KERNTECHNIK 2022

Radiation Environment inside the IFMIF-DONES Target Interface Room

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KernD KTG

Radiation Environment inside the IFMIF-DONES Target Interface Room

EUROfusion

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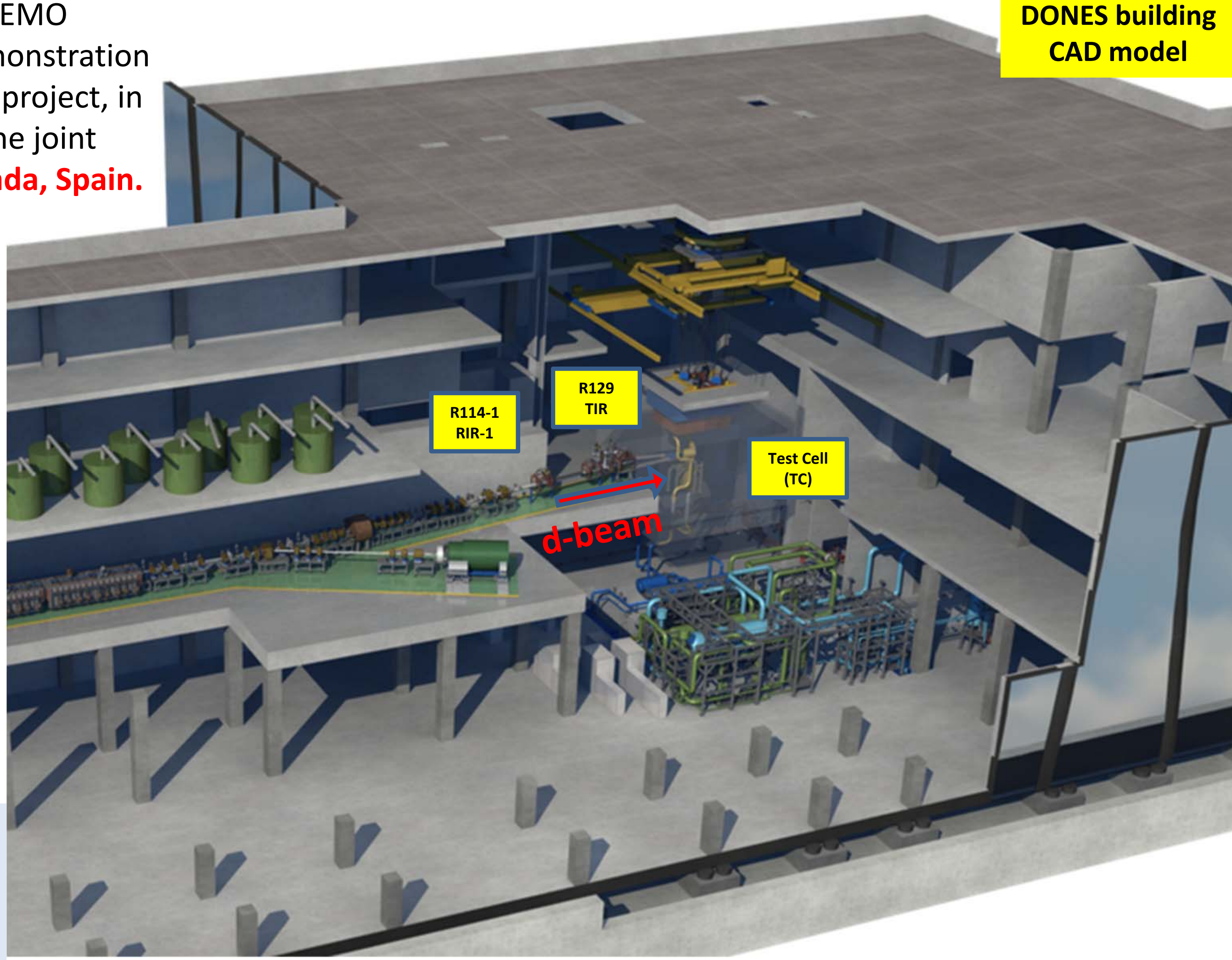
Intro - EU DONES Working group, DONES facility

The International Fusion Materials Irradiation Facility – DEMO Oriented NEutron Source (IFMIF-DONES). DEMO is a demonstration fusion reactor prototype. In relation to this international project, in Dec. 2017, Fusion for Energy (F4E) evaluated positively the joint Spain-Croatia proposal **to site the IFMIF-DONES in Granada, Spain.**

DONES building CAD model



DONES Working Group	
Country	Comments
Hungary	
Croatia	
Italy	
Spain	
Germany	
Slovenia	
Denmark	
Greece	
Finland	
Sweden	
Lithuania	
Estonia	
France	
F4E	Support
EUROfusion	Observer
DG-ENER	Lead
DG-RTD	Observer

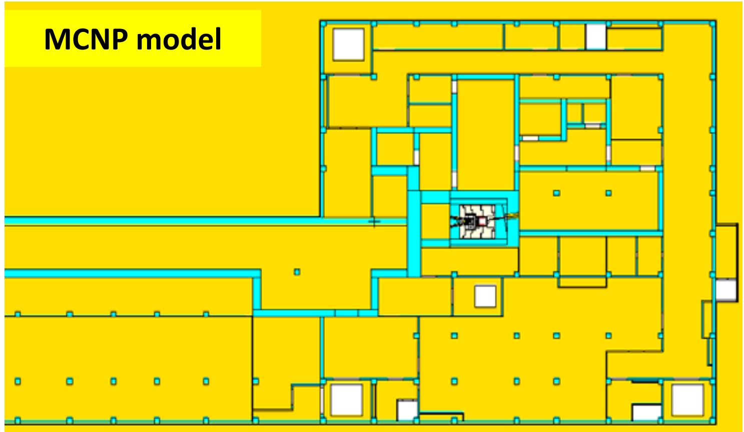
EURATOM (DG-ENER) organized a Working Group with Spain, Croatia and other interested EU countries and with the support of F4E to define an implementation scenario for the start of the IFMIF-DONES project, governance, possible sharing and international collaborations.

Updates of the IFMIF-DONES: https://ifmif-dones.es/

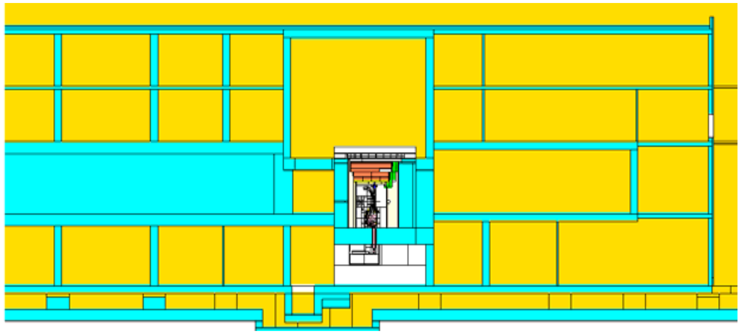
Conclusions and recomendations show general agreement that it is the rigth moment to start the construction phase of the DONES Program

IFMIF-DONES geometry CAD-to-MCNP conversion

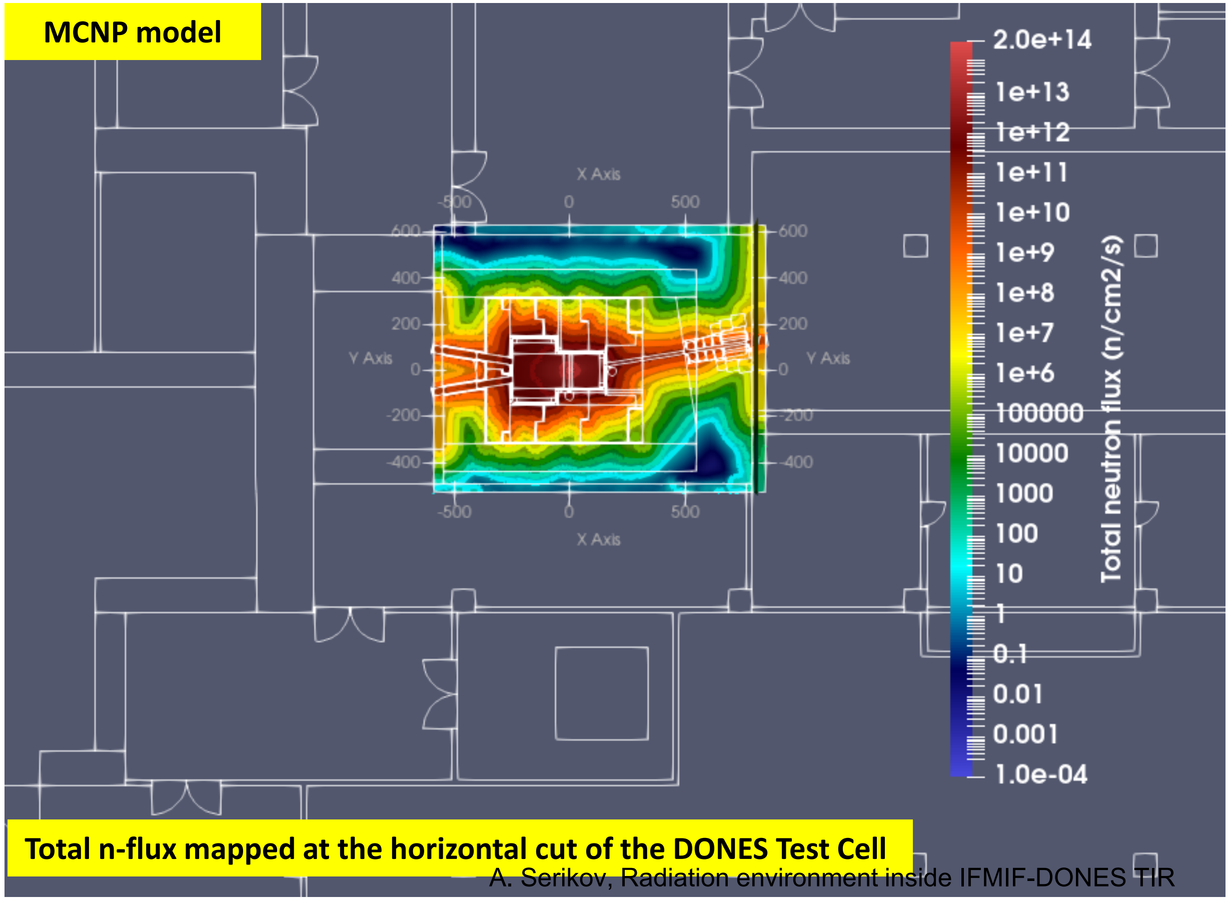
- The CAD model of IFMIF-DONES building is properly prepared to be used with the MCNP code. The geometry of each component of the building was simplified and decomposed into a number of simple primitive blocks. Then the CAD model is converted into MCNP model and fill into the separate envelope using the MCNP universe card. The CAD-to-MCNP conversion is performed using **McCad and SuperMC programs.**



DONES building model horizontal cut at the beam level.



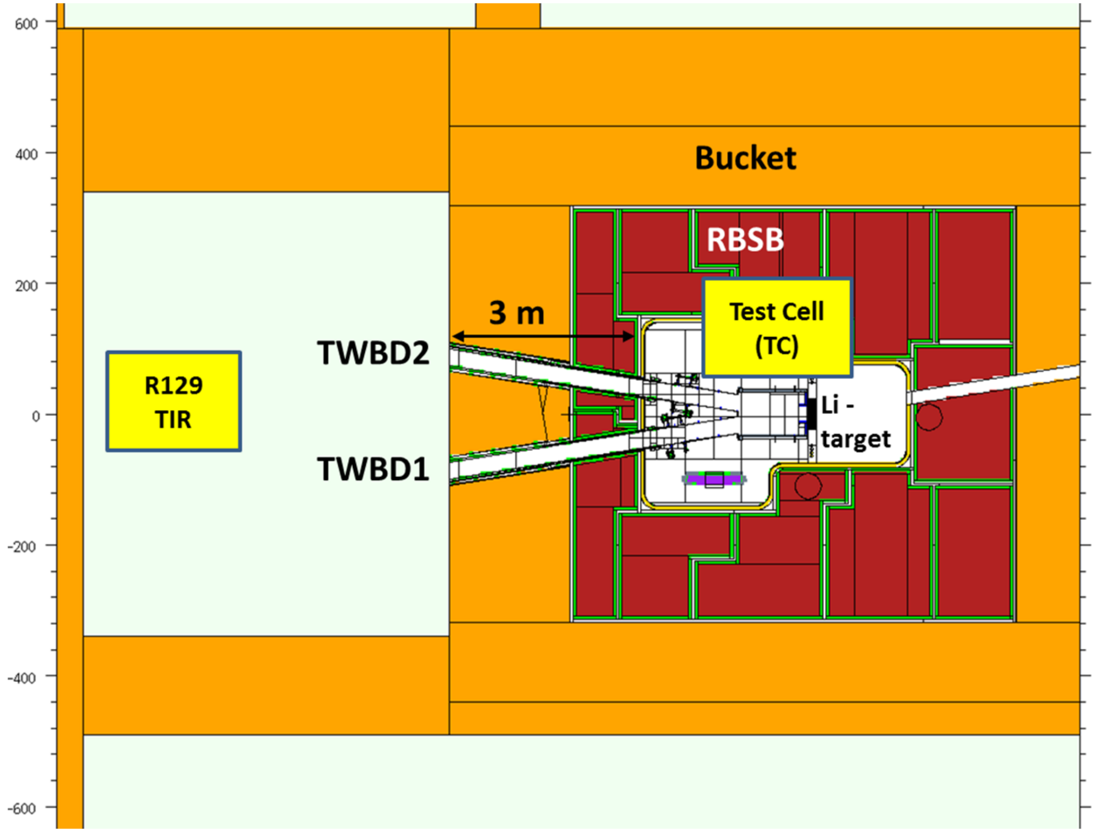
DONES building model vertical cut at the target center



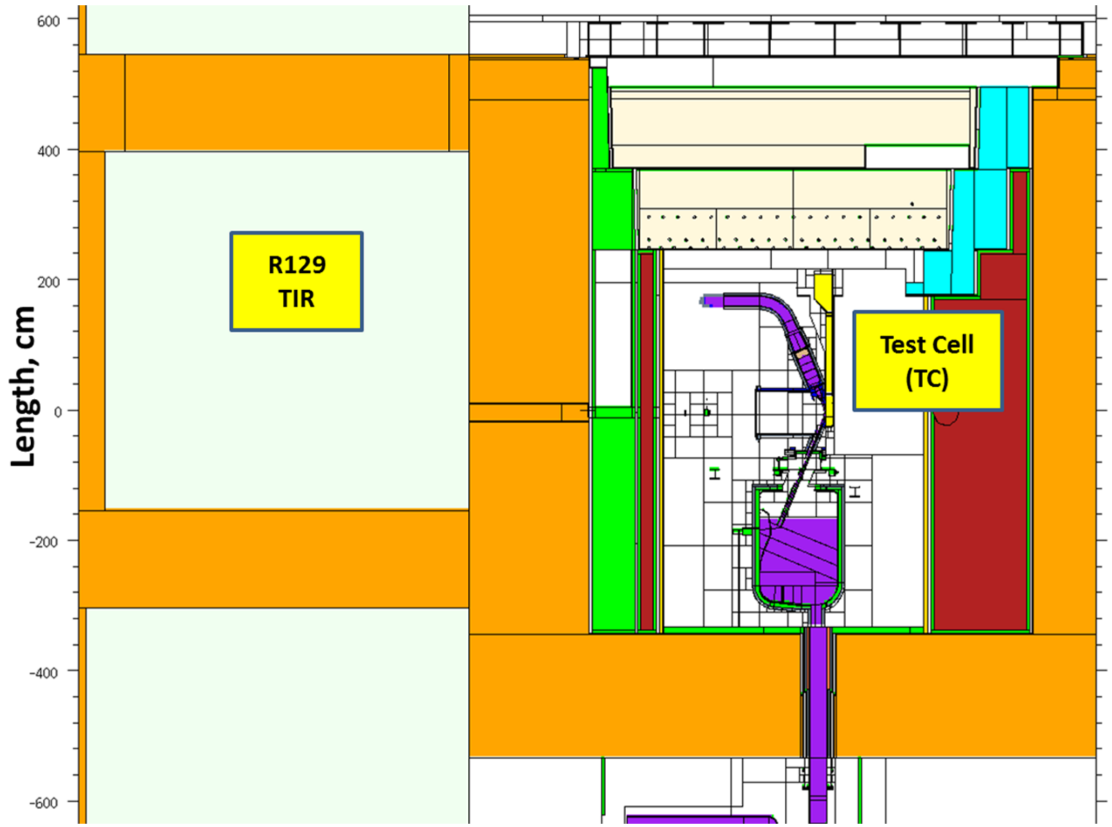
Total n-flux mapped at the horizontal cut of the DONES Test Cell

Neutronics modeling of the IFMIF-DONES

The neutron and photon radiation transport was performed by the **McDeLicious** code package – an **MCNP** source extension that simulates the deuteron-lithium (d-Li) nuclear reactions in Li of Test Cell. The neutron cross-sections library FENDL-3.1d used in calculations. The neutronics results were normalized to a 125 mA deuteron beam of 40 MeV deuterons impinging the Li target.

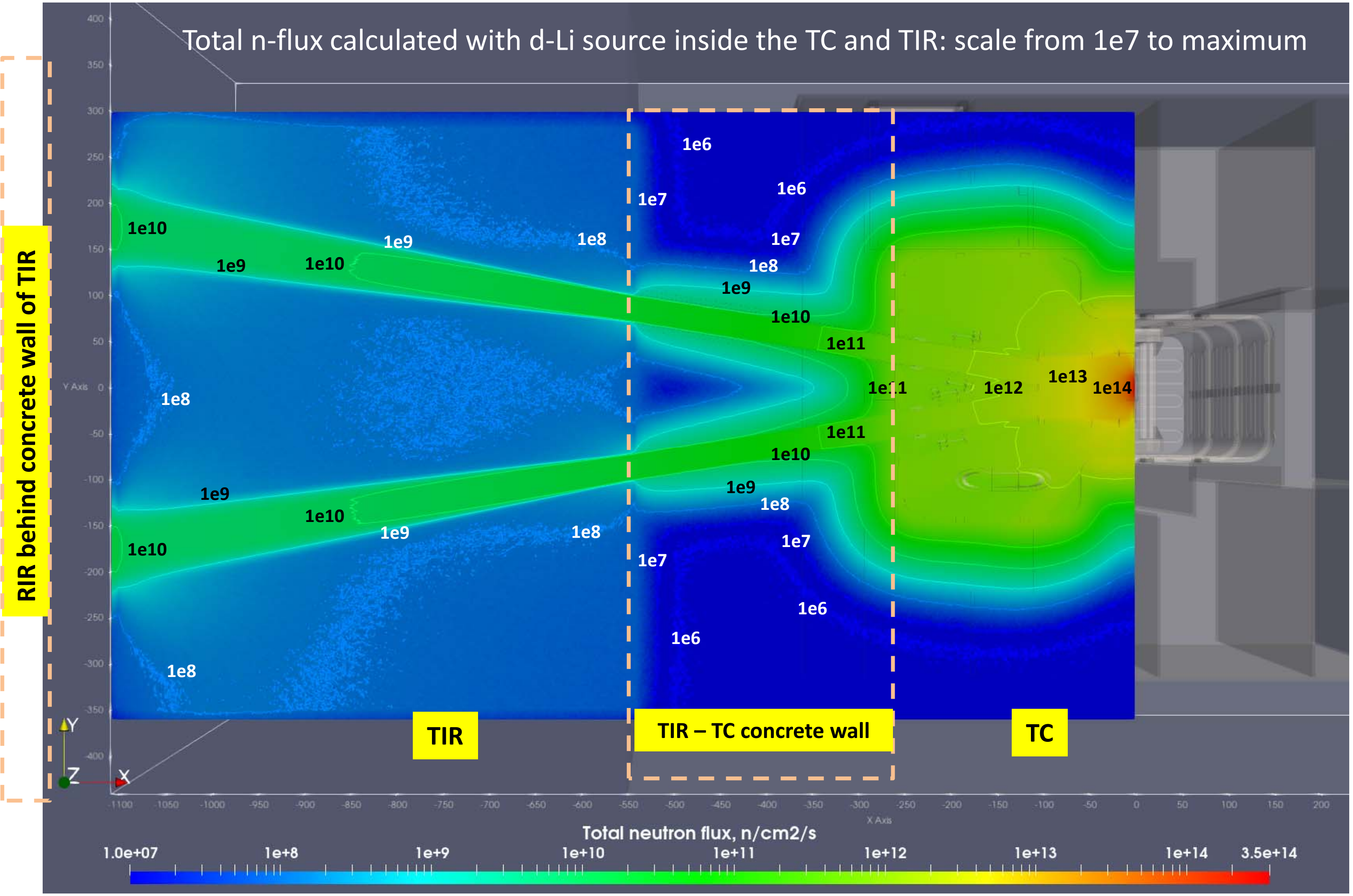


MCNP model horizontal cut at the center of the Li target and two TWBD beam ducts.



MCNP model vertical cut throught the center of the Li target. The spacial dimension of the model is given in the length scale [cm].

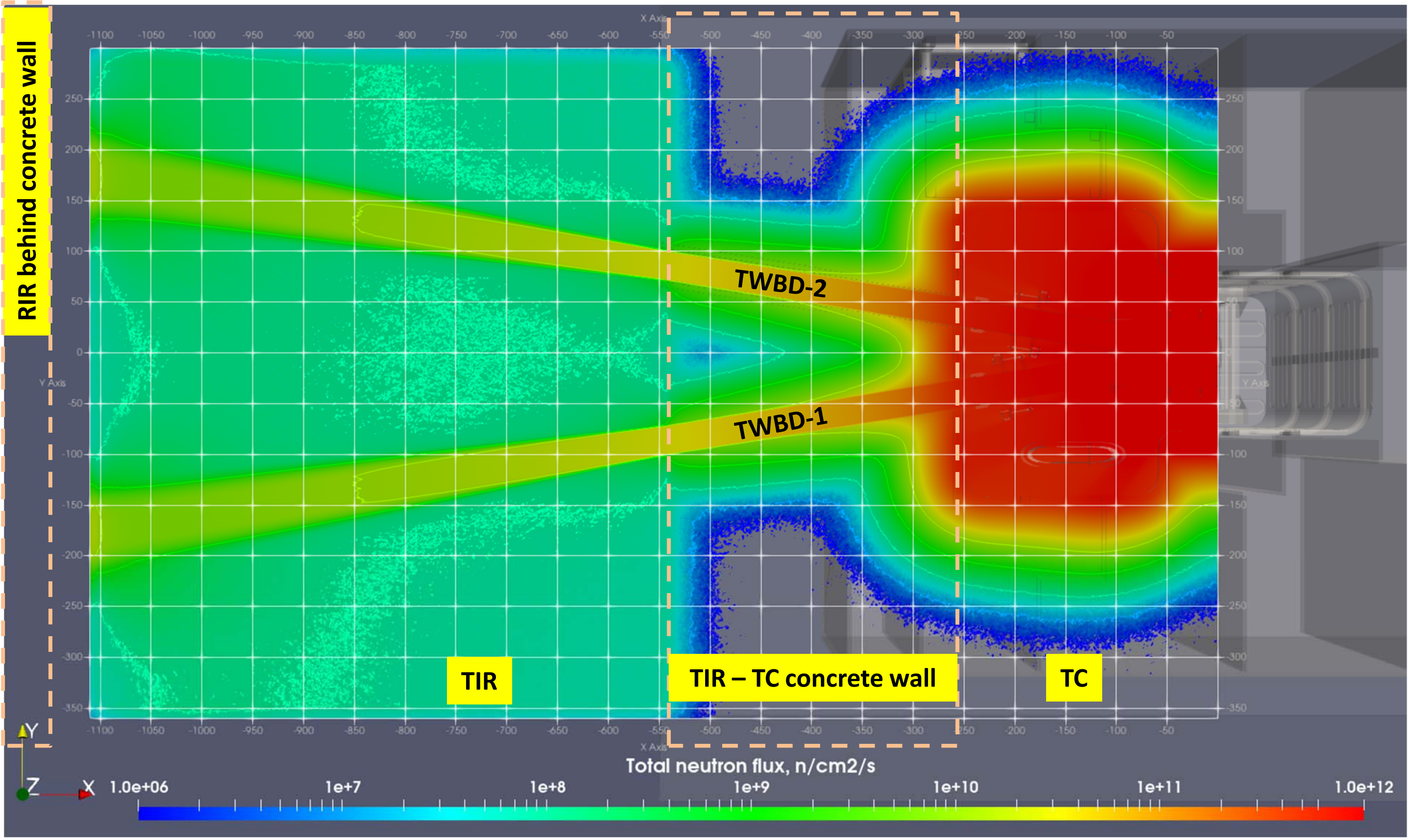
Total n-flux distribution in TC and empty TIR



A. Serikov, Radiation environment inside IFMIF-DONES TIR

Total n-flux distribution in TC and empty TIR thresholded scale

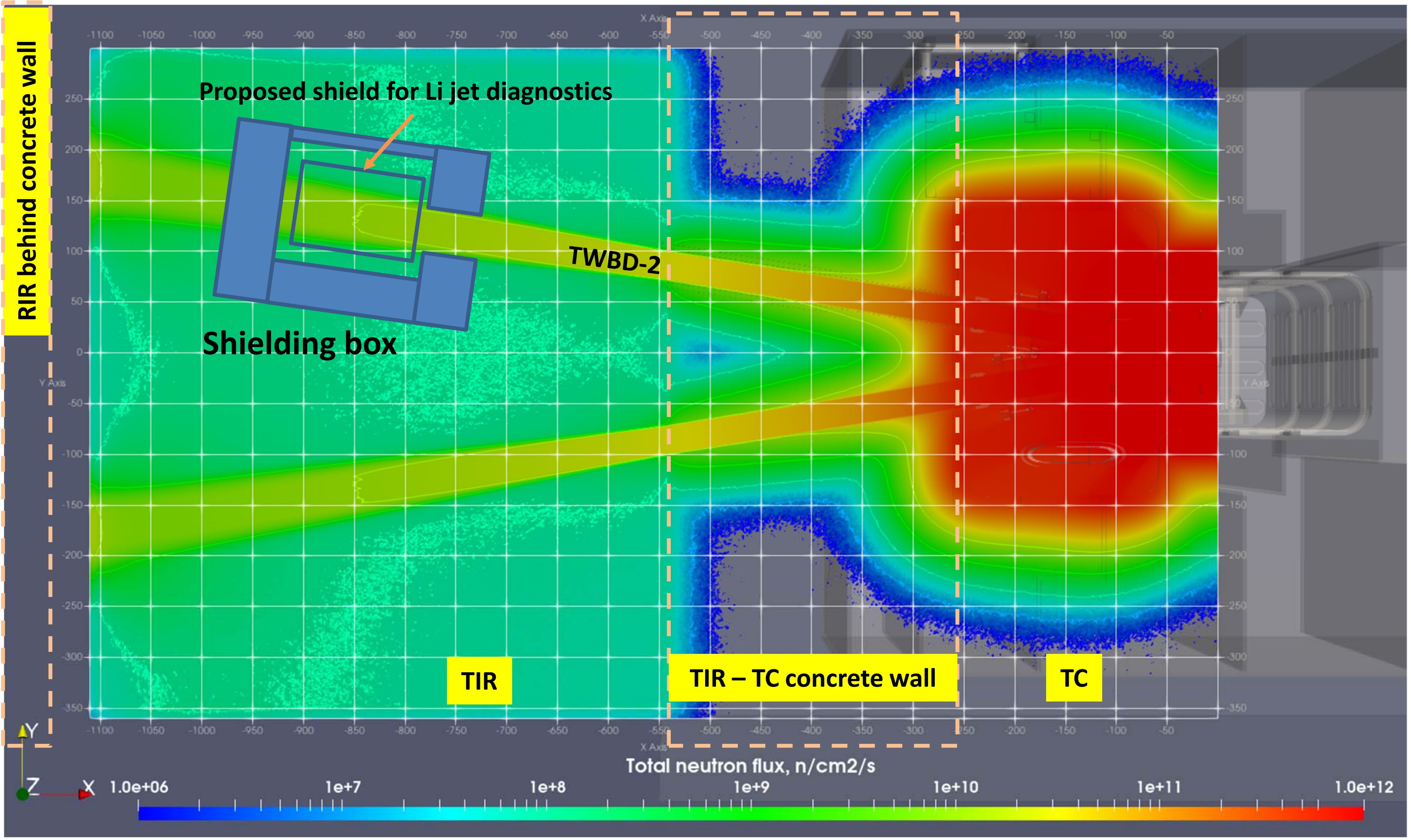
Total n-flux calculated with d-Li source on scale from 1e6 to 1e12, with flux threshold at 1e6 n/cm2/s



A. Serikov, Radiation environment inside IFMIF-DONES TIR

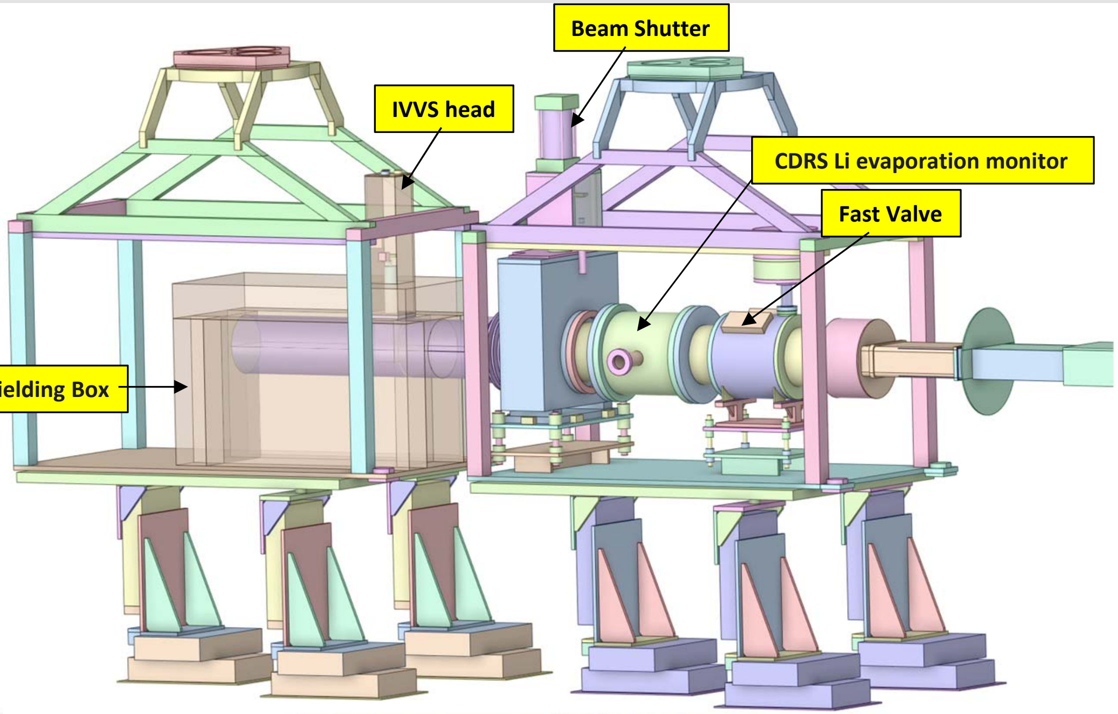
Total n-flux distribution in TC and TIR – proposed shielding box

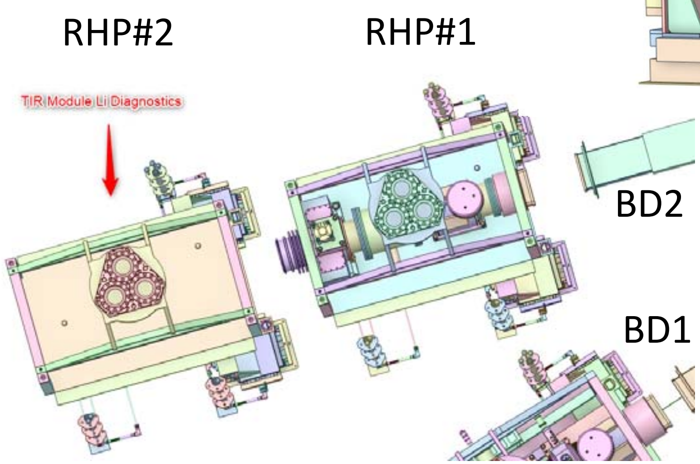
Total n-flux calculated with d-Li source on scale from 1e6 to 1e12, with flux threshold at 1e6 n/cm2/s

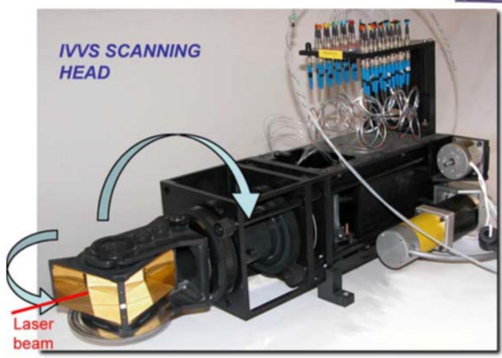


Installation of the IVVS head and Shielding Box on the Remote Handling Platform #2 (RHP#2) at BD2

Installation of the IVVS head and Shielding Box on the RH Platform#2 (RHP#2) at the secondary Beam Duct (BD2)







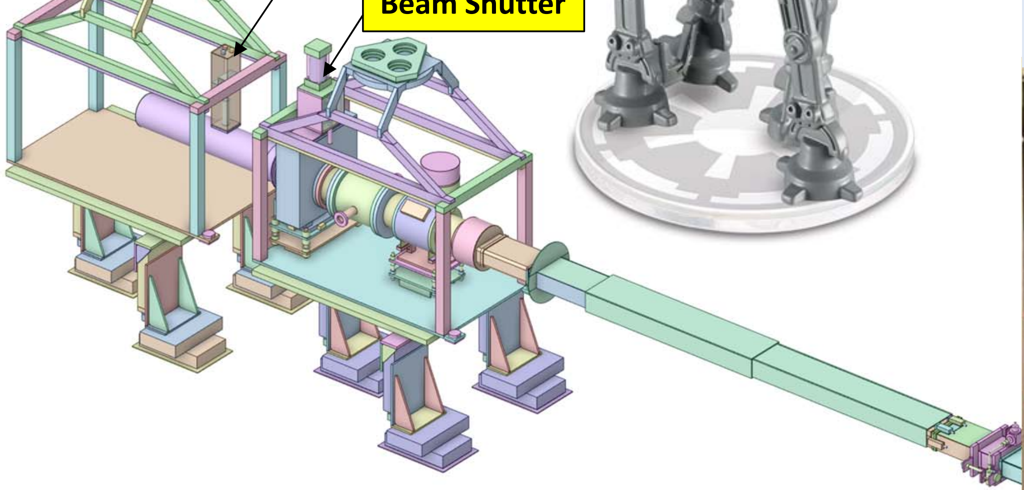
[Ref. 1] authors from ENEA worked on IVVS prototype under F4E grant for ITER.

Björn Brenneis from KIT will conduct experiments with IVVS at F4E next year for DONES.

[Ref.1] C. Neri, et al., "ITER in vessel viewing system design and assessment activities", Fusion Engineering and Design, 86 (2011) 1954–1957.

What reminds you the view of RHP#2 with IVVS? - Imperial AT-ACT Cargo Walker – from Star Wars Rogue One

The **All Terrain Armored Cargo Transport** (**AT-ACT**) was a larger version of the standard All Terrain Armored Transport combat walker that featured a dedicated cargo bed for the transportation of heavy building materials or combat munitions.



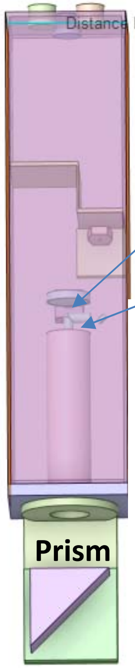
Remote Handling Platform #2 (RHP#2) with IVVS installed at the secondary Beam Duct (BD2)

VS.

Imperial AT-ACT Cargo Walker

In-Vessel Viewing System (IVVS) for Li jet diagnostics

IVVS optical head of the Li jet diagnostics to be installed in the second beam duct



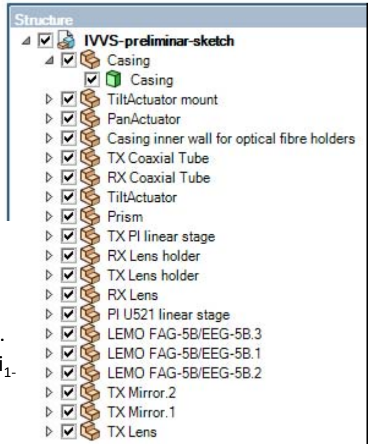
IVVS optical head

Lenses

Mirrors

IVVS optical head materials:

Silica: (Lenses, Mirrors, Prism) 2.32 g/cc; 66.67% at O, 33.33% at Si.
Lead Zirconate Titanate: ($Pb[Zr_xTi_{1-x}]O_3$) (Both actuators and linear stages) Density 7.75 g/cc; O 60% at, Pb 20% at, Zr 10.4% at, Ti 9.6% at.
SS316L: Rest of the IVVS components, Density 7.9 g/cc.



Description: material, function	Total (n+p) nuclear heat density, [W/cc]	Photon (p) absorbed dose rate [Gy/FPY]	Neutron (n) absorbed dose rate [Gy/FPY]	Total (n+p) absorbed dose rate [Gy/FPY]
Silica (SiO2) - Prism	8.35E-05	6.14E+05	5.21E+05	1.13E+06
Silica (SiO2) - Lens	6.75E-07	4.98E+03	4.20E+03	9.18E+03
Silica (SiO2) - Mirror	6.88E-07	5.41E+03	3.94E+03	9.35E+03
Silica (SiO2) - Lens	5.61E-07	4.54E+03	3.08E+03	7.62E+03
Silica (SiO2) - Mirror	7.04E-07	5.26E+03	4.31E+03	9.57E+03
Steel SS316L - back-end of the Diag. tube	1.56E-04	5.41E+05	7.73E+04	6.19E+05
Lead_zirconate_titanate - Tilt actuator	1.32E-04	4.55E+05	8.41E+04	5.39E+05
Steel SS316L - Tilt Actuator mount	8.68E-05	2.85E+05	6.01E+04	3.45E+05
Steel SS316L - Diag. tube	3.92E-05	1.31E+05	2.47E+04	1.56E+05

The gamma irradiation test of the IVVS actuating components reached a total dose of 4.88 MGy, without any evident and significant damages and degradation of the piezo-motor functionality – see [**Ref.2]**:

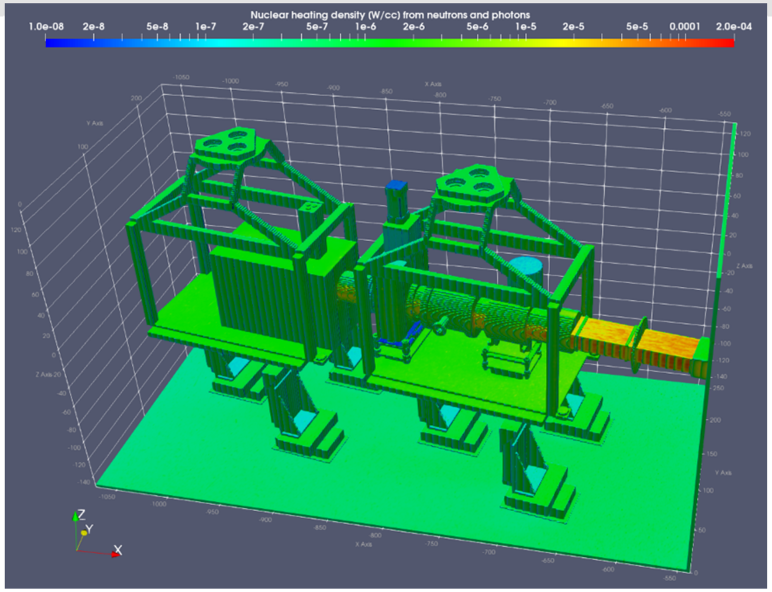
[Ref. 2] P. Rossi et al., "IVVS actuating system compatibility test to ITER gamma radiation conditions," Fusion Engineering and Design, 88 (2013) 2084 – 2087.

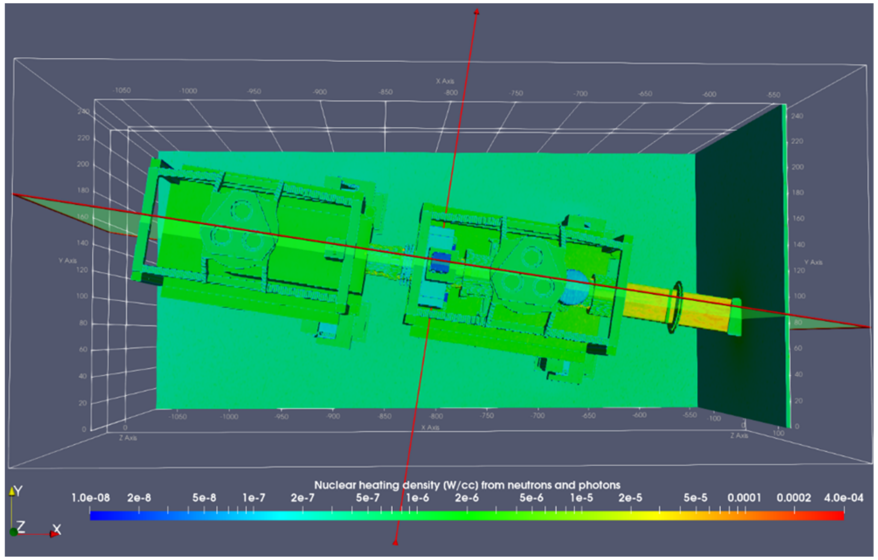
The IVVS will withstand very severe radiation environment conditions [Ref.1]:

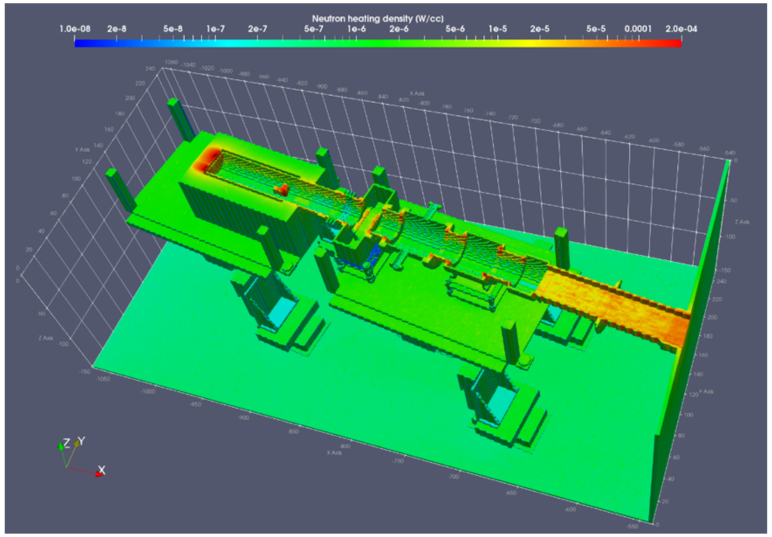
- Operating temperature $\leq 120\,^\circ C$; baking temperature $240\,^\circ C$.
- Environmental radiation dose rate up to 5 kGy/h (gamma rays).
- Total dose: up to 10 MGy (gamma rays) and total neutron up to $5 \times 10^{13}\ n/cm^2$.

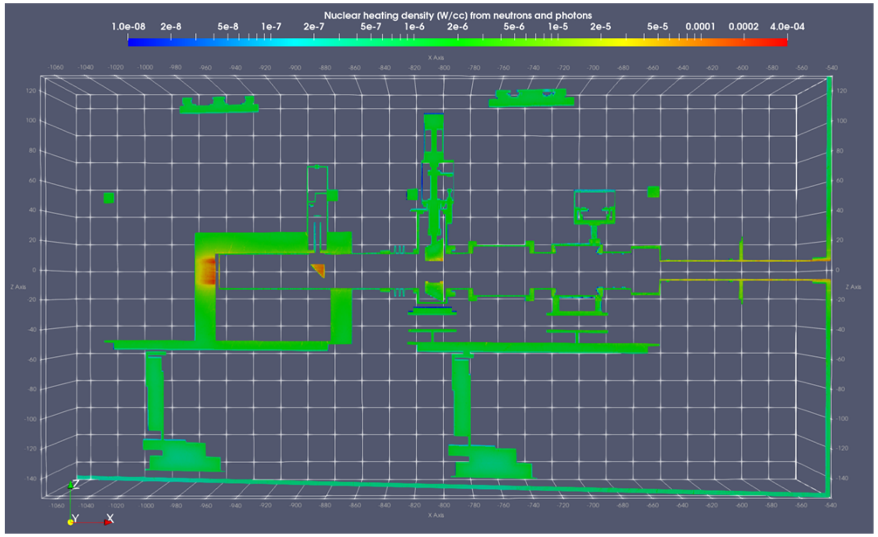
[Ref.1] C. Neri, et al., "ITER in vessel viewing system design and assessment activities", Fusion Engineering and Design, 86 (2011) 1954–1957.

Total (n+p) values of nuclear heat density in fine mesh (x=0.5, y=1, z=1) cm^3

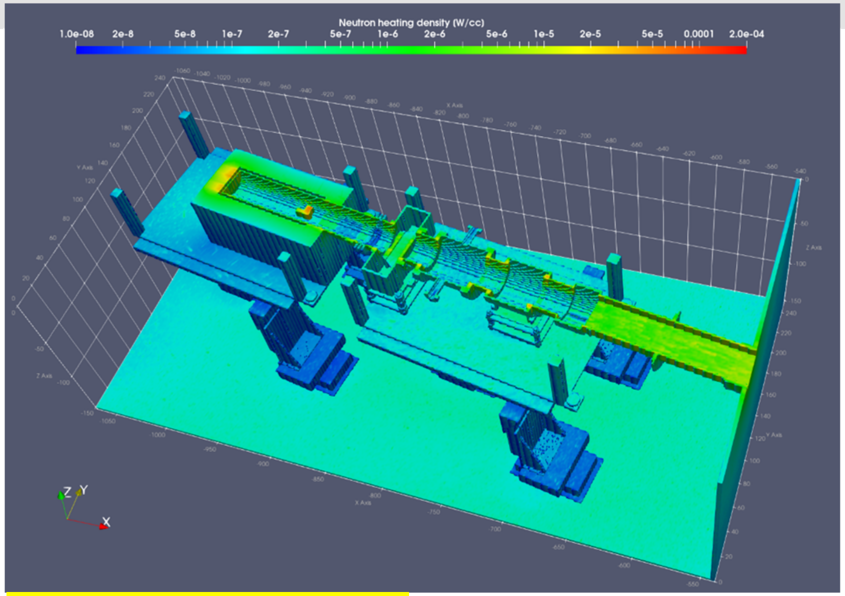




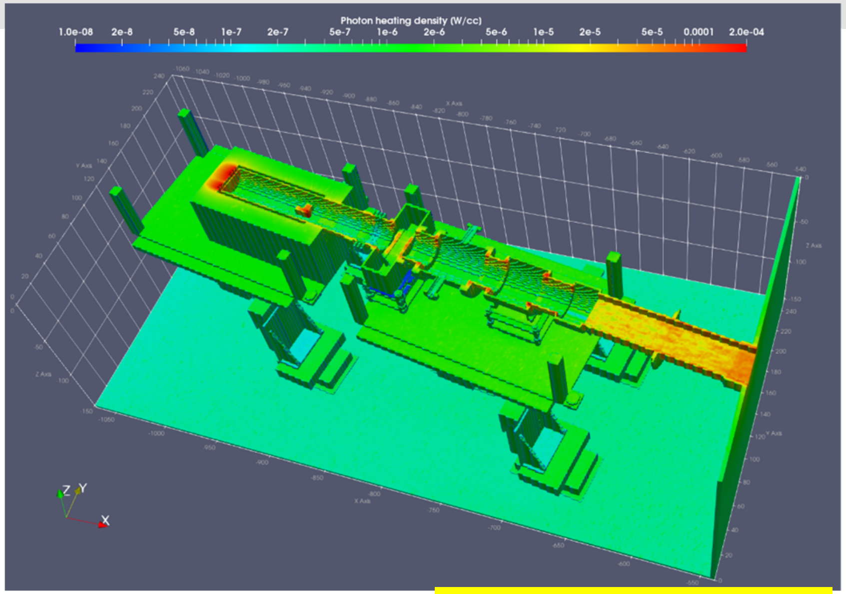




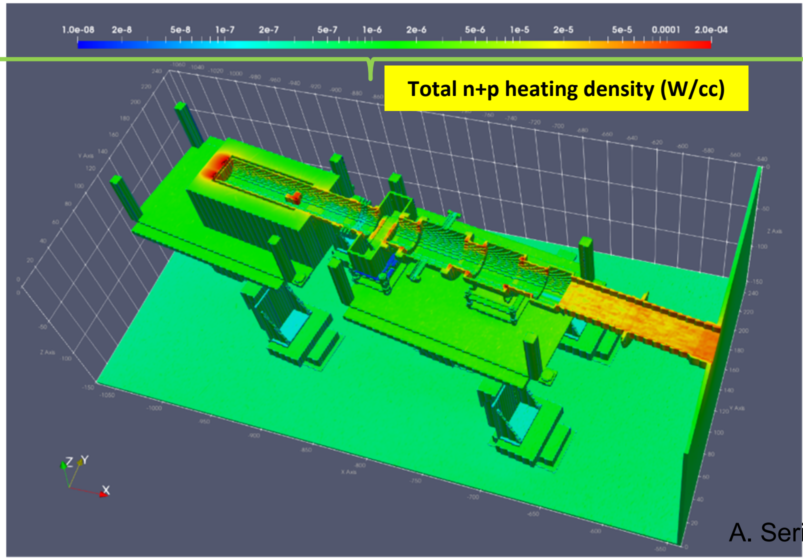
Neutron and photon heating contributors to nuclear heat density (W/cc)



Neutron heating density (W/cc)



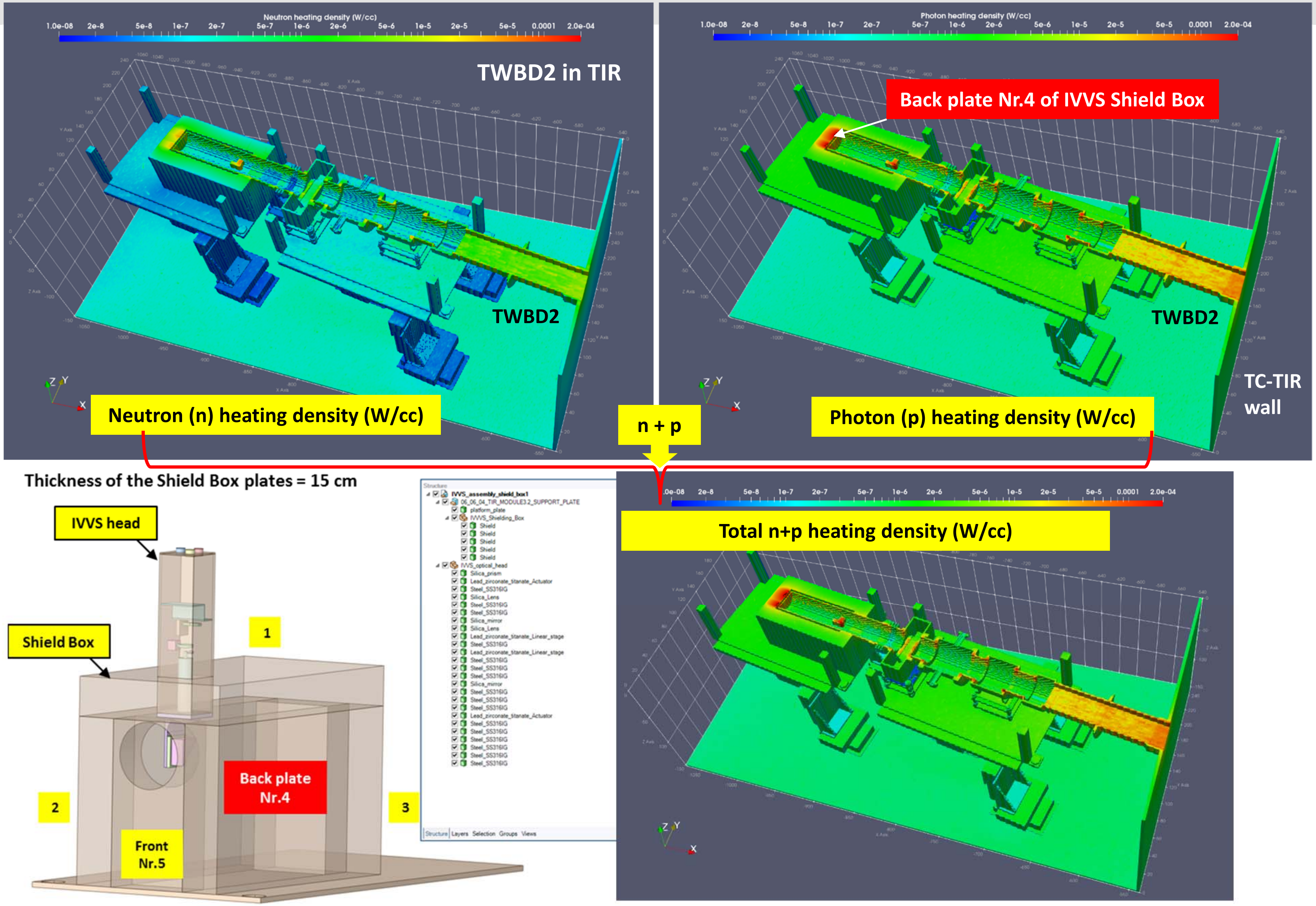
Photon heating density (W/cc)



Total n+p heating density (W/cc)

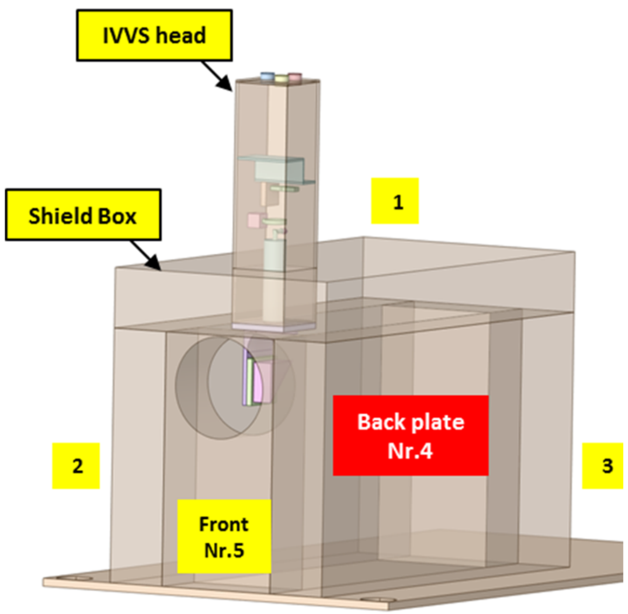
A. Serikov, Radiation environment inside IFMIF-DONES TIR

Neutron and photon heating contributors to nuclear heat density (W/cc)



Nuclear heating [W] in steel plates of IVVS Diagnostics Shield Box at the end of TWBD2

Thickness of the Shield Box plates = 15 cm



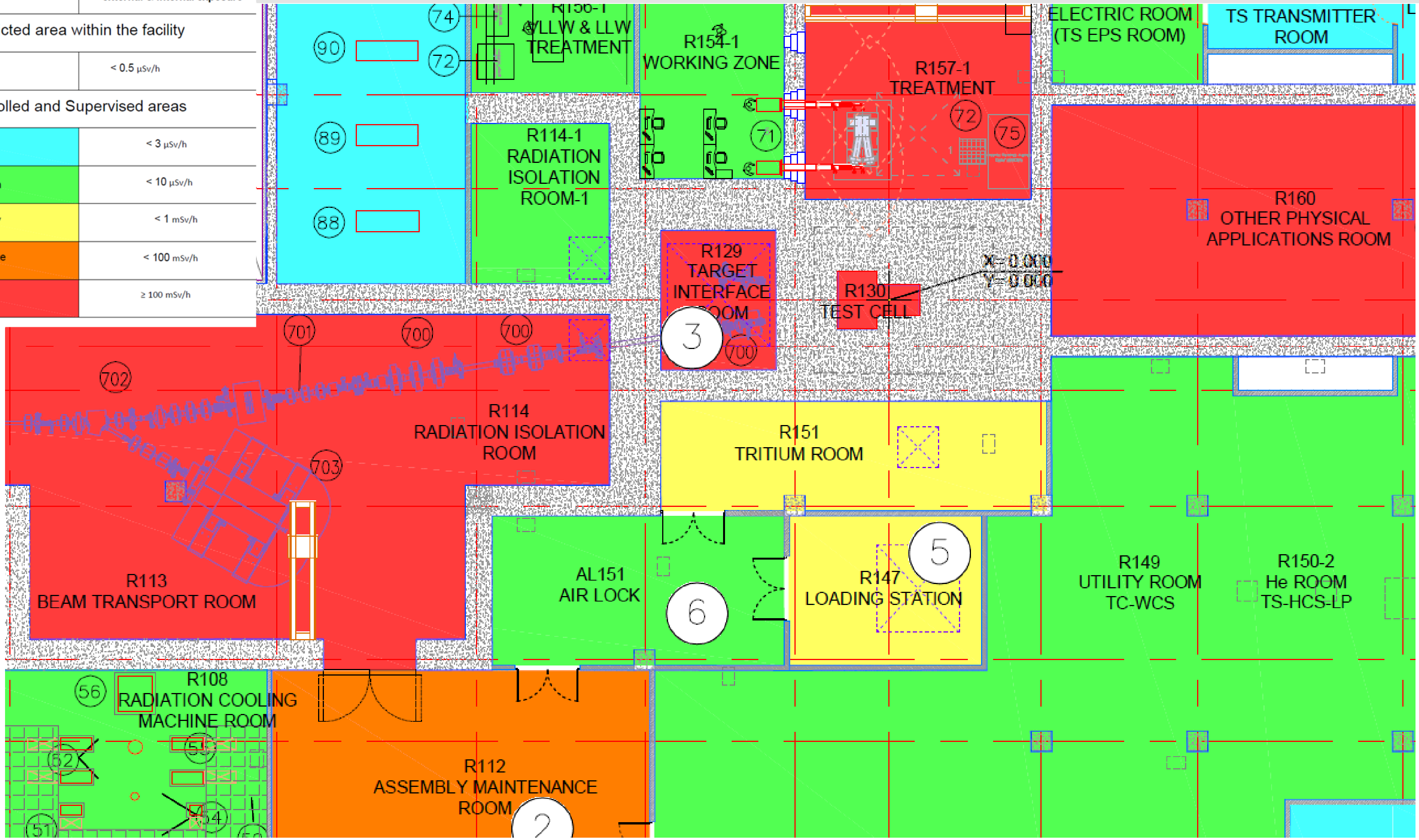
Shield Plate Nr.	Volume [cc]	Plate side in Shield Box. Plate thickness = 15 cm	Photon heat [W]	Neutron heat [W]	Total (neutron+photon) nuclear heat, [W]
1	1.03E+05	Upper plate of shield box (steel SS316L)	1.94E-01	3.12E-02	2.25E-01
2	1.09E+05	Left plate of shield box (steel SS316L)	2.16E-01	3.38E-02	2.50E-01
3	1.09E+05	Right plate of shield box (steel SS316L)	2.09E-01	3.30E-02	2.42E-01
4	2.95E+04	Back plate of shield box (steel SS316L)	5.56E-01	1.02E-01	6.58E-01
5	2.20E+04	Front plate of shield box (steel SS316L)	5.51E-02	9.13E-03	6.42E-02
Total:	3.73E+05	Integral heating for Shield Box	1.23E+00	2.09E-01	1.44E+00

Radiation Zoning according to DONES Preliminary Safety Analysis Report and [EFDA_D_2MMRME]

IRRADIATION AREA CLASSIFICATION

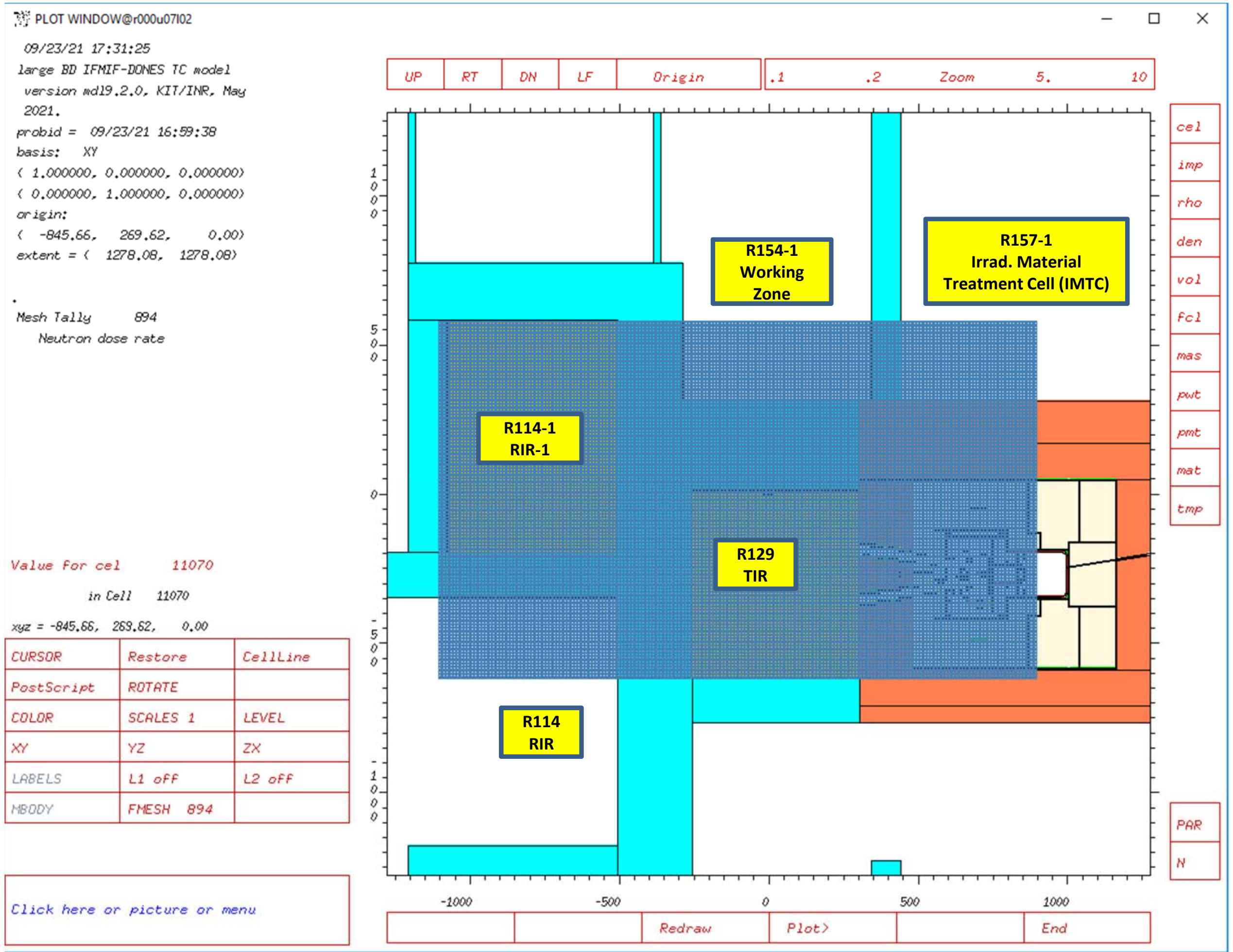
Area		Colour	Total dose rate Effective dose rate external & internal exposure
Unrestricted area within the facility			
Unrestricted area		White	< 0.5 μSv/h
Controlled and Supervised areas			
Supervised area		Blue	< 3 μSv/h
Controlled area	Free Permanenced	Green	< 10 μSv/h
	Limited Regulated	Yellow	< 1 mSv/h
	Specially Regulated	Orange	< 100 mSv/h
	Forbiden	Red	≥ 100 mSv/h

FIRST FLOOR
PLAN VIEW
EL +9.000



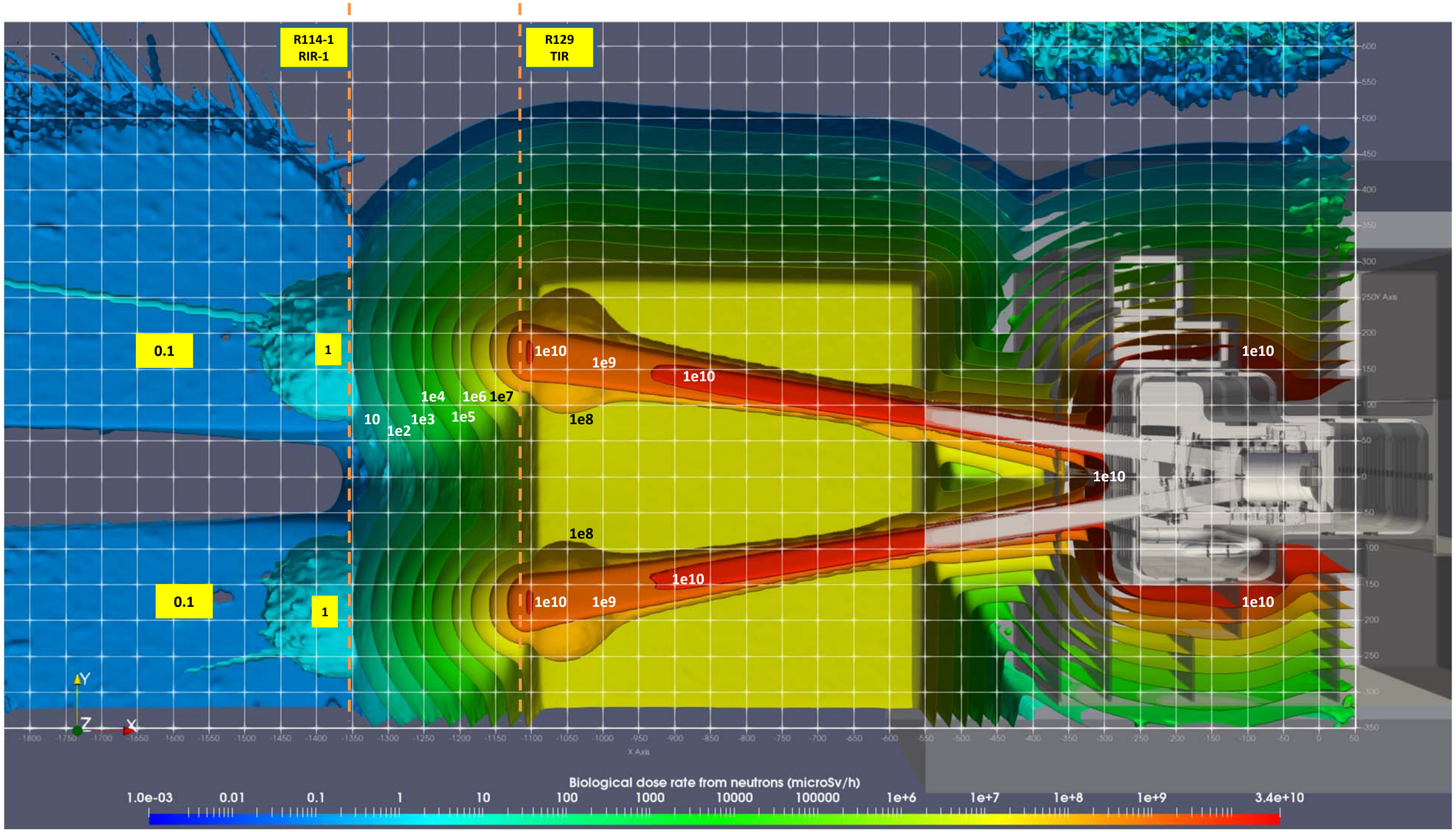
A. Serikov, Radiation environment inside IFMIF-DONES TIR

MCNP model mesh-tally for TIR and adjacent rooms

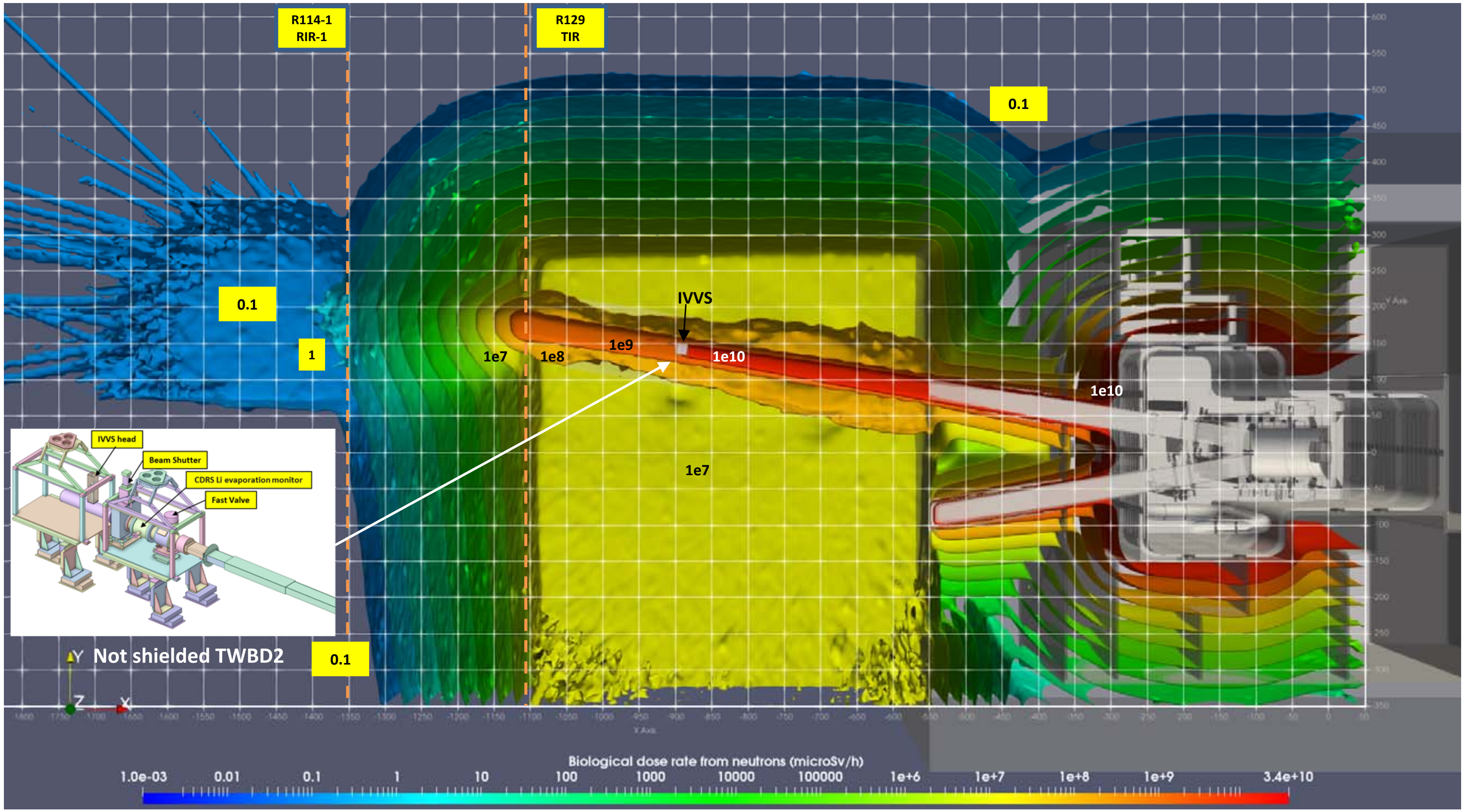


A. Serikov, Radiation environment inside IFMIF-DONES TIR

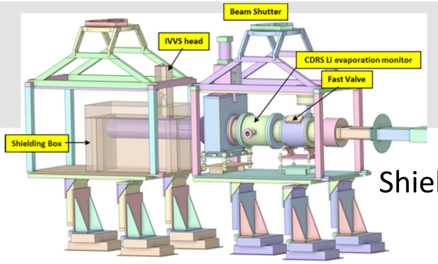
Empty TIR: map of biological dose rate (microSv/h) from neutrons. Top view.



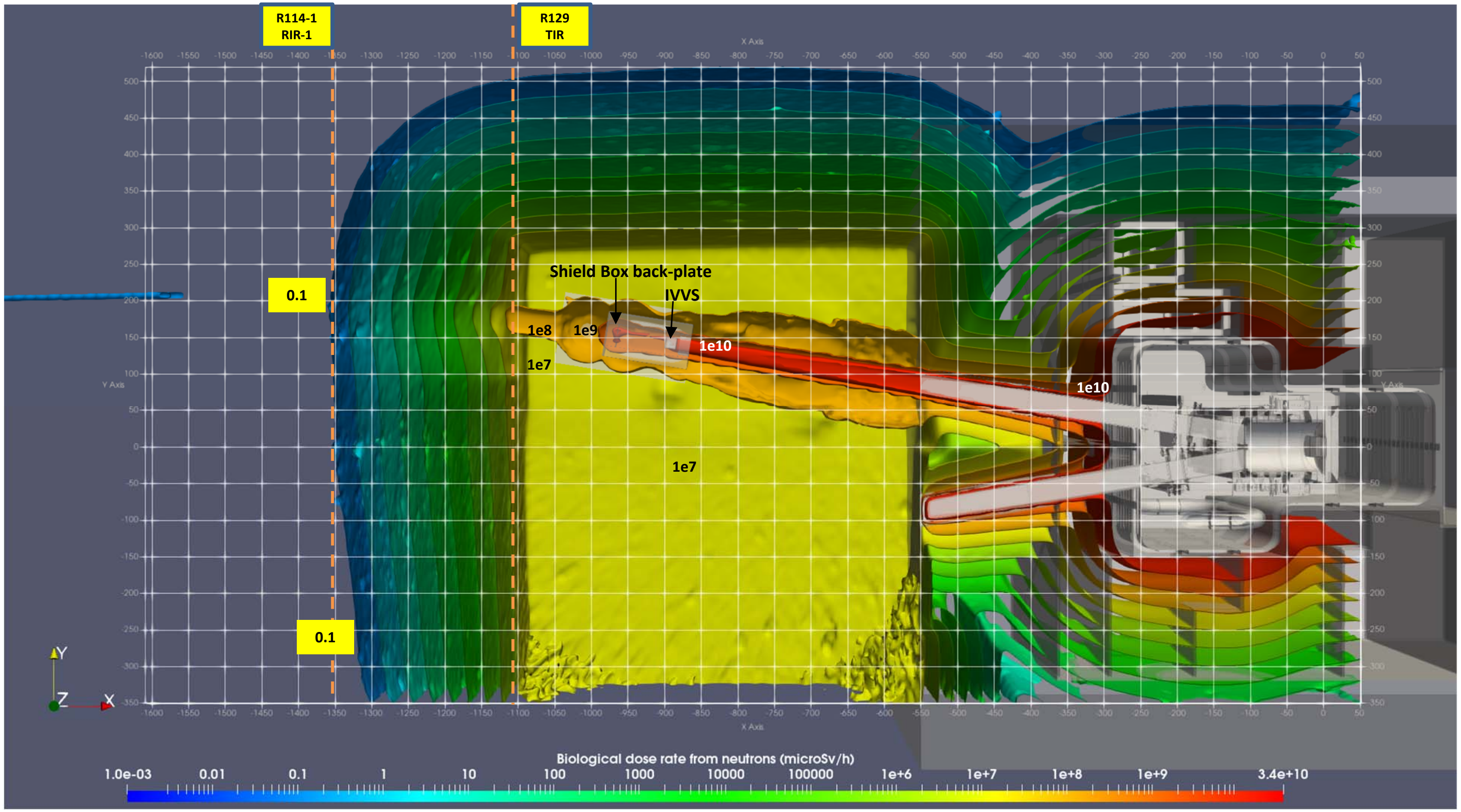
Not shielded secondary Beam Duct (BD2): map of biological dose rate (microSv/h) from neutrons



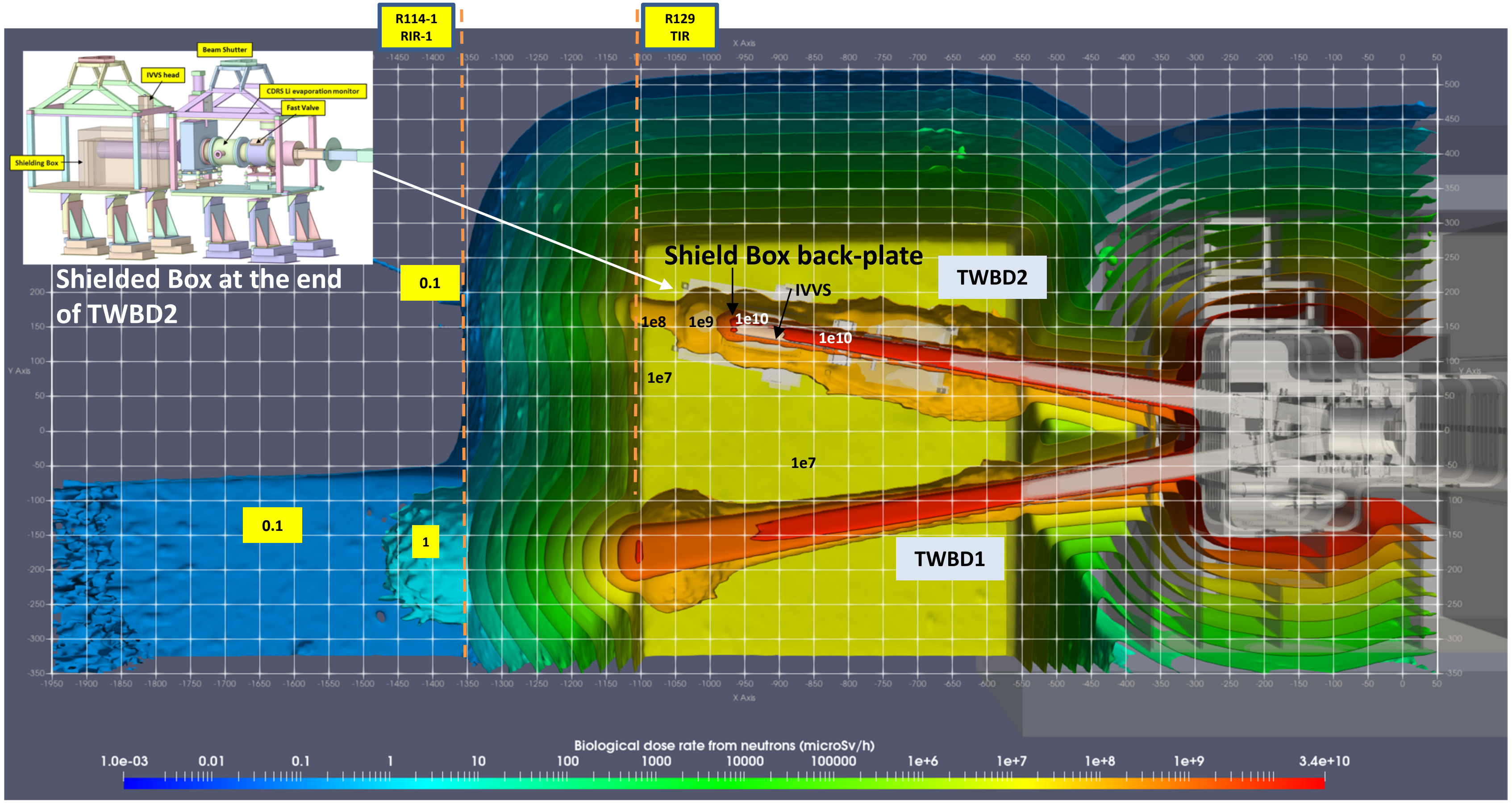
Shielded secondary Beam Duct (BD2): map of biological dose rate (microSv/h) from neutrons



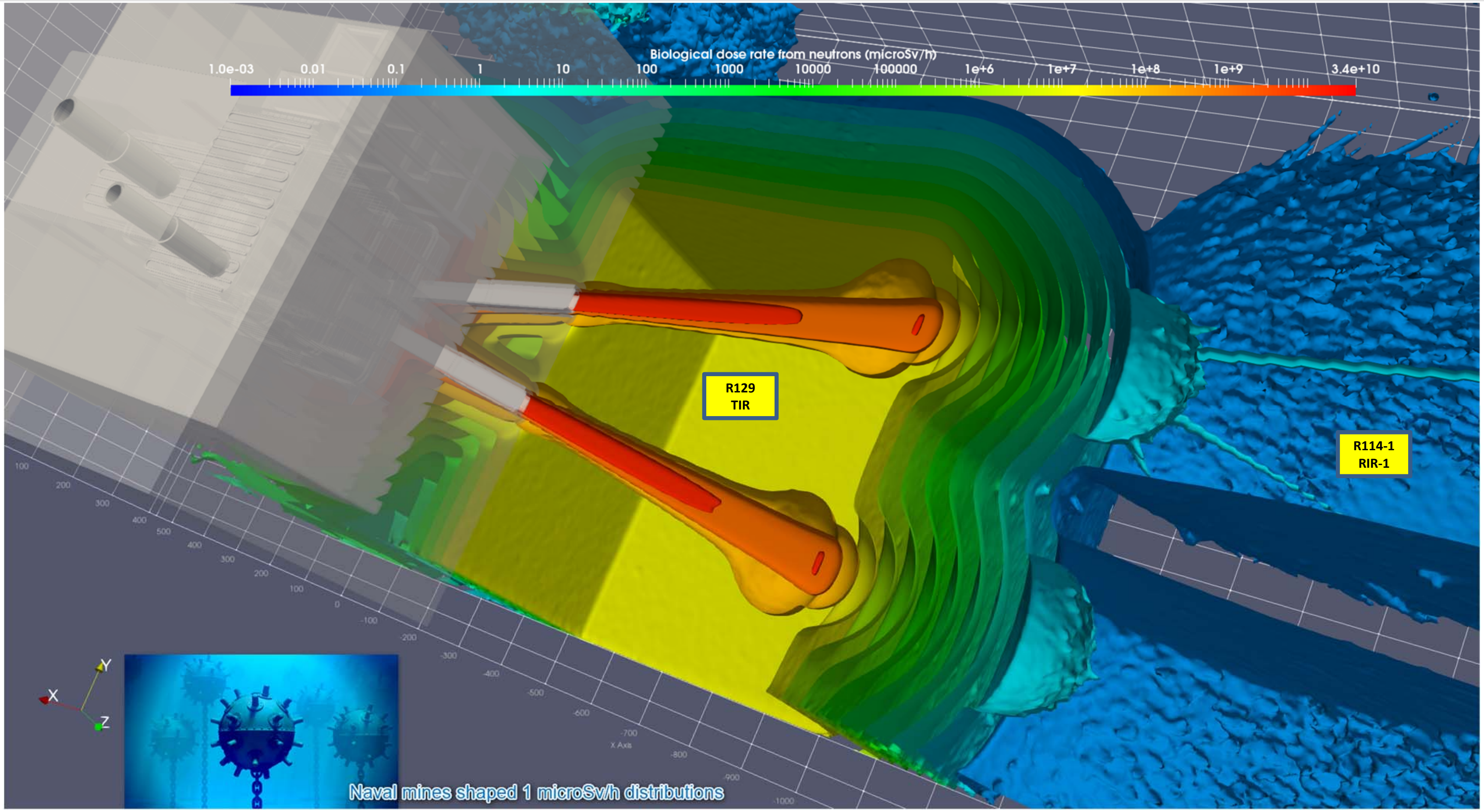
Shielded BD2



Comparison of two BDs: Shielded BD2 vs. Empty BD1:
View from the top on the map of biological dose rate (microSv/h) from neutrons



View from the bottom to empty TIR (no any BD material) map of biological dose rate (microSv/h) caused by neutrons



Conclusion: use of the Shielded BD2 reduces the biological dose rate at least by one order of magnitude in the RIR-1. **Shield box allows avoiding 1 microSv/h naval mines – shaped bumps of dose rate inside RIR-1**

Conclusions

- The proposed Shield Box around the IVVS Diagnostics at the end of the secondary **Through Wall Beam Duct #2 (TWBD2)** inside the room TIR allows reducing the biological dose rate at least by one order of magnitude inside the next room RIR-1.
- The Shield Box is made of steel SS316L plates with a thickness of 15 cm, the box's whole weight is 2.96 tons.
- The total (neutron + photon) nuclear heating in steel plates integrated over the Shield Box volume is 1.44 W.
- Performed neutronics analysis provided supporting results for the proposed design of the IVVS Diagnostic system.
- Neutronics results indicated the possibility to implement the IVVS Shield Box design in TWBD2 inside the TIR of IFMIF-DONES.
- Neutronics results for TWBD2 in TIR of DONES:
  - Photon absorbed dose rate 70 Gy/h in the IVVS prism is less than the 5 kGy/hr limit of the IVVS operability.
  - Sum of photon and neutron radiations rises absorbed dose in the IVVS prism to 130 Gy/hr, still less than 5 kGy/hr limit.
  - The IVVS actuator worked at 4.88 MGy, the limit for the life-time integrated photon dose is 10 MGy.
  - Maximum absorbed dose in IVVS prism is 0.6 MGy/FPY (photon), total (n+p) dose is 1.13 MGy/FPY. Taking into account the reference data 4.88 Mgy for photons and 10 MGy for total absorbed doses, the actual lifespan of IVVS operation will be found.
- Performed neutronics analysis provided supporting results for the proposed designs of Shield Box and IVVS. Neutronics results indicated possibility to implement these designs in TWBD2 of DONES TIR.

Shield Box allows avoiding 1 microSv/h naval mines – shaped bumps of dose rate inside RIR-1