COMPUTATIONAL NEUTRONICS APPLIED TO FUSION FACILITIES

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- PhD thesis in computational neutronics
- Projects involve (ITER, CID, IFMIF-DONES)
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- Summary

University studies
(ICF activities)

UNIVERSITY STUDIES (HEDP ACTIVITIES)

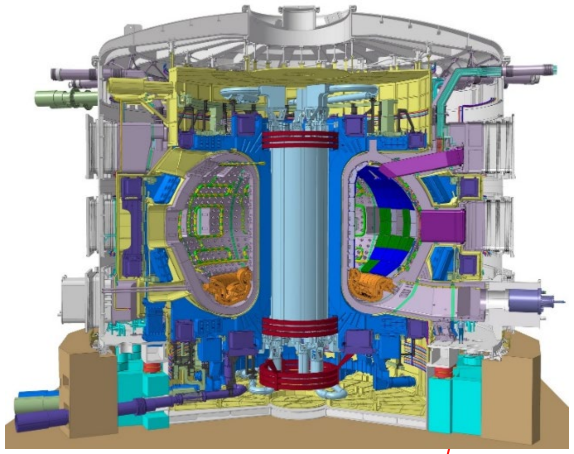
- 2015: Bachelor’s degree in Energy Engineering (Polytechnic University of Madrid, UPM, Spain)
- 2017: Master in Nuclear Science and Technology (Polytechnic University of Madrid, UPM, Spain)
  - Collaboration in the field of Inertial Fusion Confinement experiments and High-Energy-Density Physics studies: Bachelor's Final Dissertation (qualification 9.5/10) and Master's Final Dissertation (qualification 10/10)

PhD thesis in computational neutronics

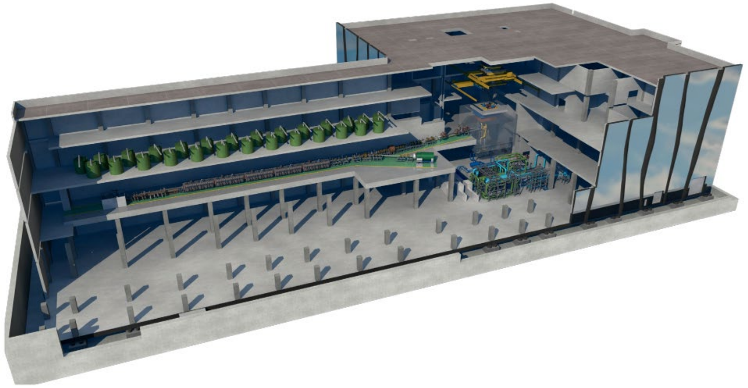
PHD THESIS IN COMPUTATIONAL NEUTRONICS

- Motivation
  - Neutronic fields in fusion facilities
    1. Shielding design
    2. Nuclear damage computation
    3. Material activation computation
  - Nuclear analysis
    1. Material activation computation
       - ACAB activation code
    2. Geometry generation
       - GEOUNED conversion tool

❖ ITER



❖ IFMIF-DONES



Reference (ITER figure): ITER webpage (https://www.iter.org/)
Reference (IFMIF-DONES figure): Annual report 2021, Consorcio IFMIF-DONES España

- Material activation
  - Activation tool: temporal evolution of the isotopic inventory
    - Reliability relies on the numerical method
  - ACAB activation tool
    - Used solver: ORIGEN tool (Matrex)
    - Nuclide separation (long-lived and half-lived): source of uncertainty

PHD THESIS IN COMPUTATIONAL NEUTRONICS

- Rate equations

$$\frac{dN_i}{dt} = \sum_{\substack{j \\ j\neq i}} (\lambda_{ij} + \sigma_{ij}\phi)N_j - \underbrace{(\lambda_i + \sigma_i\phi)}_{d_i}N_i$$

$$\frac{d\vec{N}(t)}{dt} = \boldsymbol{A}\vec{N}(t) \qquad \vec{N}(t) = e^{\boldsymbol{A}t}\vec{N}(0) \qquad e^{\boldsymbol{A}t} = \boldsymbol{I} + \boldsymbol{A}t + \frac{\boldsymbol{A}^2t^2}{2} + \cdots = \sum_{m=0}^{\infty} \frac{(\boldsymbol{A}t)^m}{m!}$$

- ACAB and ORIGEN solution: limit the transition matrix norm $[\boldsymbol{A}]$

$[\boldsymbol{A}]t \leq -2\ln(0.001)$ → $d_it \leq -\ln(0.001)$ where $d_i = \lambda_i + \sigma_i\phi$ →

Long-lived nuclides

$d_it \leq -\ln(0.001)$

Short-lived nuclides

$d_it > -\ln(0.001)$

Critical effective decay rate

$d_{Crit} = -\ln(0.001)/t$

PHD THESIS IN COMPUTATIONAL NEUTRONICS

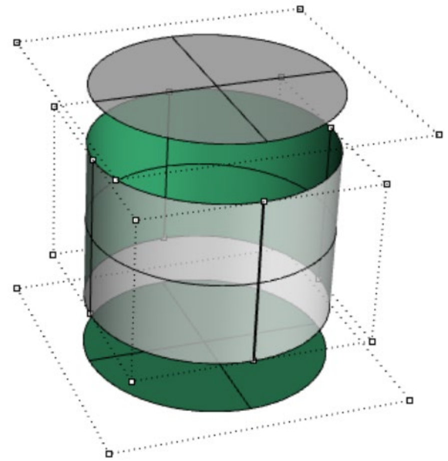
1) Improvement of time step recommendations

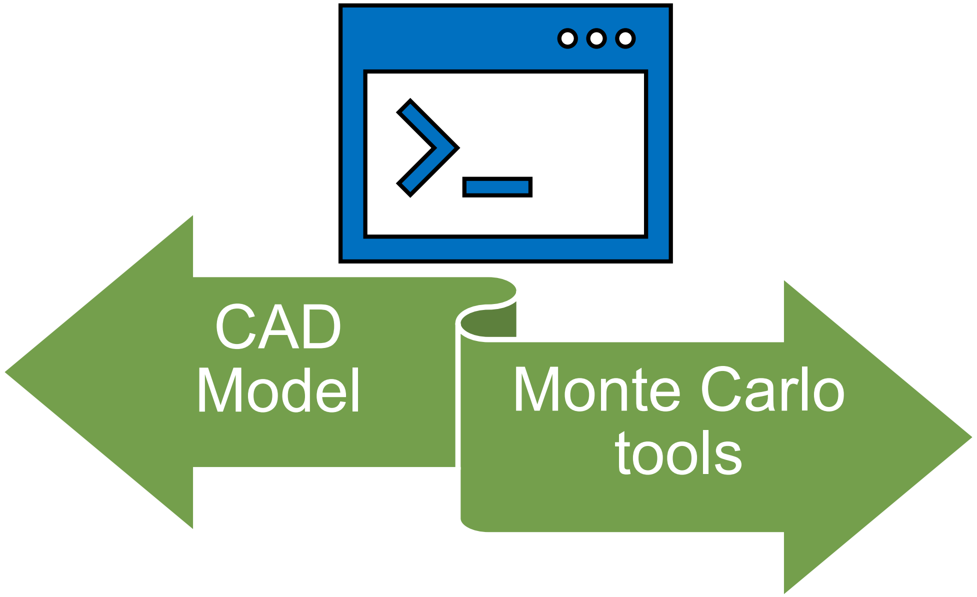
2) Reliability evaluation of linear chains up to 3 nuclides (short-linear chains)

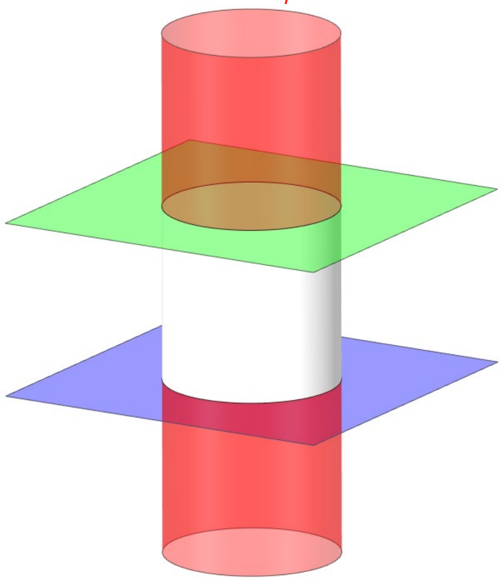
Applicability of improvements to revelant ITER material activation

PHD THESIS IN COMPUTATIONAL NEUTRONICS

- Geometry generation
  - Geometries are based on complex engineering CAD models
    - B-Rep (boundary representation) geometries
  - Radiation transport tools (in fusion facilities) are based on Monte Carlo methodology
    - CSG (Constructive Solid Geometry) geometries
  - Solution: development of exchange information programs



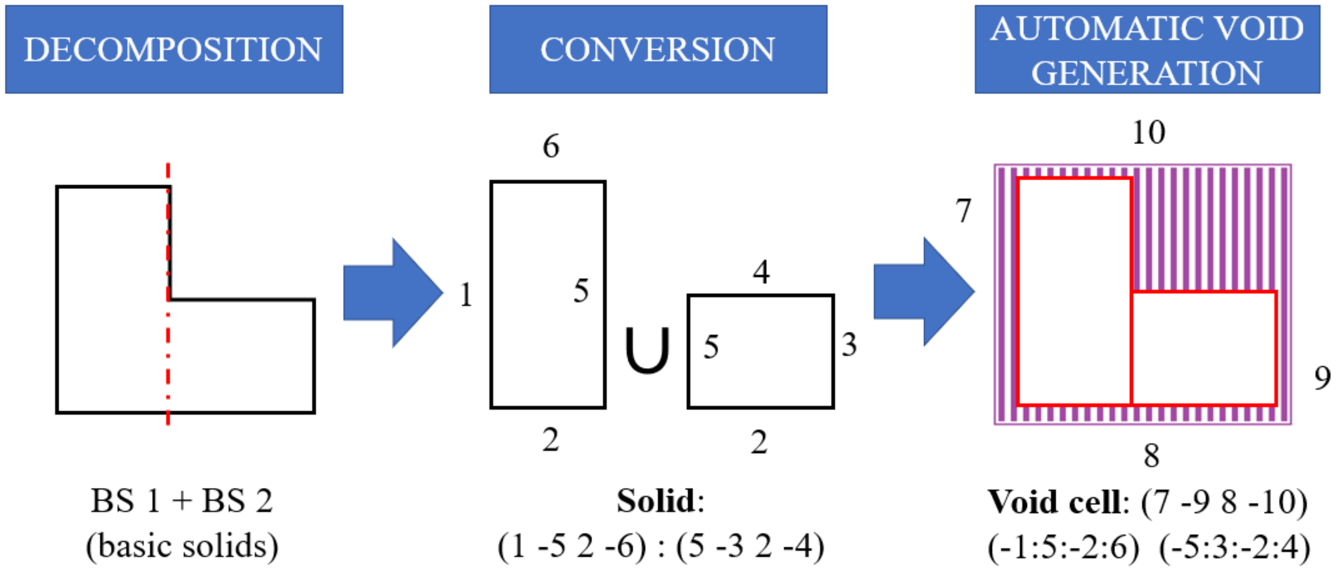




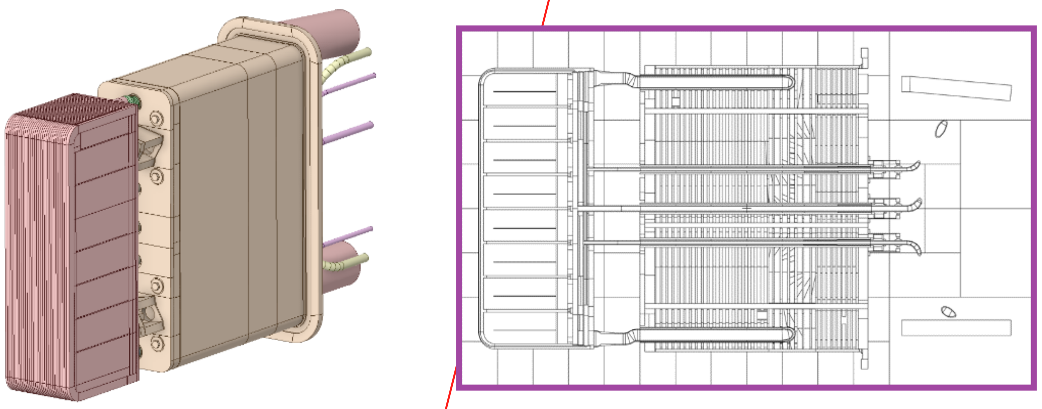
ACADEMIC/PROFESSIONAL BACKGROUND

- GEOUNED conversion tool
  - Conversion from CAD to CSG for MCNP, OpenMC, Serpent and Phist
  - Open Source (public GitHub repository). Programmed in Python
  - Widely used to create IFMIF-DONES MCNP models. Used also in DEMO, HELIAS and ITER

GEOUNED conversion tool



ITER Test Blanket Module (TBM) model (CAD and MCNP)



PHD THESIS IN COMPUTATIONAL NEUTRONICS

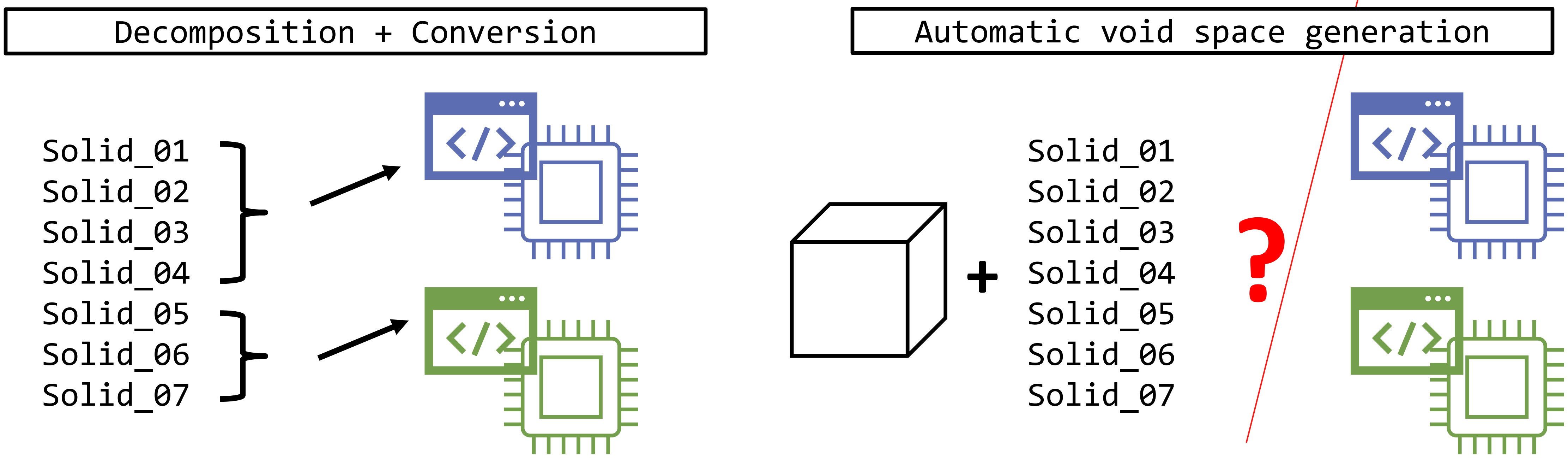
Development of GEOUNED 4 automatic void generation working modes:

- Division mode
- Intersection mode
- Fusion mode
- User defined enclosure mode

Application to IFMIF-DONES model. Evaluation of the impact of each working mode. Identification of best mode combination

PHD THESIS IN COMPUTATIONAL NEUTRONICS

- Parallelisation of GEOUNED automatic void generation
  1. Reduction of computation times
  2. Automatic void generation is one of the most complex parts to parallelise
  3. Application to parallelise rest of GEOUNED tool



PHD THESIS IN COMPUTATIONAL NEUTRONICS

2 main GEOUNED automatic void generation parallel versions

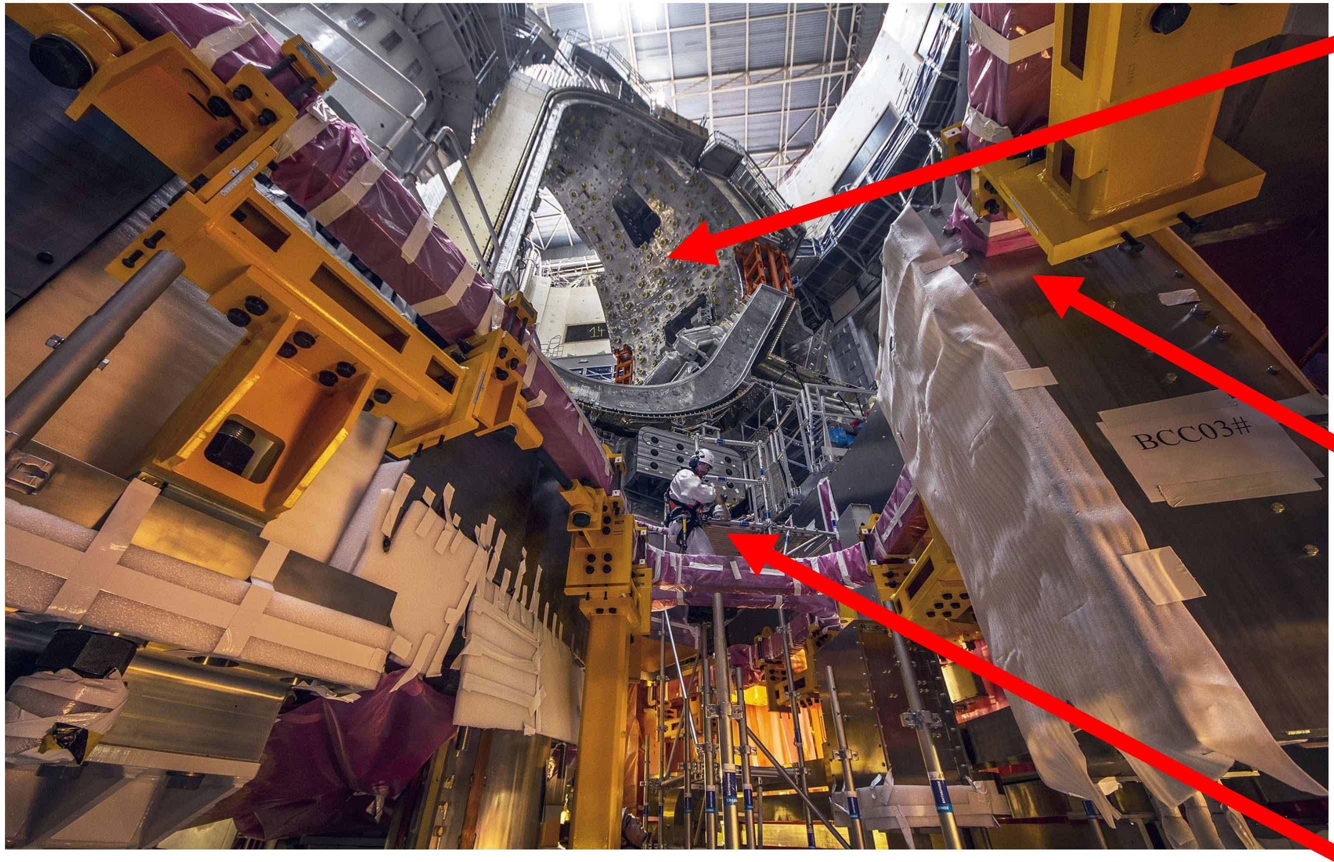
- Block parallel implementation
- Progressive parallel implementation

Application to an ITER model. Parallel performance evaluation and best version identification

Projects involve
(ITER, CID, IFMIF-DONES)

PROJECTS INVOLVE: ITER

- Generation of simplified CAD and MCNP models (year 2022)
  - 3 types of ITER Correction Coils and 2 types of magnet feeders (Fusion for Energy contract)



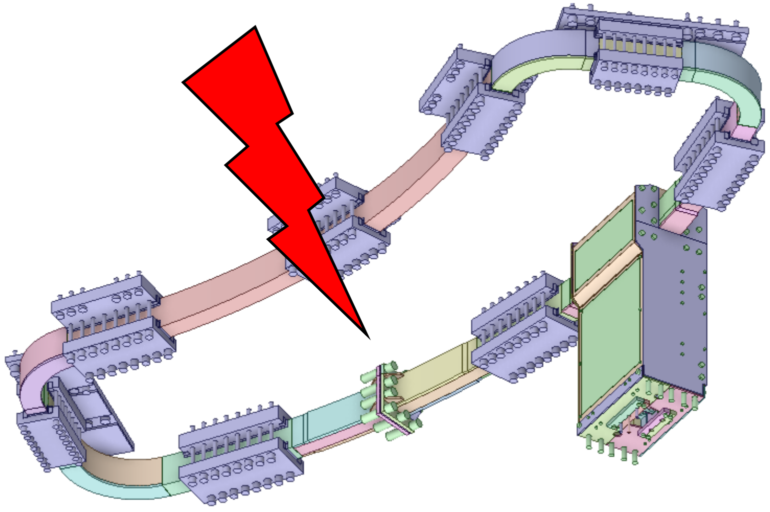
Vacuum Vessel sector #6

Bottom Correction Coil (BCC) #3

Person

Reference (ITER picture): ITER webpage (https://www.iter.org/)

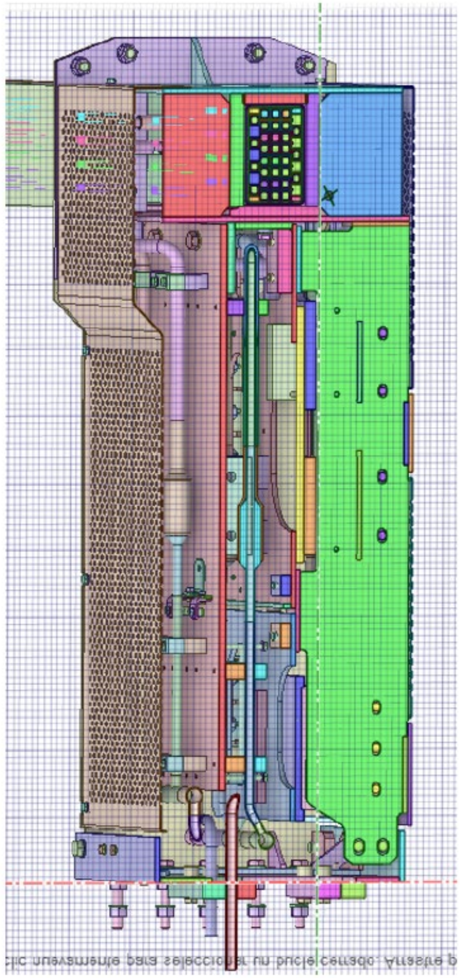
Nuclear heating (gammas, neutrons)

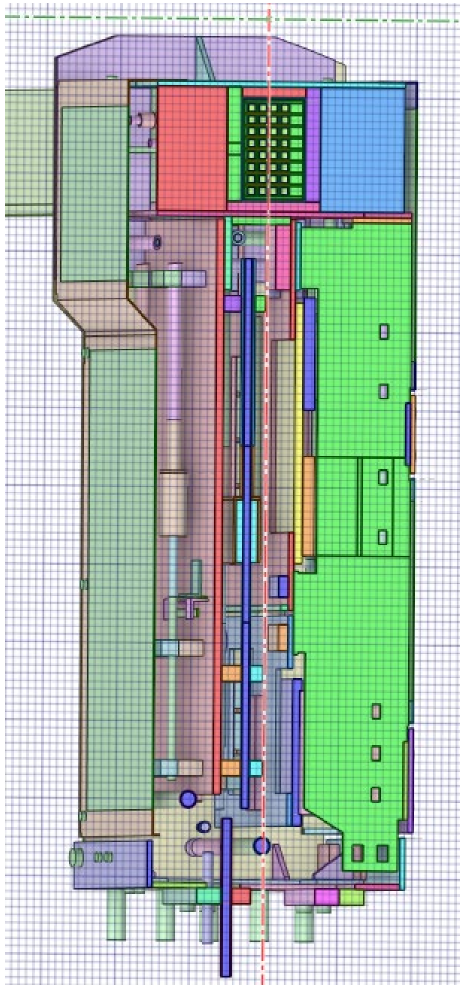


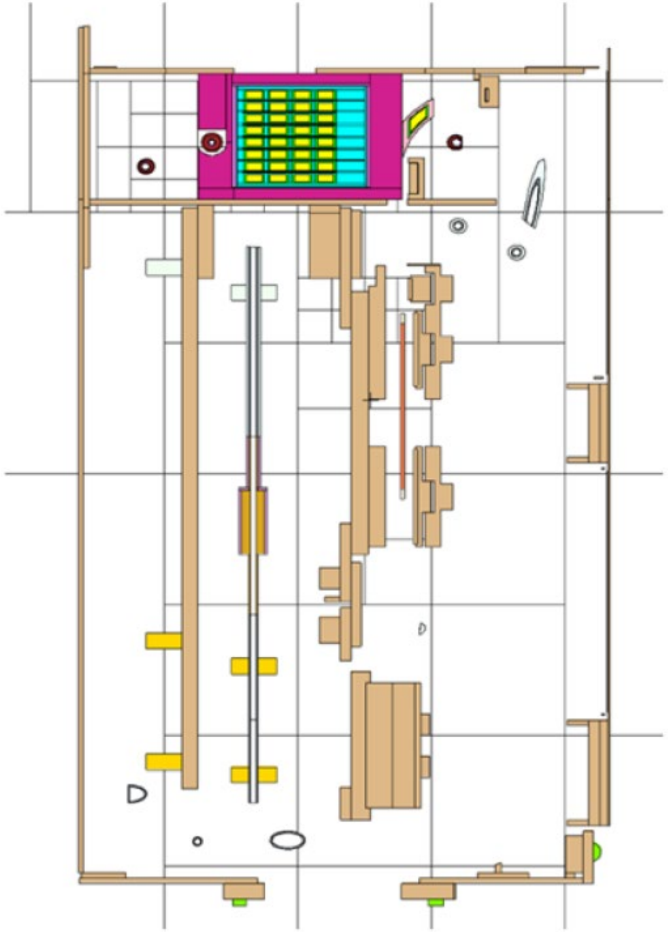
CAD model

PROJECTS INVOLVE: ITER

Engineering CAD model → Simplified CAD model → Neutronics (MCNP) model

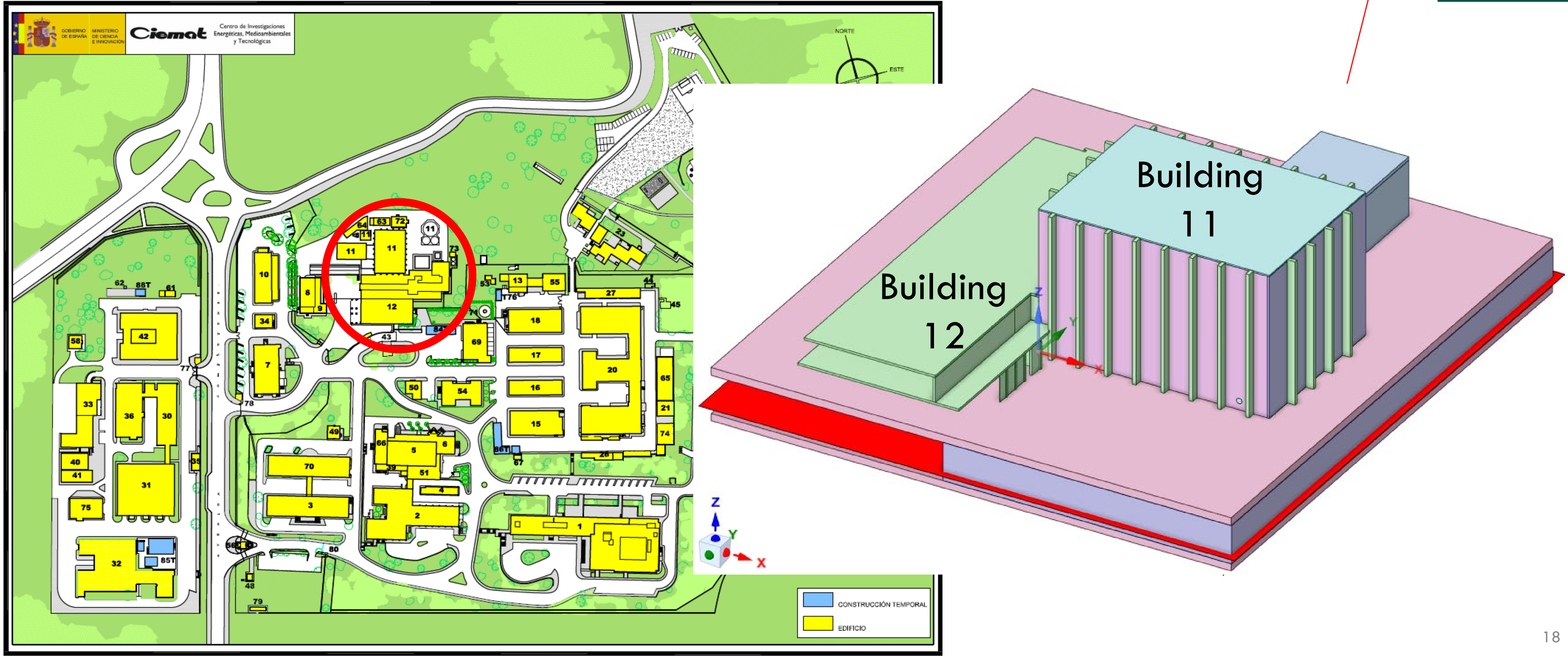






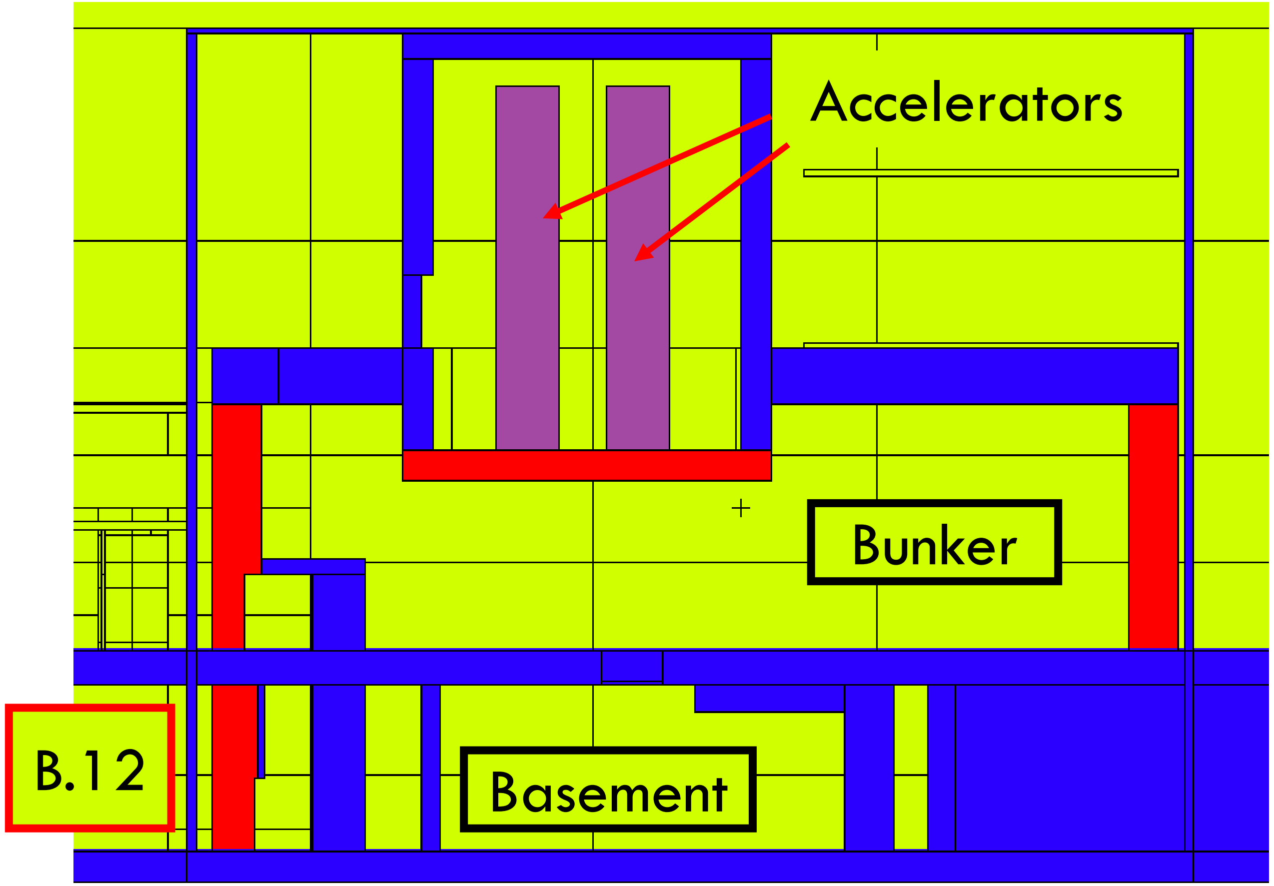
PROJECTS INVOLVE: CIEMAT ION DEVICE (CID)

- Shielding design and optimisation of a CIEMAT's double beam accelerator (CIEMAT Ion Device, CID) (year 2020)

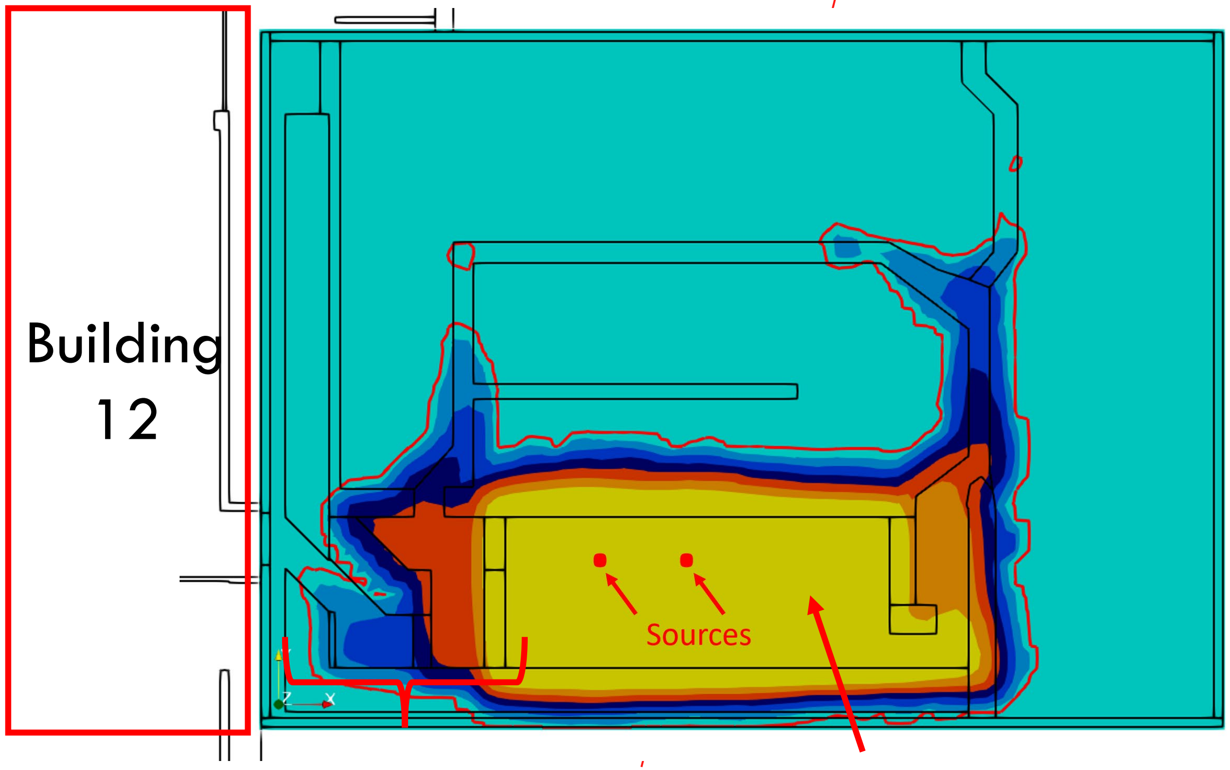


PROJECTS INVOLVE: CIEMAT ION DEVICE (CID)

Building 11 MCNP model (vertical cut)



Effective dose map (horizontal cut)



Labyrinth (shielding) Irradiation area

PROJECTS INVOLVE: IFMIF-DONES

- Mobility grant (1,5 years) funded by Granada University (UGR) to develop the neutronic design of IFMIF-DONES facility. Work done at Karlsruhe Institute of Technology (KIT)

UNIVERSIDAD DE GRANADA

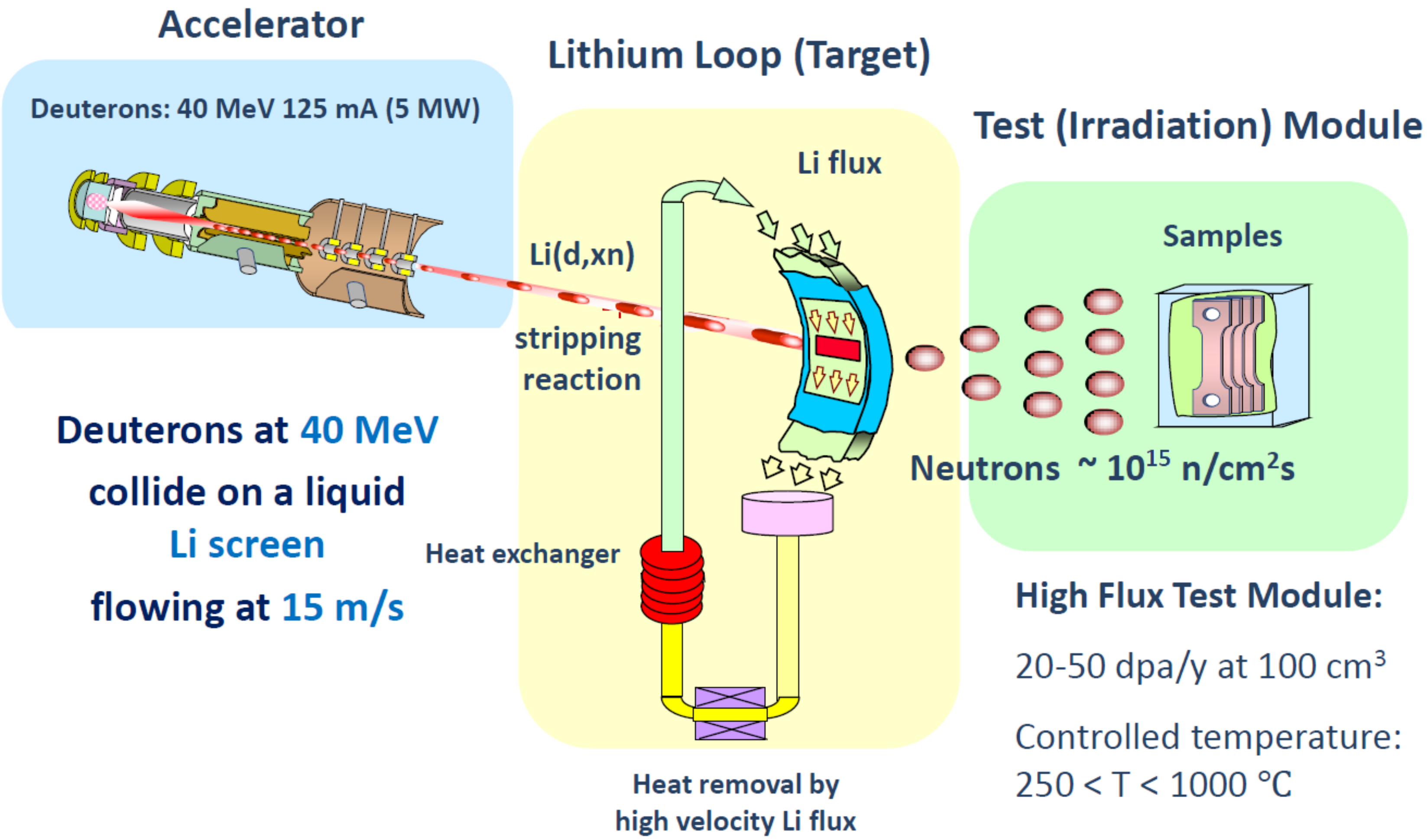
Karlsruhe Institute of Technology

DONES

Reference (Karlsruhe pictures): Wikipedia (https://de.wikipedia.org)

PROJECTS INVOLVE: IFMIF-DONES

IFMIF-DONES schematic operation



Deuterons at 40 MeV collide on a liquid Li screen flowing at 15 m/s

High Flux Test Module:

20-50 dpa/y at 100 cm^3

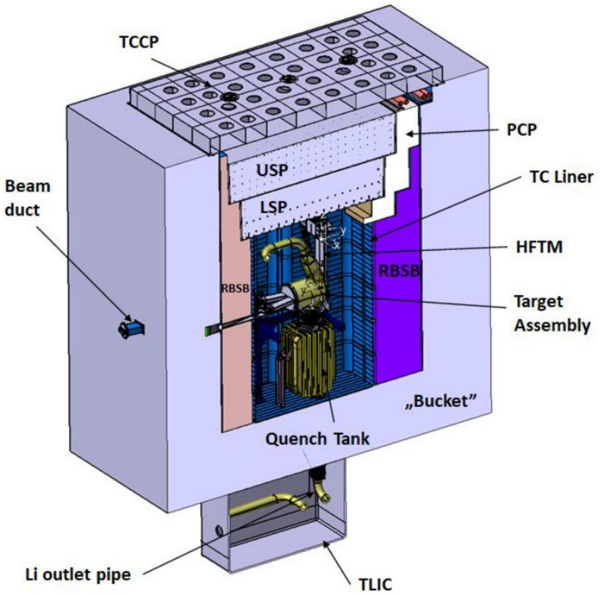
Controlled temperature:
250 < T < 1000 °C

A neutron flux of ~ 10^{15} cm^{-2}s^{-1} is generated with neutron spectrum up to 55 MeV energy

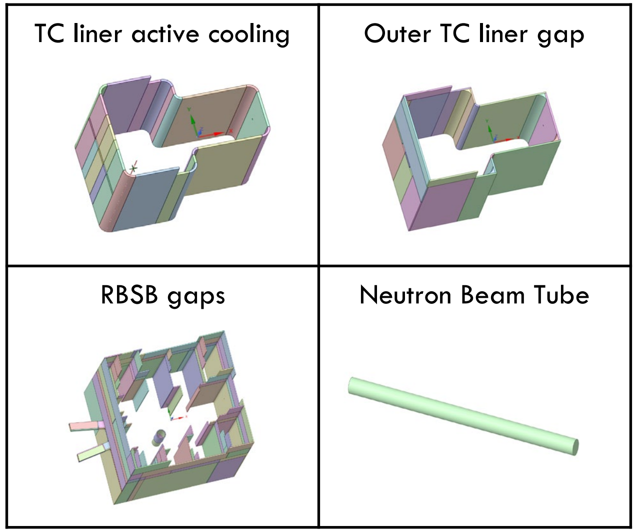
ACADEMIC/PROFESSIONAL BACKGROUND

- Computation and analysis of activated air gaps in IFMIF-DONES Test Cell (MCNP + FISPACT)

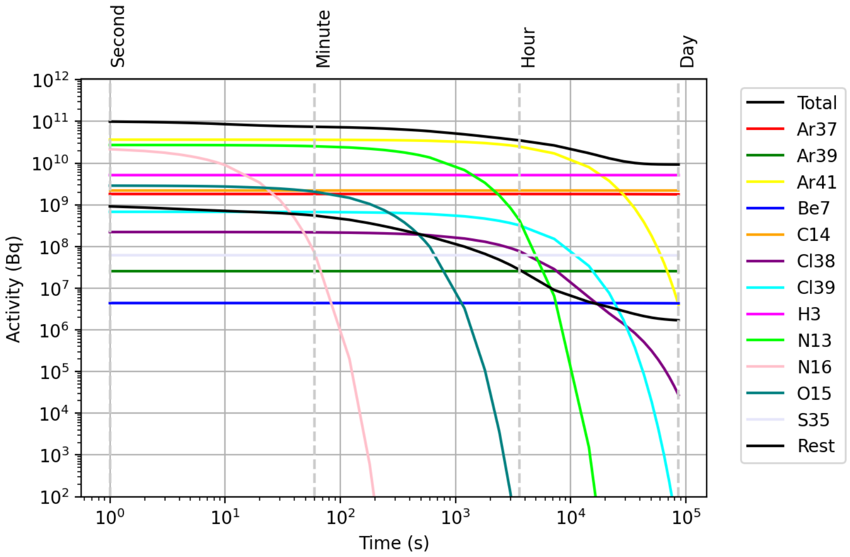
IFMIF-DONES Test Cell



Air cell groups

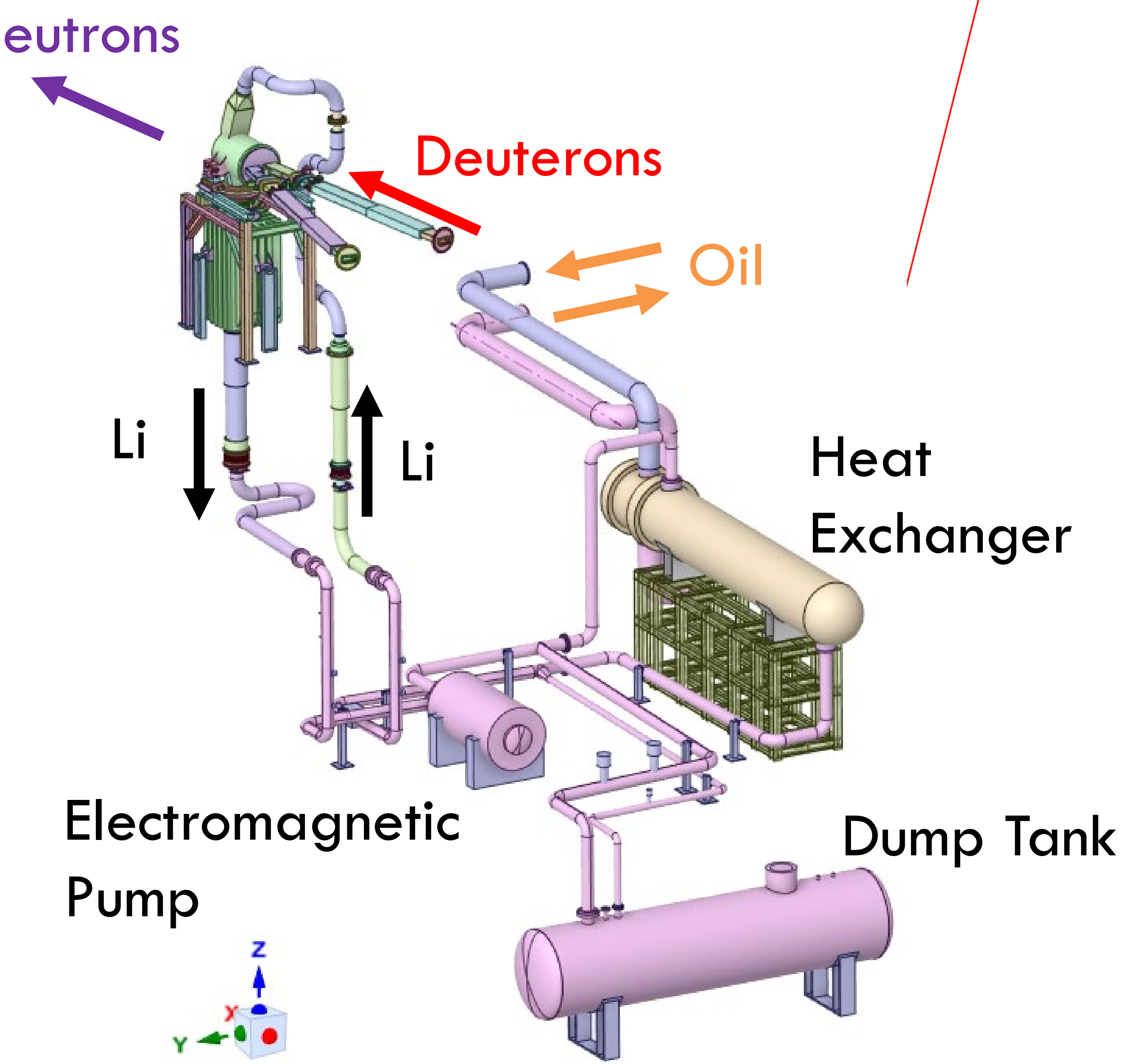


Activity temporal evolution for all air cell groups considering 1 year of operation



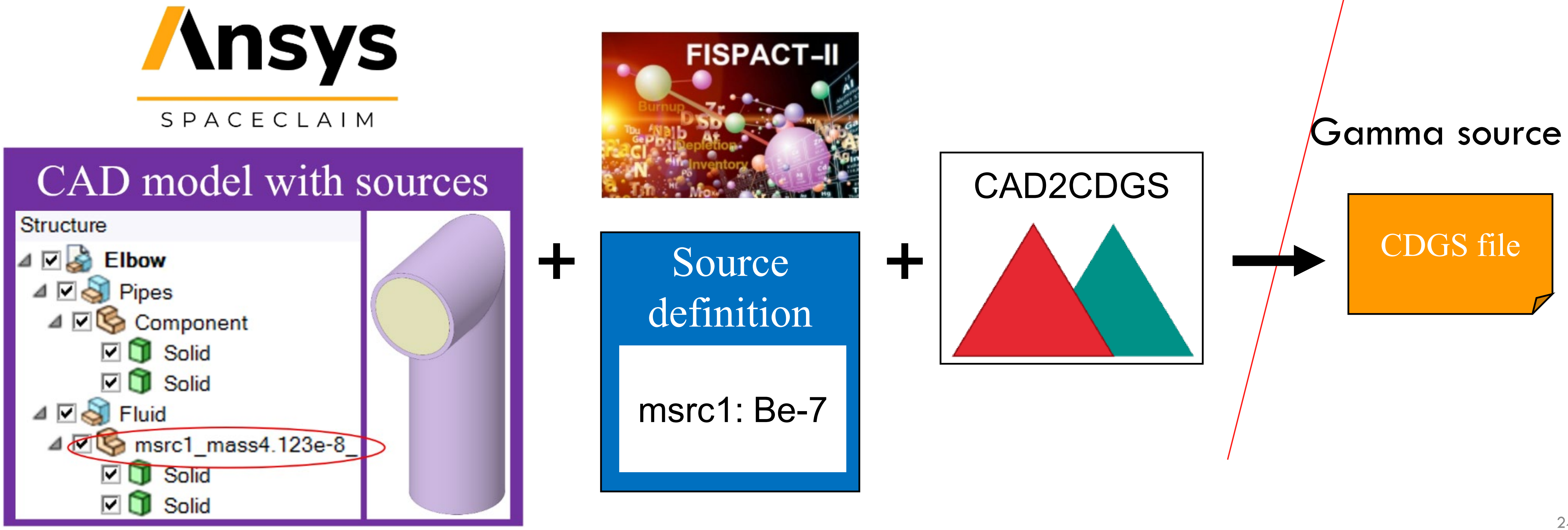
PROJECTS INVOLVE: IFMIF-DONES

- In IFMIF-DONES lithium loop, it is produced Beryllium-7 and Activation Corrosion Products (ACP). These are gamma decay sources
- Distribution of these components along the lithium loop will be heterogeneous, both dissolved in the Lithium and deposited in the pipes and containers



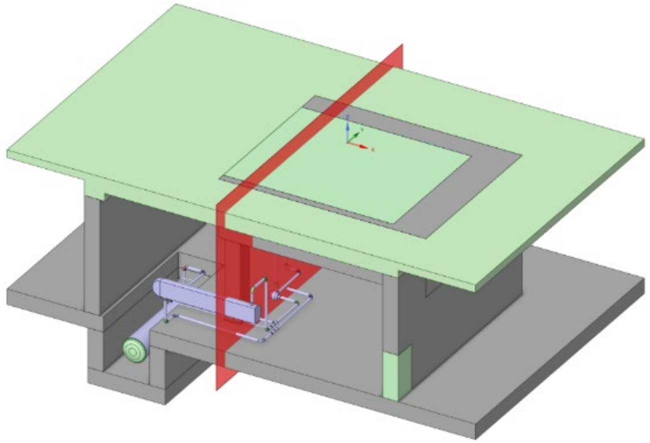
PROJECTS INVOLVE: IFMIF-DONES

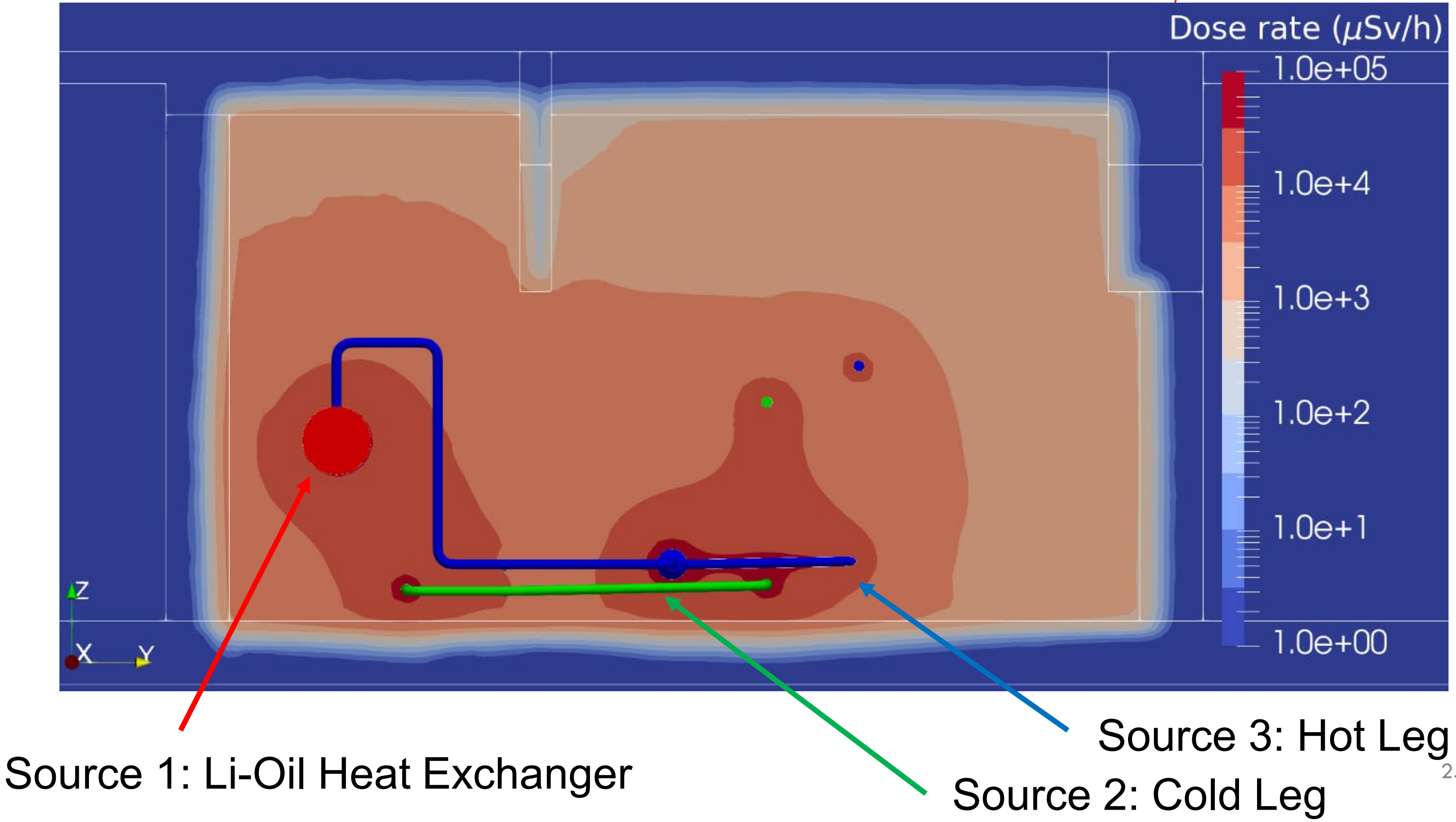
- CAD2CDGS tool: a new Python tool to generate volumetric gamma sources in MCNP based on CAD models
- Example: obtain a decay gamma source of a lithium elbow with 4.123e-8 grams of Berillyum-7



PROJECTS INVOLVE: IFMIF-DONES

- CAD2CDGS tool application to IFMIF-DONES Lithium System
  - Results (vertical cut): 10 µSv/h limit (Free permanence area – Controlled area) always inside the concrete structures





Research and outreach activities

ACADEMIC/PROFESSIONAL BACKGROUND

Experience as researcher

- Participation in international symposiums (SOFT 2020, ISFNT-15), workshops (2024 MCNP User Symposium, 15th ITER Neutronics Meeting) and technical meetings (Work Package Early Neutron Source (WPENS) years 2021, 2022, 2023)
- Author or co-author of 4 articles, 6 oral talks and 3 posters

Experience in outreach activities

- Creation of educational nuclear materials for secondary school students (ENEN+ project, 2018)*
- 2 lectures in secondary school as a diffusion activity of the produced educational materials (ENEN+ project, 18/2/2019 and 8/3/2019)**

*Link to the educational nuclear materials:
https://plus.enen.eu/competition/pdf/posters/RP1_Uned_Radiation%20protection_English.pdf
https://plus.enen.eu/competition/materials.php
** Link to a news about of one of the secondary school talks (and source of the photograph)
https://www.csanjose.org/index.php/etapas/ed-secundaria/bachillerato/item/332-08-03-2019-charla-sobre-la-energia-bachillerato

Research opportunities

RESEARCH OPPORTUNITIES

- In EVOLCODE
  1. Application of ACAB know-how
- In IFMIF-DONES
  1. Knowledge of the radiological problems of the facility
  2. Radiation fields both in operation and shutdown (e.g. background radiation fields)
- In experiment simulation
  1. Migration of GEOUNED to GEANT4
- CAD2CDGS
  1. Distribution to the group (permission to be asked)
  2. Integration with NuDEX for complex 3D gamma source definition

SUMMARY

SUMMARY

- Research career focused on nuclear field
- Experience in several research projects (ITER, CID, IFMIF-DONES)
- Experience in research and outreach activities
- Proposition of research opportunities

THANK YOU

Computational neutronics applied to fusion facilities

Juan García Bueno