INFN-E/MAFI

"Monitoraggio Alti Flussi ITER"

B. Caiffi[1,2], M. Osipenko[2], M. Taiuti[1,2], M. Ripani[2], L. Giancarli[3]

[1] Università degli Studi di Genova
[2] INFN, Sezione di Genova
[3] ITER IO

Overview

- ITER and the neutronic issue in fusion reactors
- TBM Project
- Shutdown dose rate calculation for ITER TBM Port #16

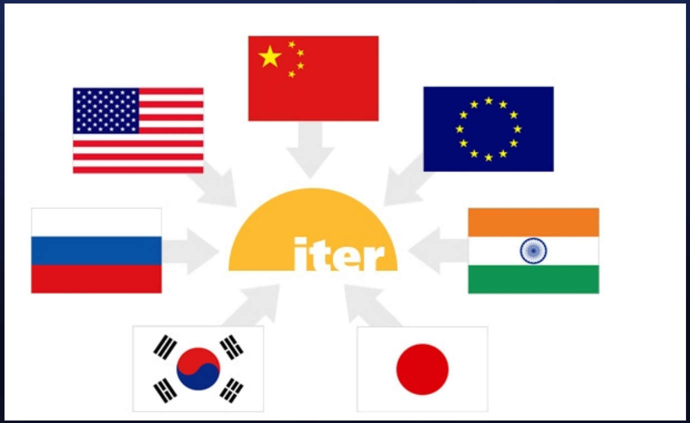
ITER
(International Thermonuclear Experimental Rector)

MAIN GOAL: Q>10

500 MW of fusion power from
50 MW input power

ITER SITE: Cadarache (France)
ITER TIMELINE:
2008: Site levelling
2010: Start Tokamak complex excavation
2013: Start Tokamak complex construction
2014: Arrival of first manufactured components
2015: Begin tokamak assembly
2019: Complete tokamak assembly
2020: First Plasma
2027: First D-T Operation

ITER (International Thermonuclear Experimental Rector)



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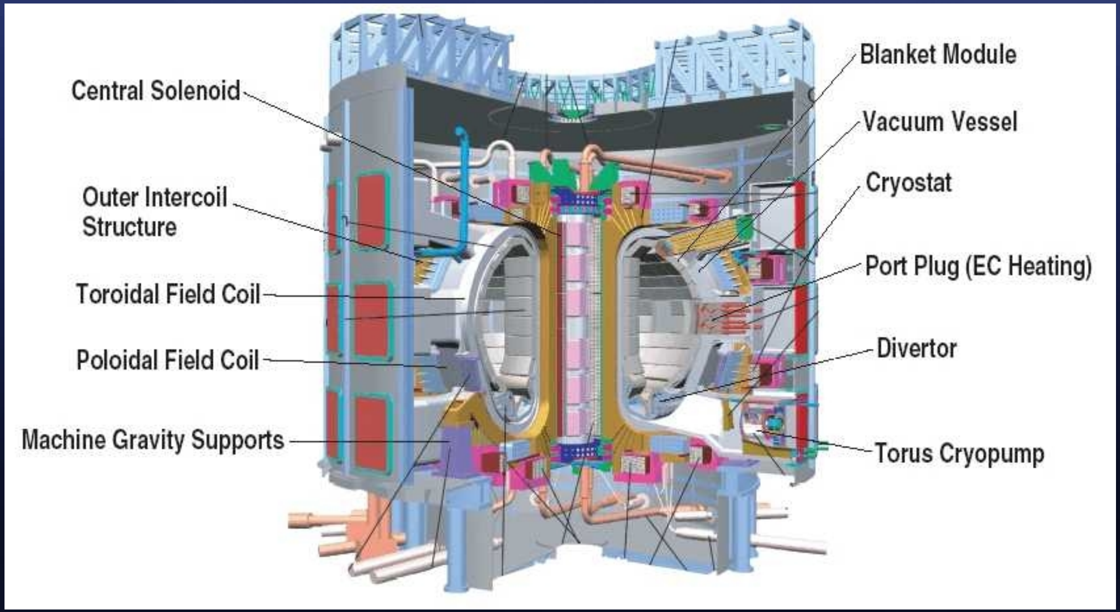
ITER machine

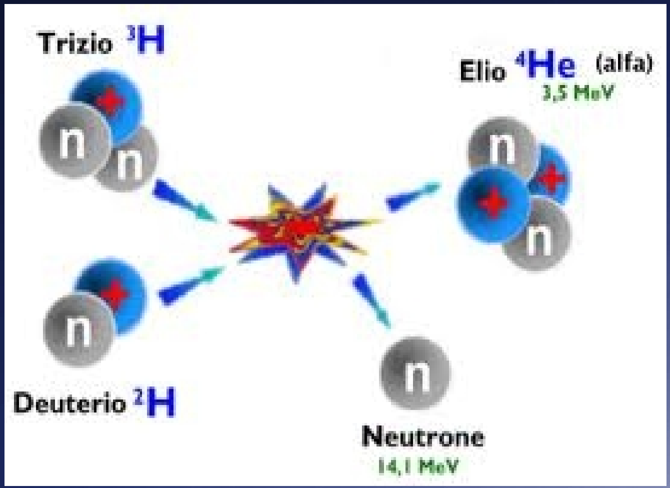


<u>Magnetic confined fusion reactor</u>
- Poloidal field magnets
- Toroidal field magnets

<u>Heating:</u>
- Ohmic heating (Central solenoid)
- Electron/Ion Resonance Cyclotron Heating
- Neutral Beam Injection

<u>Divertor</u> for the control of the exhaust gas, impurities and heat load

D-T Fusion Reaction

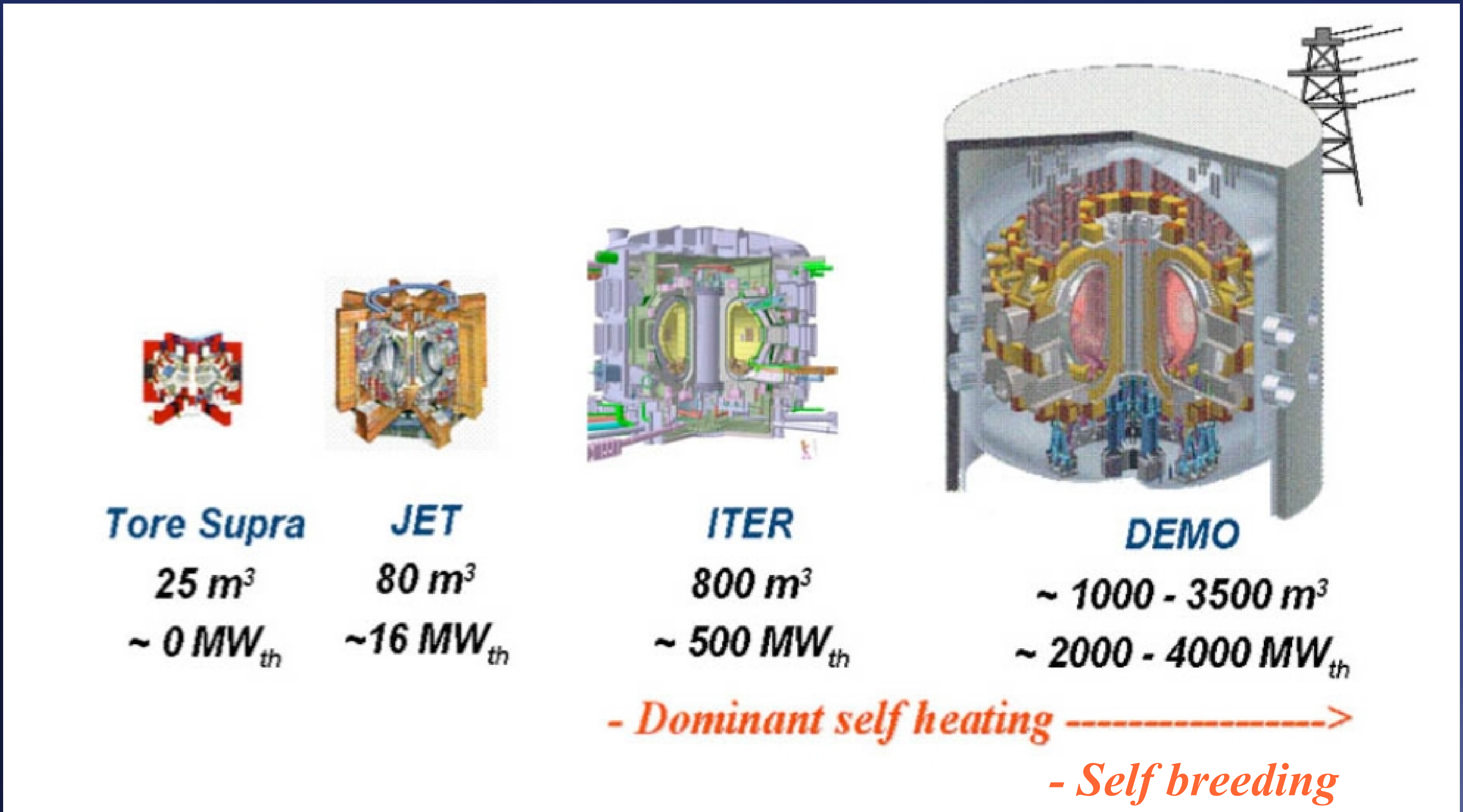


Q_{DT}=17.6 MeV

P_{FUSION}=500 MW

$\Phi_n = 10^{14} n/cm^2 s$
on the First Wall

THE NEXT STEPS

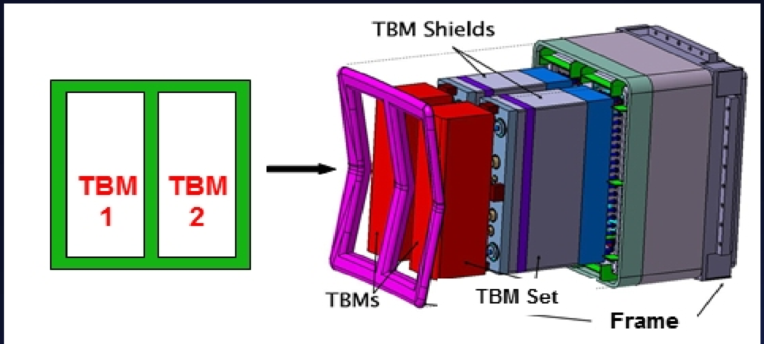


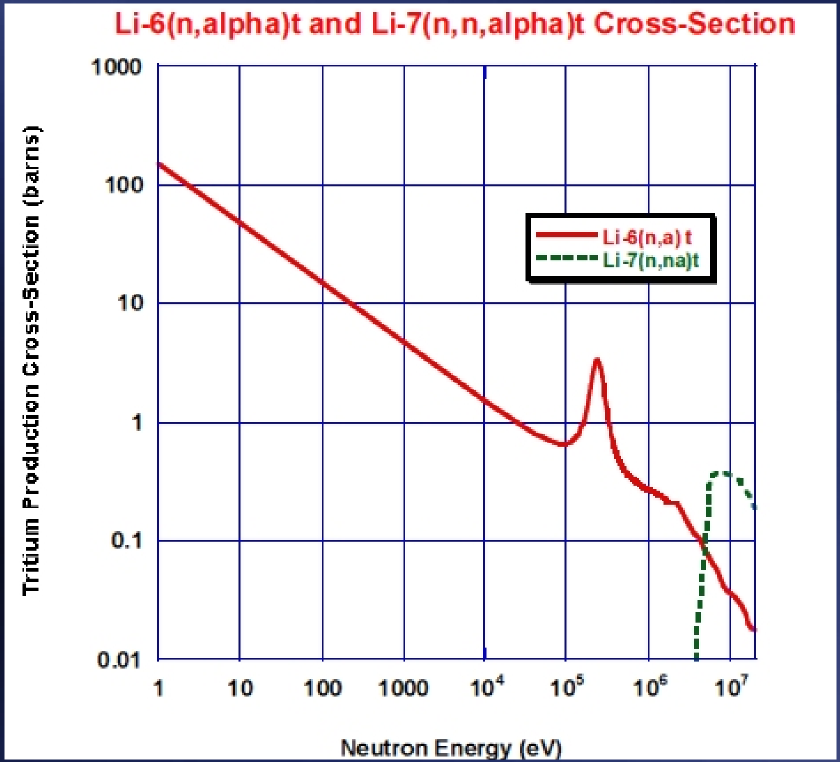
HOW TO REACH SELF-BREEDING: the Test Blanket Modules Project

TBM (Test Blanket Module): modules containing Li, in order to have the following reactions:

$$n + {}^{6}Li \rightarrow t + \alpha + 4.8\ MeV$$

$$n + {}^{7}Li \rightarrow n + t + \alpha - 2.8\ MeV$$



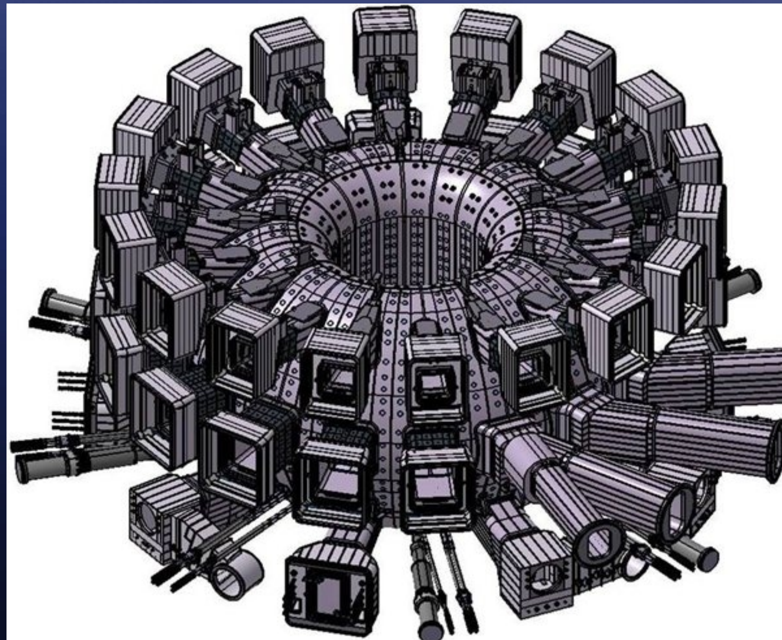


N° Port	TBM Concept 1	TBM Concept 2
16	Helium Cooled Lithium Lead	Helium Cooled Pebble Beds
18	Water Cooled Ceramic Breeder (+ Be)	Dual Coolant (He+LiPb) Lithium Lead
2	Water Cooled Ceramic Breeder (+ Be)	Lithium Lead Ceramic Breeder

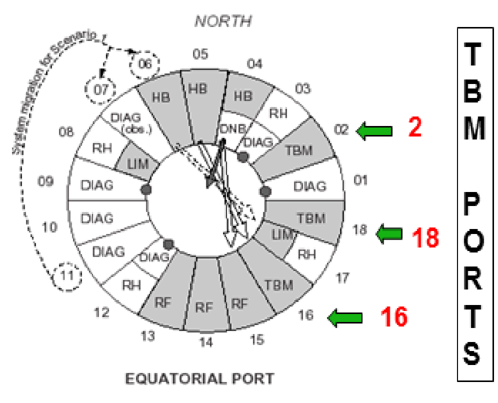
TBM HCPB Helium-Cooled Pebble Bed: lithiated ceramic pebbles (Li_4SiO_4 or Li_2TiO_3) as breeder and beryllium pebbles as neutron multiplier

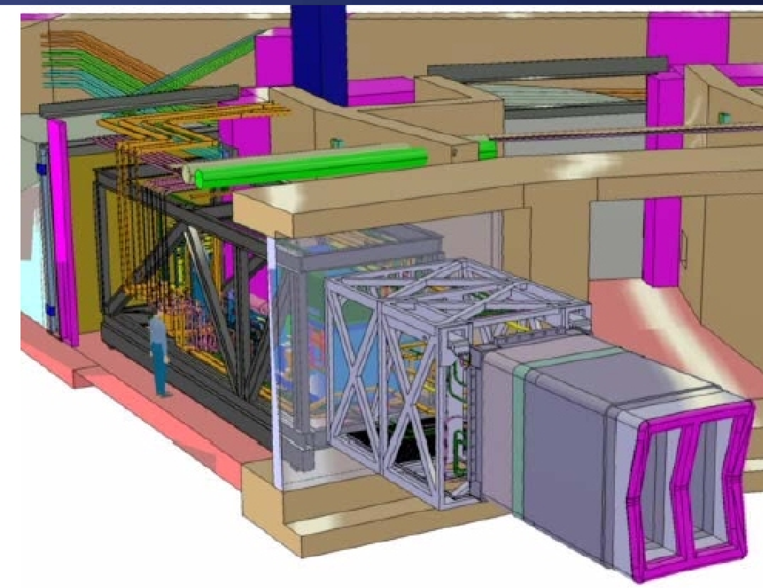
TBM HCLL Helium Cooled Lithium Lead: PbLi eutectic (liquid at operating temperatures) both as tritium breeding material and neutron multiplier

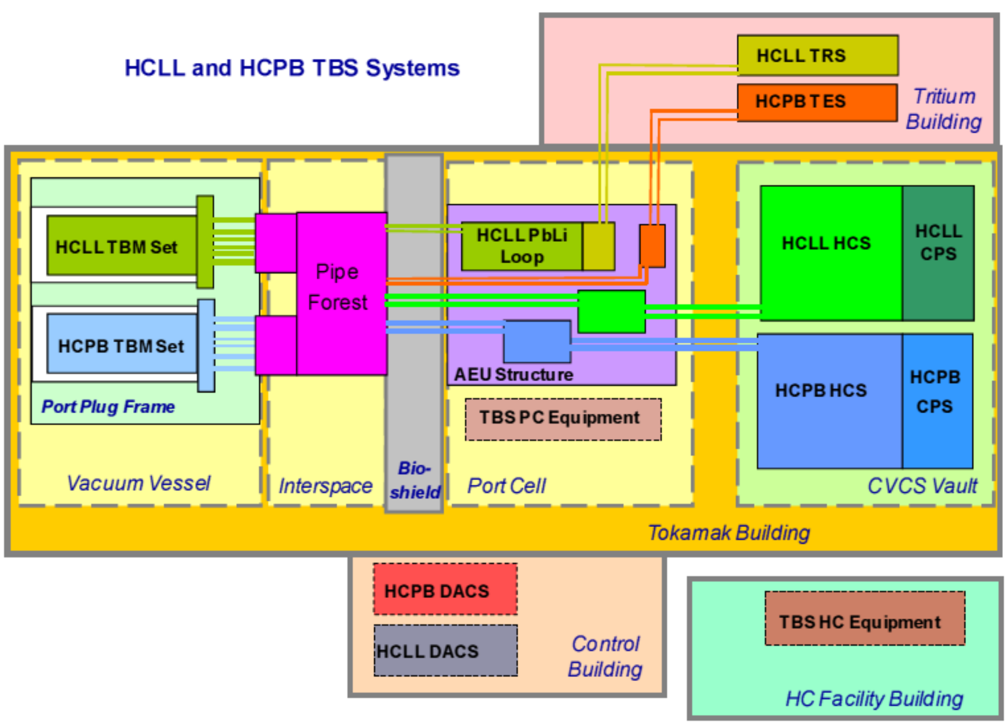
ITER TBM Port #16



ITER Vacuum Vessel:
- 18 Upper Ports
- 17 Equatorial Ports
- 9 Lower Ports







<u>HCLL TBM (Helium Cooled Lithium Lead):</u>

-LiPb Loop

-Helium Coolant System + Cooling Purification System

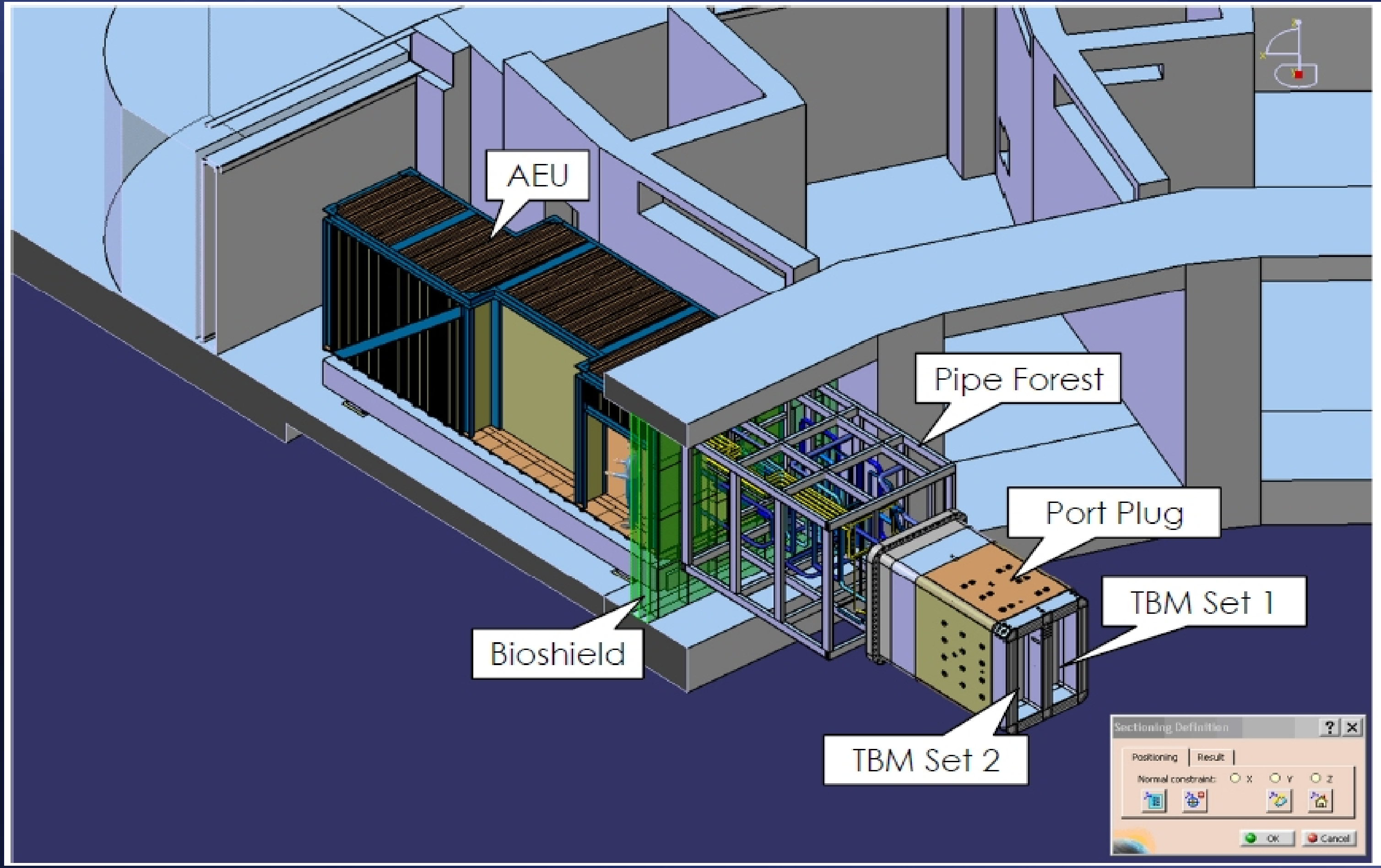
- Tritium Removal System

<u>HCPB TBM (Helium Cooled Pebble Bed):</u>

-Helium Coolant System + Cooling Purification System

-Tritium Extraction System

SHUTDOWN DOSE RATE IN THE ITER TBM Port #16



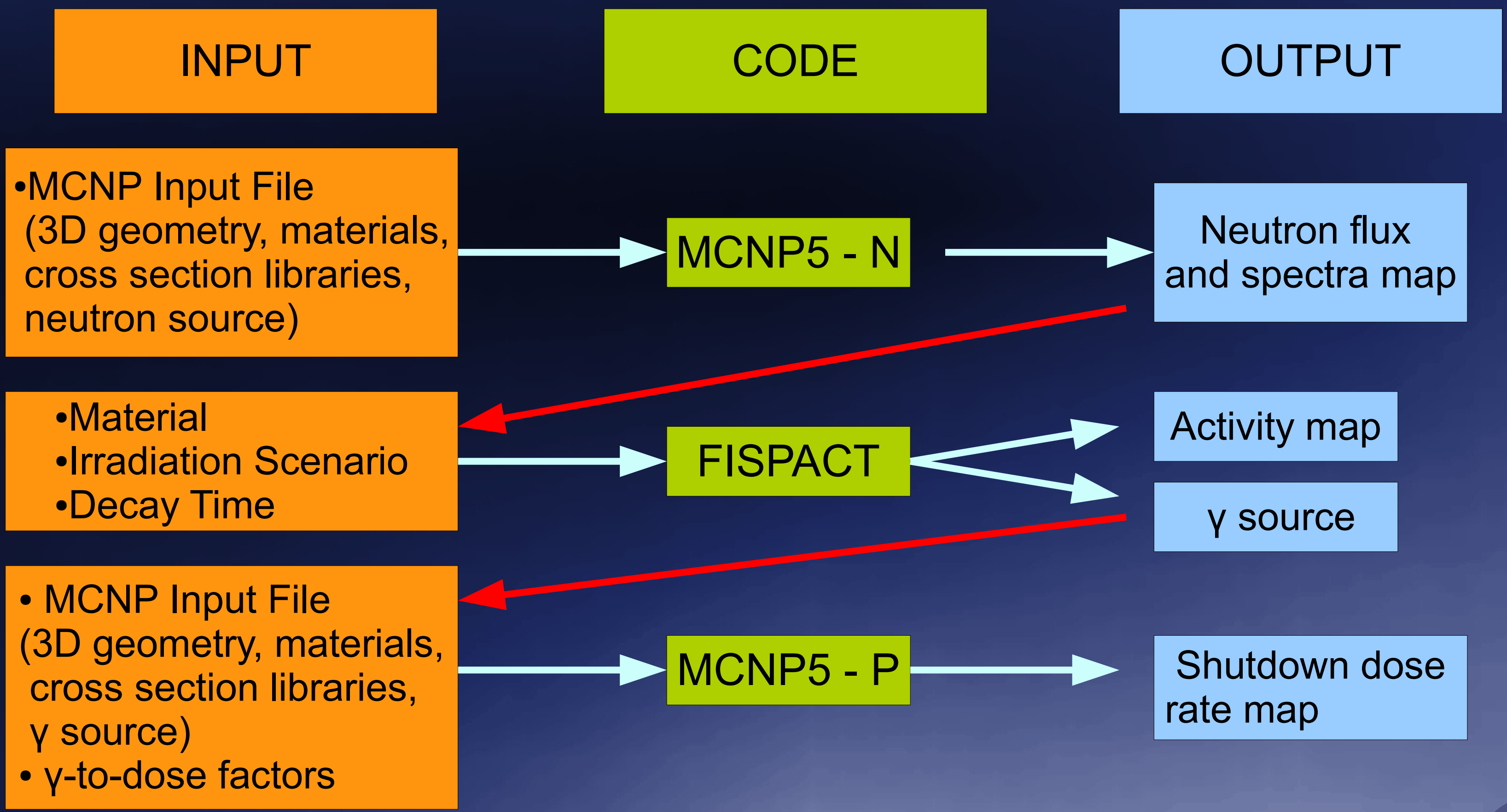
Nuclear Safety Authority limits:

- 100 μSv/h 10^6 s after the shutdown in the Pipe Forest Region [$\phi \sim 10^7$ n/(cm^{2}s)]
- 10 μSv/h 24h after the shutdown beyond the bioshield, where the l' Ancillary Equipment Unit (AEU) is located

DOSE RATE CALCULATION

MCR2S (Mesh Tally Coupled Rigorous 2 Steps) METHOD [1,2,3]:

- MCNP Transport Code
- IAEA Fusion Evaluated Nuclear Data Libraries (FENDL)
- FISPACT inventory CODE



[1]Y.Chen, U.Fischer, Fusion Engeneering and Design, 63,64 (2002), 107-114
[2]P. Pereslavtset, U. Fischer, Fusione Engeneering and Design (2013)
[3]A. Davis, R. Pumpin, Fusion Engeneering and Design, 85 (2010), 87-92

R2S (Rigorous 2 Steps) vs D1S (Direct 1 Step)

Direct 1 Step method[4] is based on the assumption that the decay gammas of the radioactive nuclides are promptly emitted. The neutrons and the decay gammas are transported in a single Monte Carlo simulation.

D1S

Cons:

Ad hoc libraries should be produced for the activation dose relevant nuclides, so an a priori decision has to be made.

Each set of libraries is suitable just for 1 cooling interval.

Pros:

Just one simulation is needed.

There are no approximations in the geometrical distribution of the gamma source.

MCR2S

Cons:

Discretization of the geometry into mesh voxels, treated separately.

A huge amount of voxels must be interfaced between MCNP and FISPACT.

The geometrical distribution OF THE activation gamma source is approximate.

Pros:

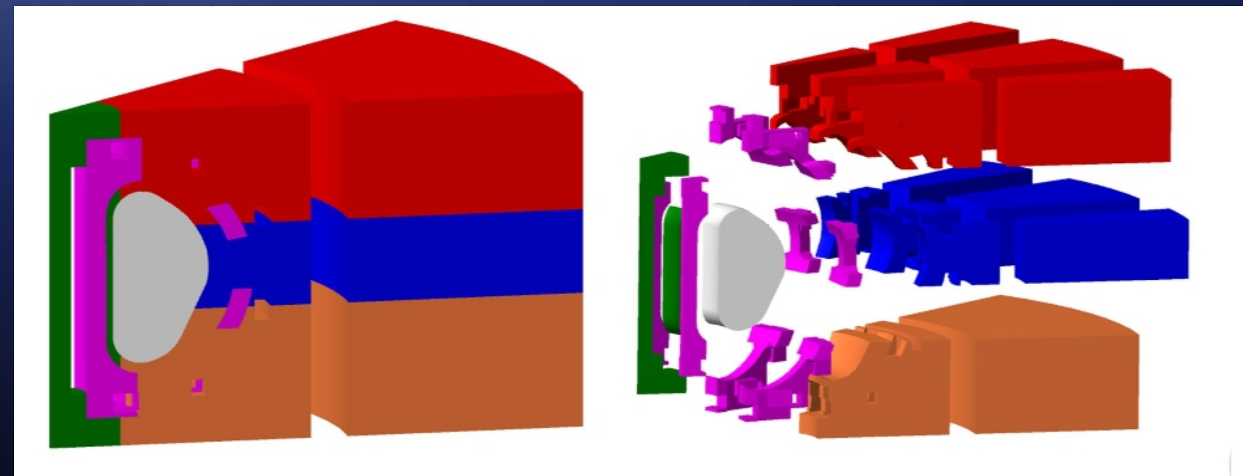
All the nuclides can be included in the calculation, to evaluate which are the important ones for the shutdown dose.

All the important cooling steps can be considered.

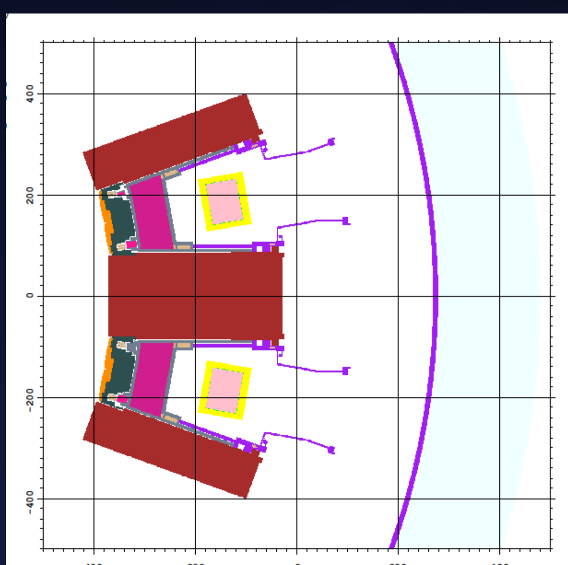
[1]R. Villari et al. Shutdown Dose Rate Benchmark to Validate 3D D1S Method, Proceeding of the 10th International Symposium of Fusion Nuclear Technology (Portland 2011)

ITER MCNP INPUT FILE: B-LITE

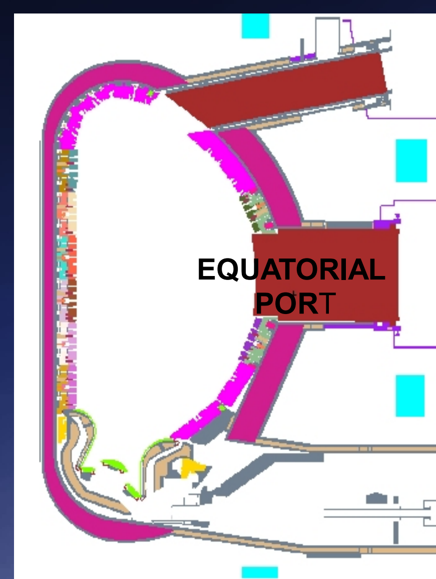
MCNP universes concept: the geometry is divided into levels or universe, according a matrioska concept. The outer level is just a box in which the more detailed inner one is located.



TOP VIEW



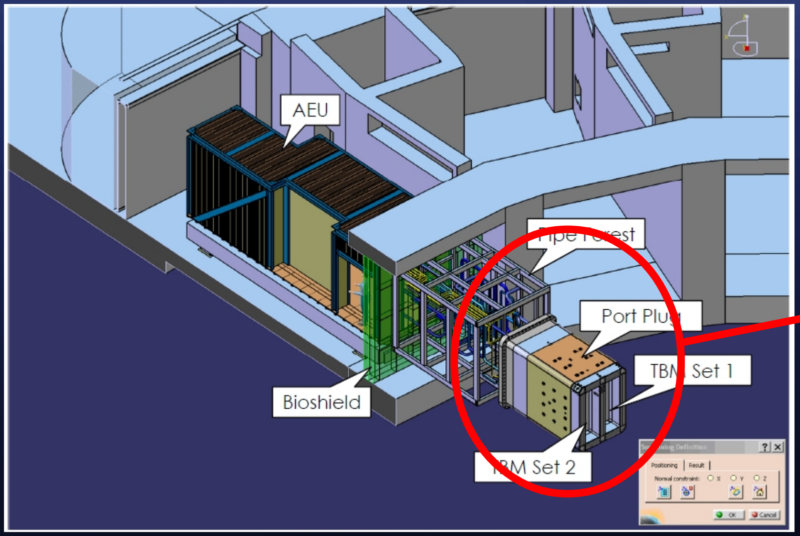
SIDE VIEW

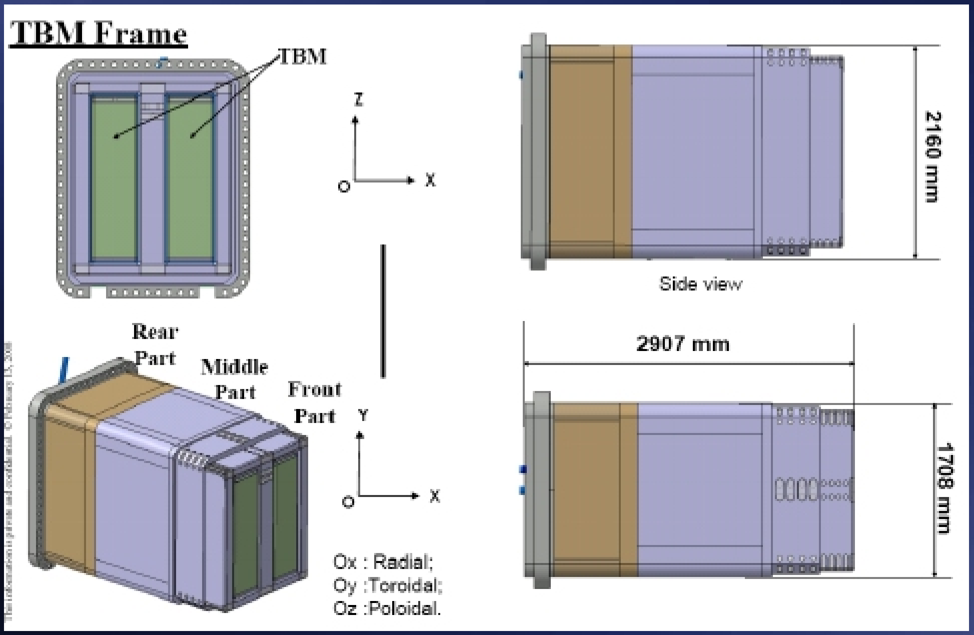


Main features of B-lite:
- describes a 40° section of ITER reactor, with reflecting boundary condition
- Uses MCNP universes
- Contains 21216 cells, 27920 surfaces, 26 materials
- Run 57 histories per second per core (10^9 histories take 24h using 250 cores)

TBM PORT #16 IN B-LITE

CATIA TECHNICAL DESIGN



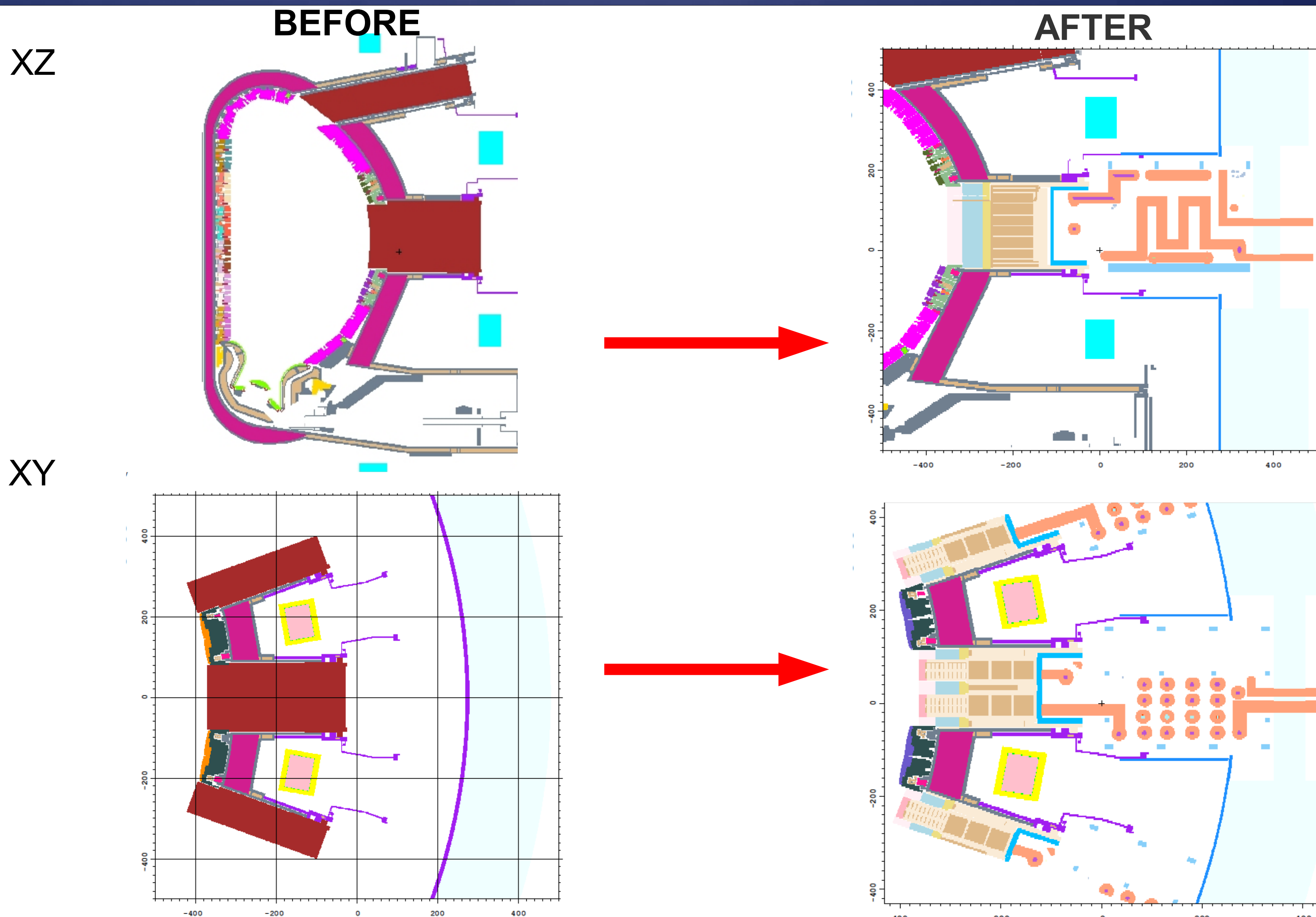


Recommended procedure to import the CATIA design in BLITE:

(1) Clean the CAD with Space Claim 2012 software to eliminate errors, coincident surfaces, gaps, hole, spline and complex shape in general.

(2) Convert the CAD file into MCNP geometry file with MCAM software (possibly splitting the draw into slices)

TBM PORT #16 IN B-LITE



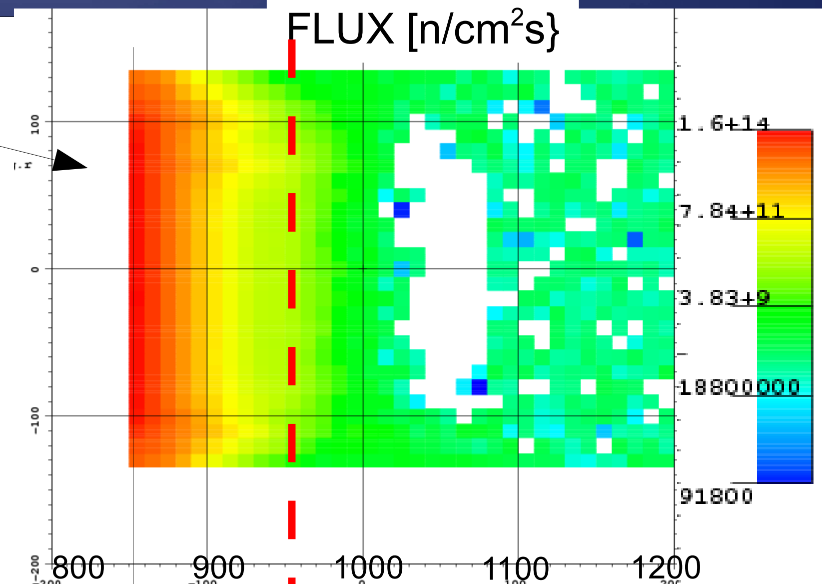
In collaboration with R. Villari (ENEA), M Laughlin (ITER IO) and E. Polunovskyi (ITER IO).

PRELIMINARY RESULTS: NEUTRON TRANSPORT

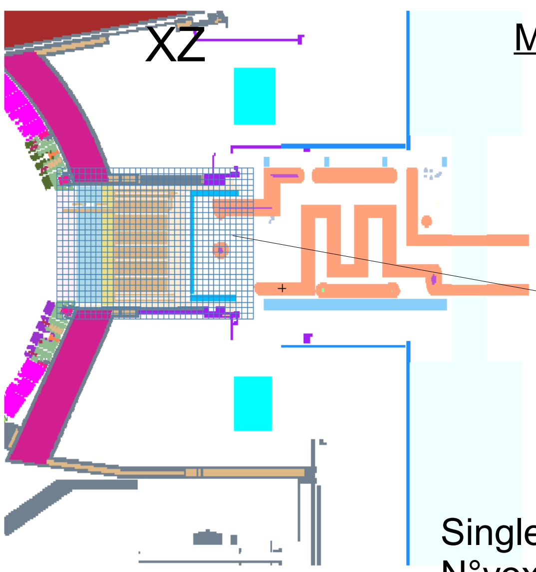
Preliminary results on INFN cluster:
- Parallel MCNP5 (6 core)
- N° history: 10^9
- Run time: 14 days

XZ

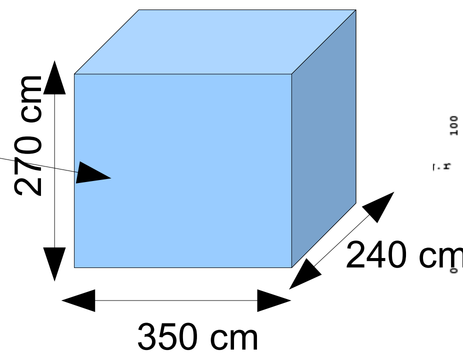
MESH TBM Port Plug



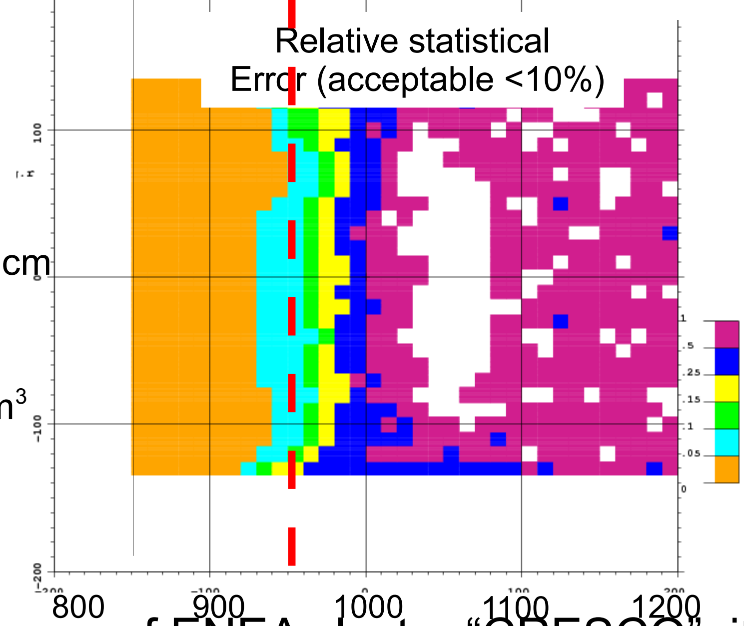
First wall:
$2\ 10^{14}$ n/cm²s
After 1 meter:
~ $5\ 10^9$ n/cm²s



Mesh TBM Plug region



Single Mesh voxel 10*10*10 cm³
N°voxel 35*24*27=22680



First wall:
Rel Err < 5 %
After 1 meter:
Rel Err ~10%

How to proceed:
- More powerful cluster: using all the 600 cores of ENEA cluster "CRESCO", it takes t=24h to run 10^{11} histories, still not sufficient.
- Variance Reduction Techniques

Conclusions

-The next generation tokamaks will produce more than 500 MW fusion power.

-The First Wall Facing Components (FCs) will undergo more than 10^{14} n/cm^{2}s neutron flux.

-The study of neutron activation of the FCs is one of the most relevant issues in the design approval phase

- INFN-E/MAFI goal: calculate the shutdown dose rate map in the ITER TBM Port #16 with the MCR2S method

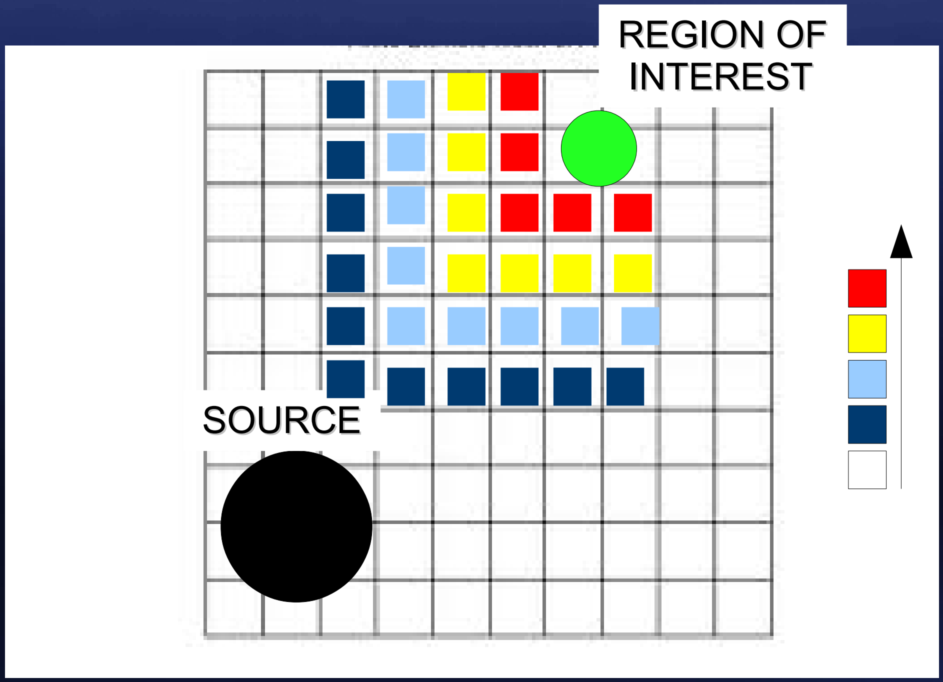
- Preliminary results have low statistics which has to be improved by Variance Reduction (VR) techniques (MCNP Weight Window).

- First test of VR on a simplified geometry shows that the necessary accuracy can be achieved also in B-LITE.

Thank you

VARIANCE REDUCTION TECHNIQUES

Weight Window



Contribution of the flux in the voxel to the flux in the region of interest

-According to the contribution to the flux in the region of interest, the flux in each voxel of the WW mesh is splitted or undergoes Russian Roulette.

-At least 1 particle should reach the region of interest.

-To optimize the WW production:

1. Multigroup Cross Sections
2. density rescaled
3. E(cut)>10^{-3}MeV