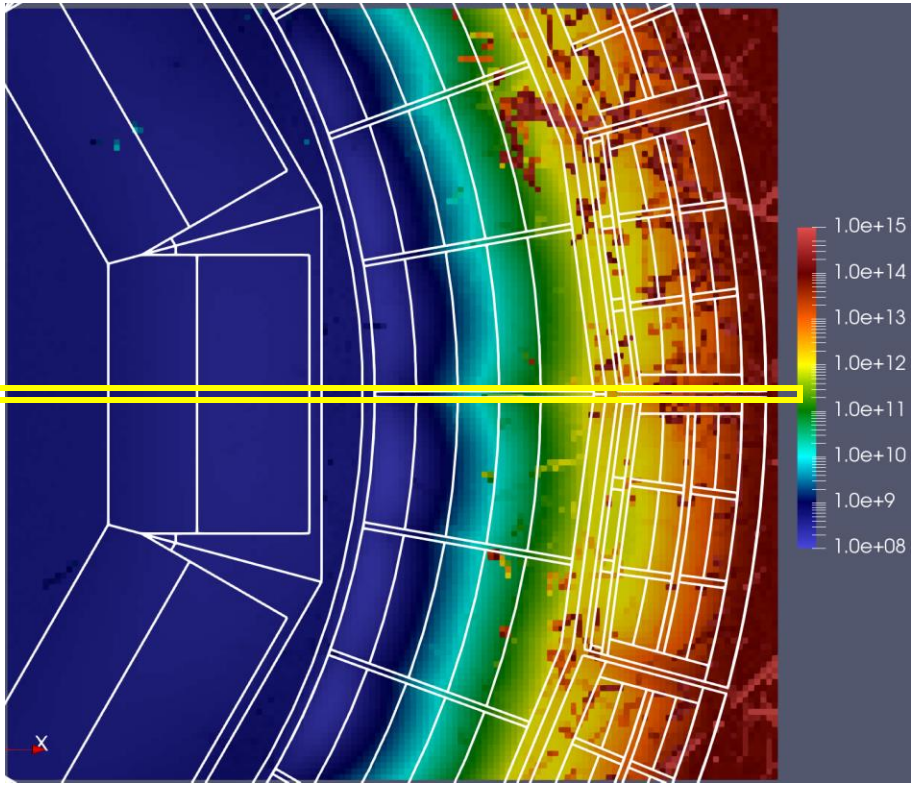
MCNP



MCNP 1E7 nps (3.5h)
OpenMC 1E4 nps (8.5days)

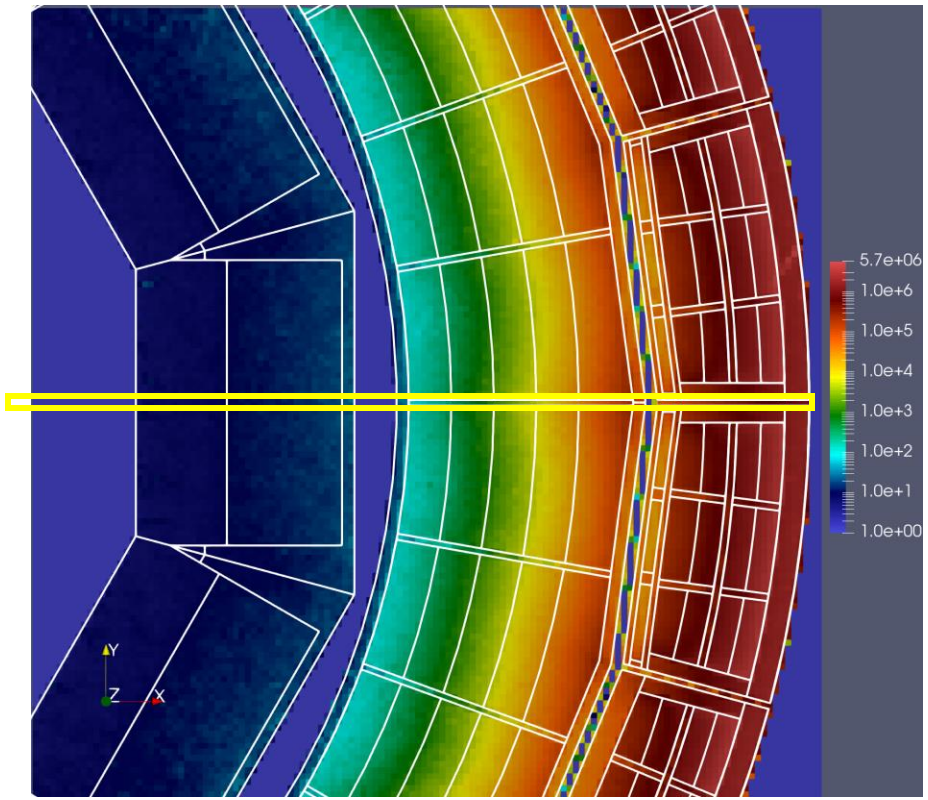


OpenMC

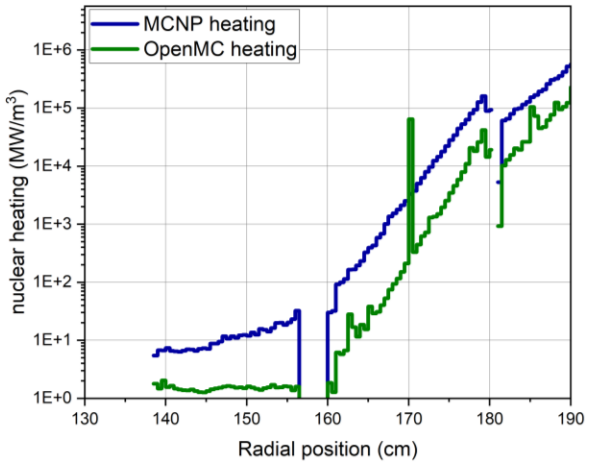


VNS + weight window – heating (n+p)

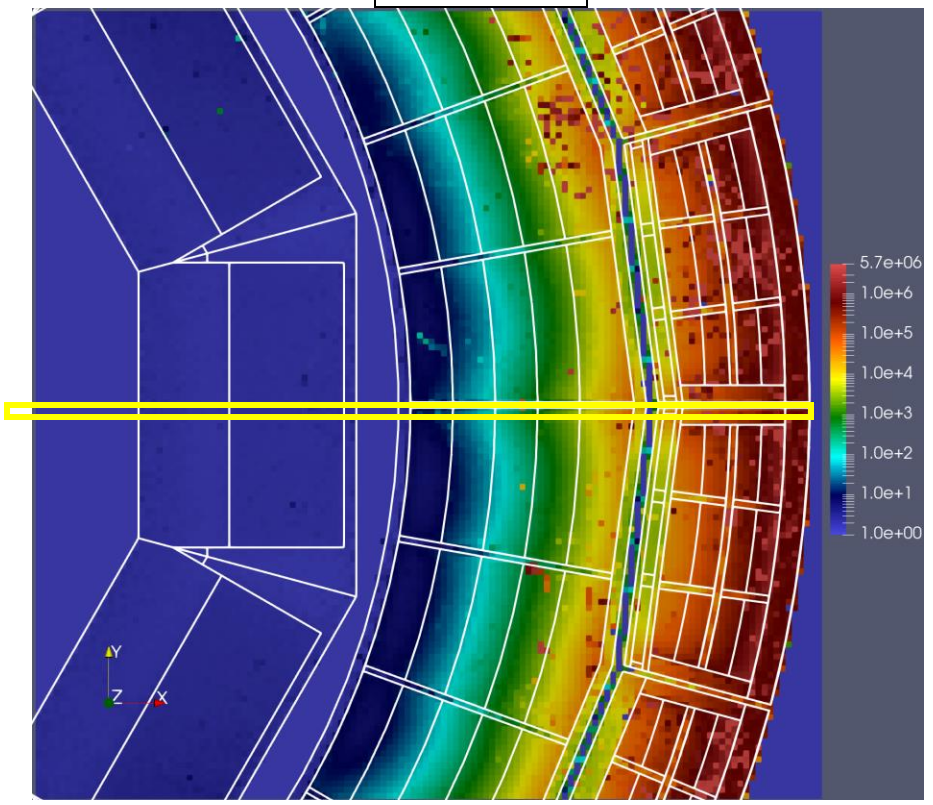
MCNP



MCNP 1E7 nps (3.5h)
OpenMC 1E4 nps (8.5days)



OpenMC

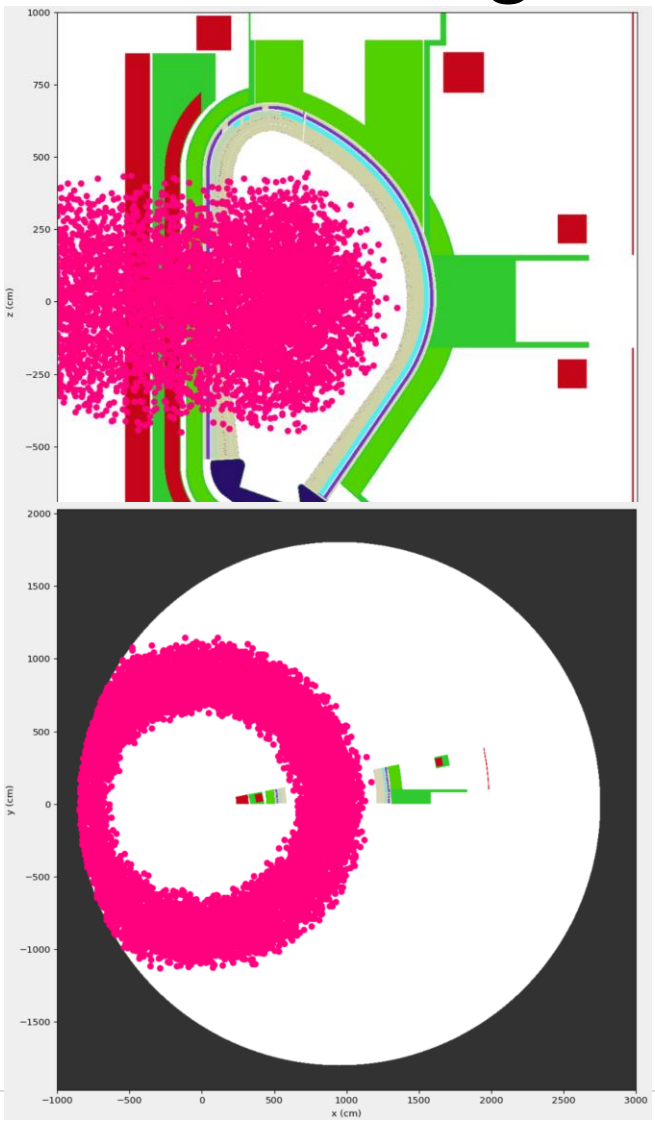


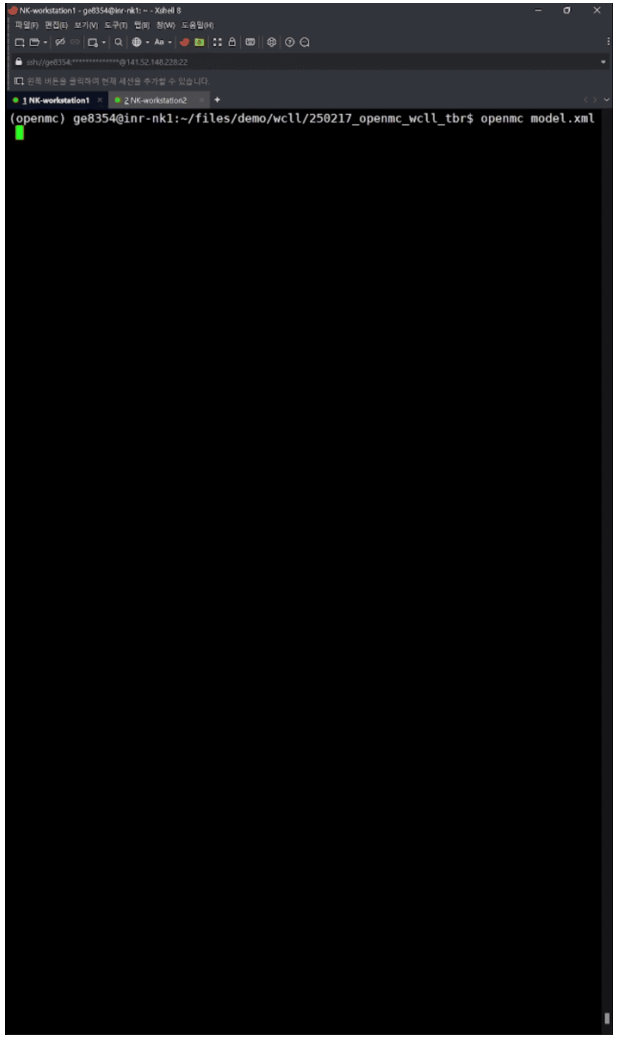
Summary and planning

- MCNP-to-OpenMC source convertor
- Lattice structure flexibilities - MCNP-to-OpenMC converter doesn‘t support
- Boundary(only reflective boundary??) issue with source
- MCNP and OpenMC TBR results are different
- WW calculation performance
  - photon transport with weight window (for ADVANTG, OpenMC MAGIC + on-the-fly) performance
- Surface tally for NWL comparison
- Shutdown dose rate methodology on main openmc distribution

- CAD & unstructured mesh base model benchmark studies
- Normalized WW, materials

Tritium Breeding Ratio – 11.25° DEMO + WCLL





1E+7 nps	
MCNP:	1.150
OpenMC:	1.323