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Nuclear Integrated Engineering approach following ALARA principle in ITER project

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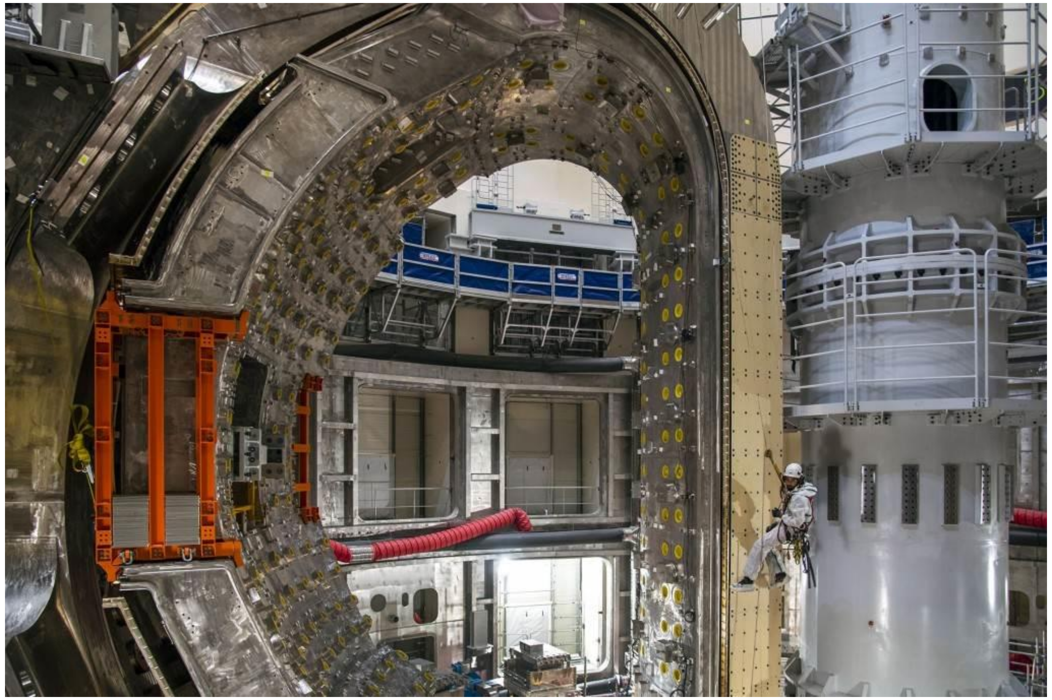
Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Introduction to ITER

ITER will be a research-oriented nuclear Tokamak

Main objective: To produce 500 MW in DT plasmas with Q>10 during ~ 450s, (and Q>5 ~ 3000s)

ITER is under construction, with the first plasma targeted in a few years followed by a nuclear phase



Courtesy of ITER Organization
Jun 22

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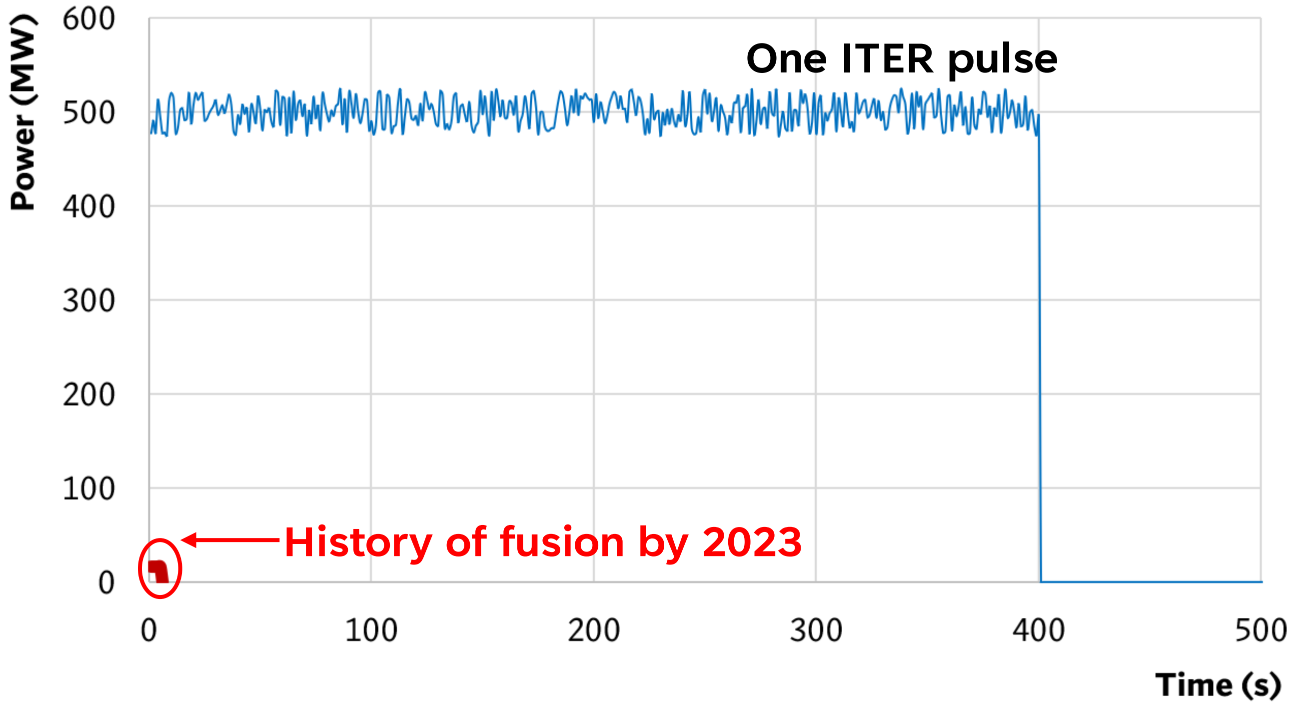
Neutron production in ITER



One ITER reference pulse:

- Power 500 MW
- Energy amplification Q~10
- Pulse duration ~450s

History of fusion power production as per 2023	~ 10^{20} neutrons
First DT pulse of ITER	~ 10^{23} neutrons
ITER at end of life	~ 10^{27} neutrons

Nothing similar done before!

Issue #1: ITER will present diverse sources of radiation induced by plasma neutrons

Issue #2: Radiation will make a Tokamak blind, aged, unreliable and difficult to maintain

Distribution of radiation sources in ITER

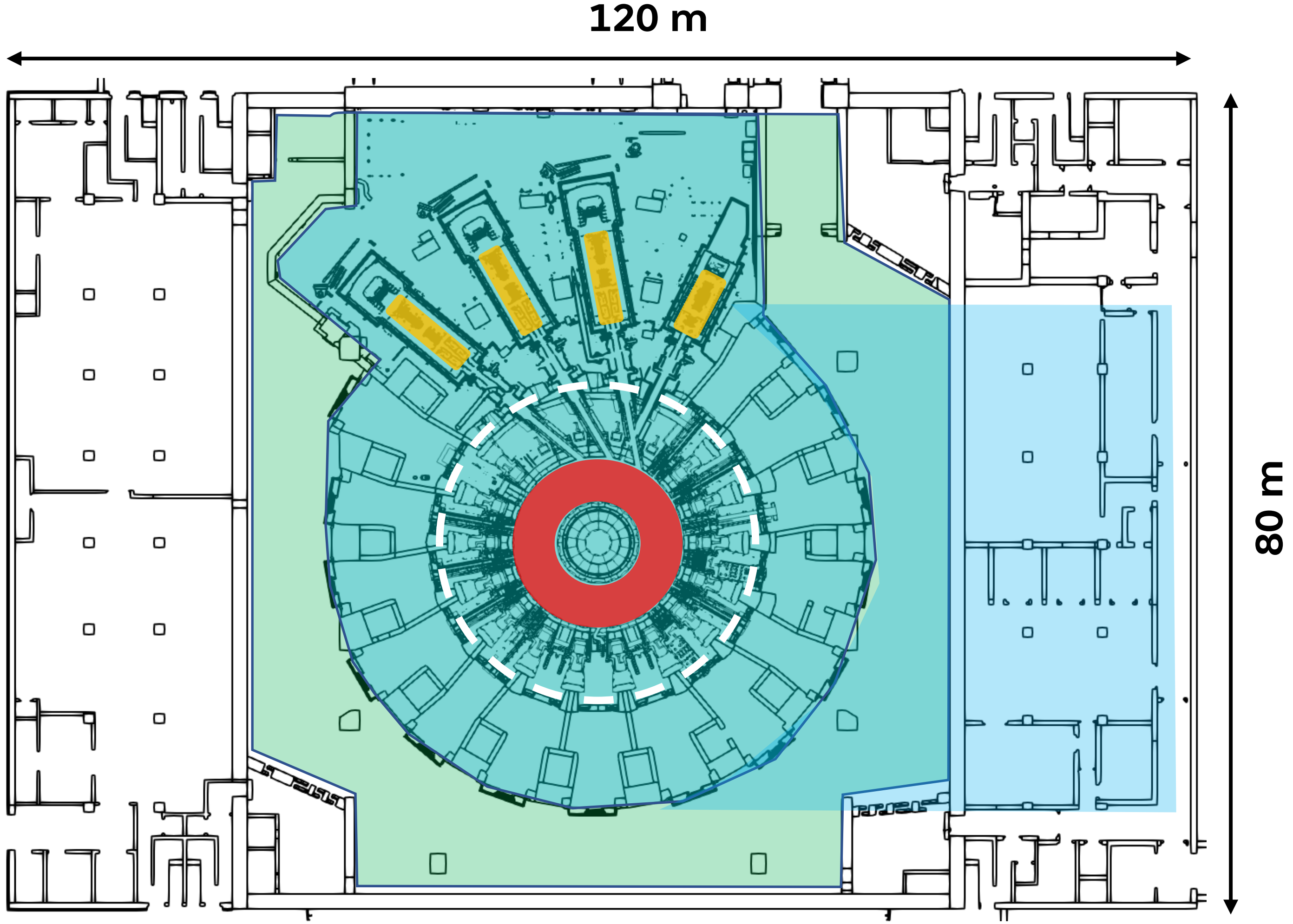
Radiation sources in ITER:

- Pre-DT plasmas
- Plasma DT neutrons and subsequent photons
- Plasma DD neutrons and subsequent photons
- Photo-neutrons from run-away electrons
- Photo-neutrons from Be

- ERID & calorimeter source

- Water activation: ^{16}N & ^{17}N
- Activated corrosion products

- Radioactive decay of activated components
- Activated W and SS dust



Widely distributed delayed sources!

ITER maintenance

Maintenance activities in ITER will present:

- Radioactive & contaminated environments
- Dark rooms & limited visibility
- Narrow spaces and limited mobility
- Assisted breathing with special suits
- Surrounded by sharp objects
- Need to carry heavy loads & tools
- Life-lines to secure the workers
- Permanent overview of an in-situ supervisor
- Rescue plans
- Time controlled

→ **Comparable to maintenance in the orbit!**

Extravehicular activities in the ISS:
237 interventions for a total of 1491 h 54' over 23 years

ITER maintenance:
Hundreds of interventions adding even 2500 h are expected ITER per year

Nuclear Integrated Engineering for ITER

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Requirements:

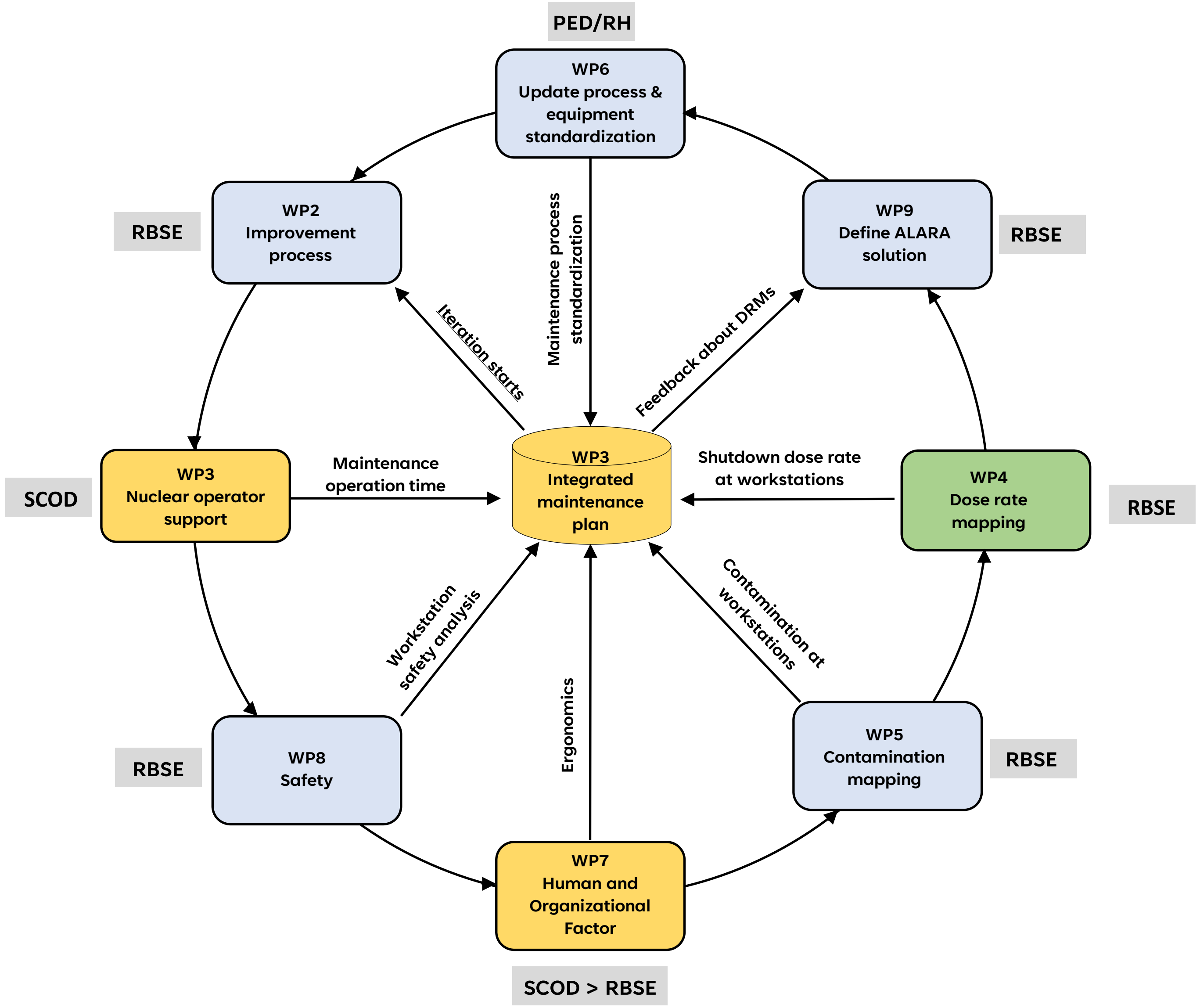
- [PR5355-R]: dose rate shall not exceed **100 µSv/h & 10 µSv/h in yellow & green zones** at 10^6 s after shutdown
- [PR1782-R]: dose rate in the port cells with the bioshield plug shall not exceed **10 µSv/h** at 24 h after shutdown
- [PR2000-R]: Demonstrate **ALARA**
- [PR1129-R]: collective annual worker dose over the operational life-time of ITER shall not exceed **0.5 man.Sv.y^{-1}**

Plant Breakdown Structure shows strong limitations to address these requirements, since

1. Maintenance will take place during shutdown in 172 yellow rooms & 293 green rooms
2. Radiation and contamination spreads: upstream & downstream considerations are needed
3. Standardization of evaluation methods ensures consistency
4. Standardization of operations saves time and resources

→ An integrated approach has been adopted for a seamless exercise of evaluation and design from 2019

Nuclear Integrated Engineering contract for ITER



ITER | JACOBS | Orano | UNED

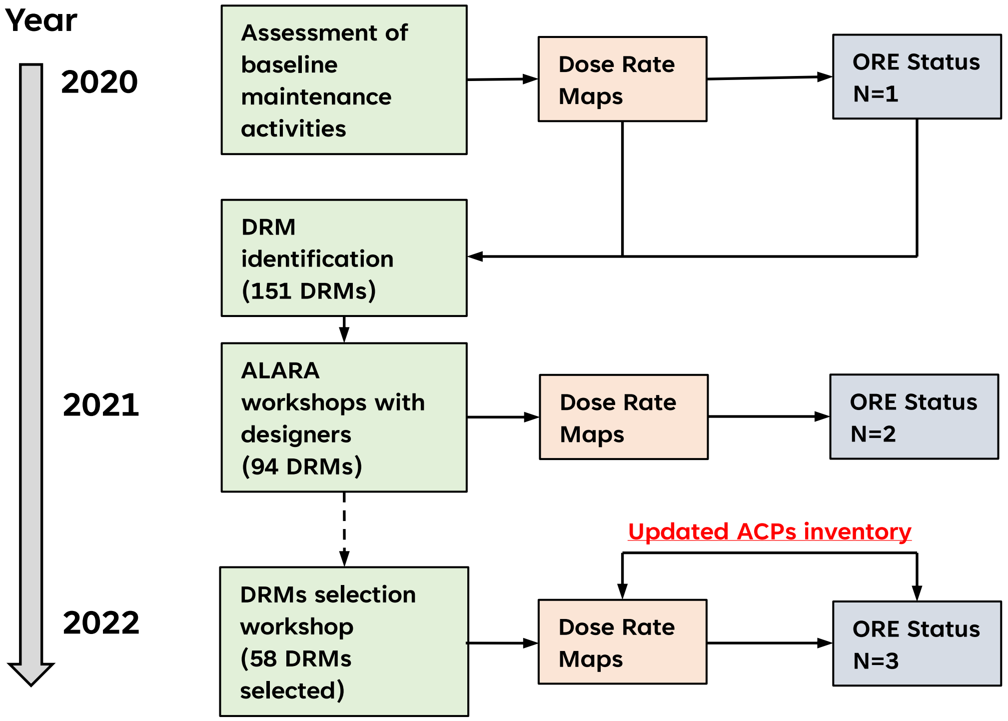
NIE contract was launched in 2019 for an ALARA predictive, formalized and iterative approach:

- Push and formalize the ALARA approach: workshops & formalization of "Dose Reduction Measures
- Zone-based approach rather than system-based (oversystem vision).
- Integrating nuclear operator feedback.
- Radioprotection engineering file to feed into the safety files (updated RPrS).

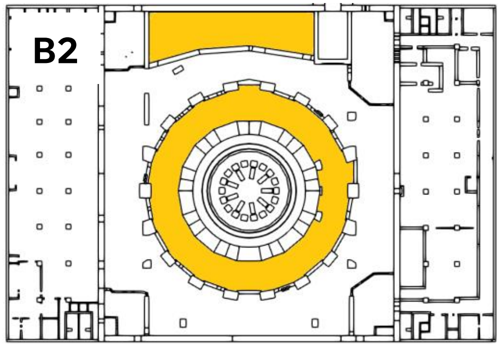
ALARA process and representative areas

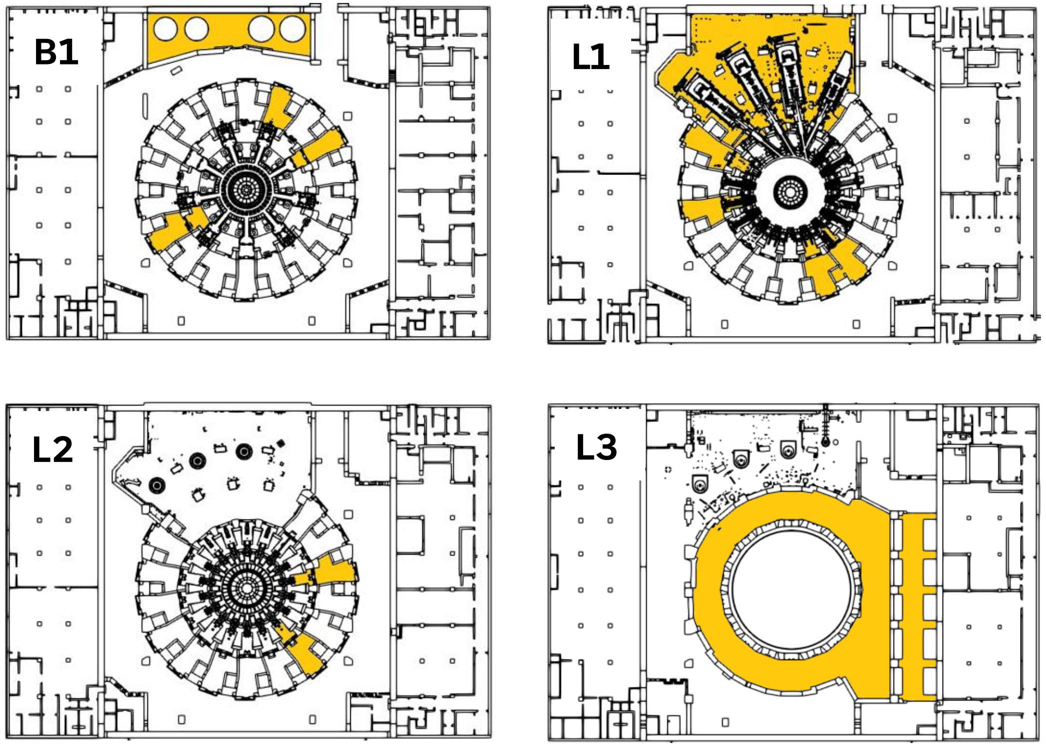
Results from them were extrapolated to obtain the Occopational Radiation Exposure (ORE)

Three <u>ALARA cycles</u> identifying <u>Dose Reduction Measures</u> (DRMs) were executed between 2020 and 2022



A total of 13 representative areas were studied in detail



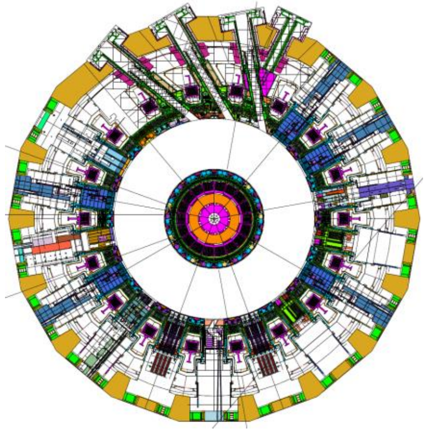


Methods for shutdown dose rate determination

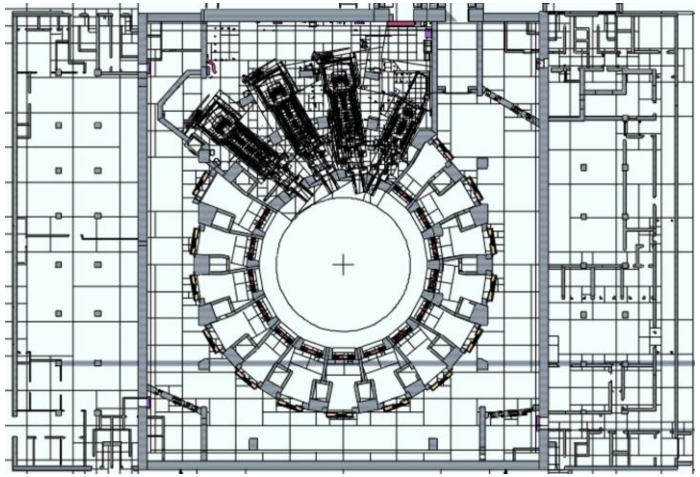
The most advanced techniques in radiation transport have been considered

- **D1SUNED (2nd SOFT innovation prize 2022)** [Fusion Engineering and Design **151** (2020) 111399]
- **Tailored D1S data: 123 reactions from 57 precursors** [Fusion Engineering and Design **170** (2021) 112646]
- **Full resolution 3D ACPs sources** [Fusion Engineering and Design, **171** (2021), 112575]
- **Full site model: First integral ITER facility MCNP model →** 1,400,000 surfaces

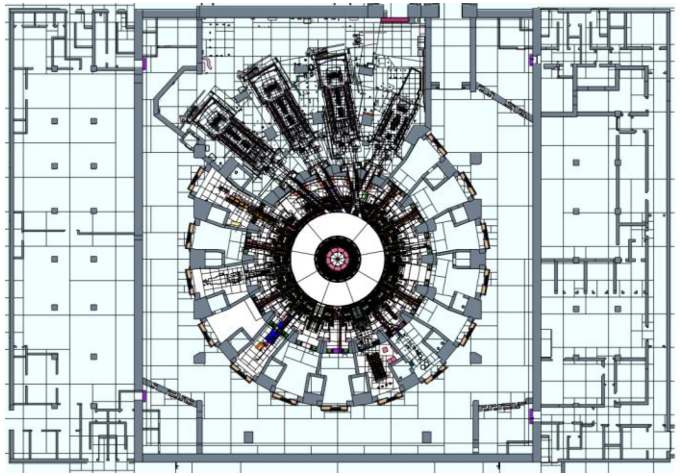
E-lite, [Nature Energy **6** (2021) 150-157]



Tok Com, [Scientific Reports **13** (2023) 3544]



Full model



3D interactive visualization of the dose

Simulated maintenance in the upper port #16

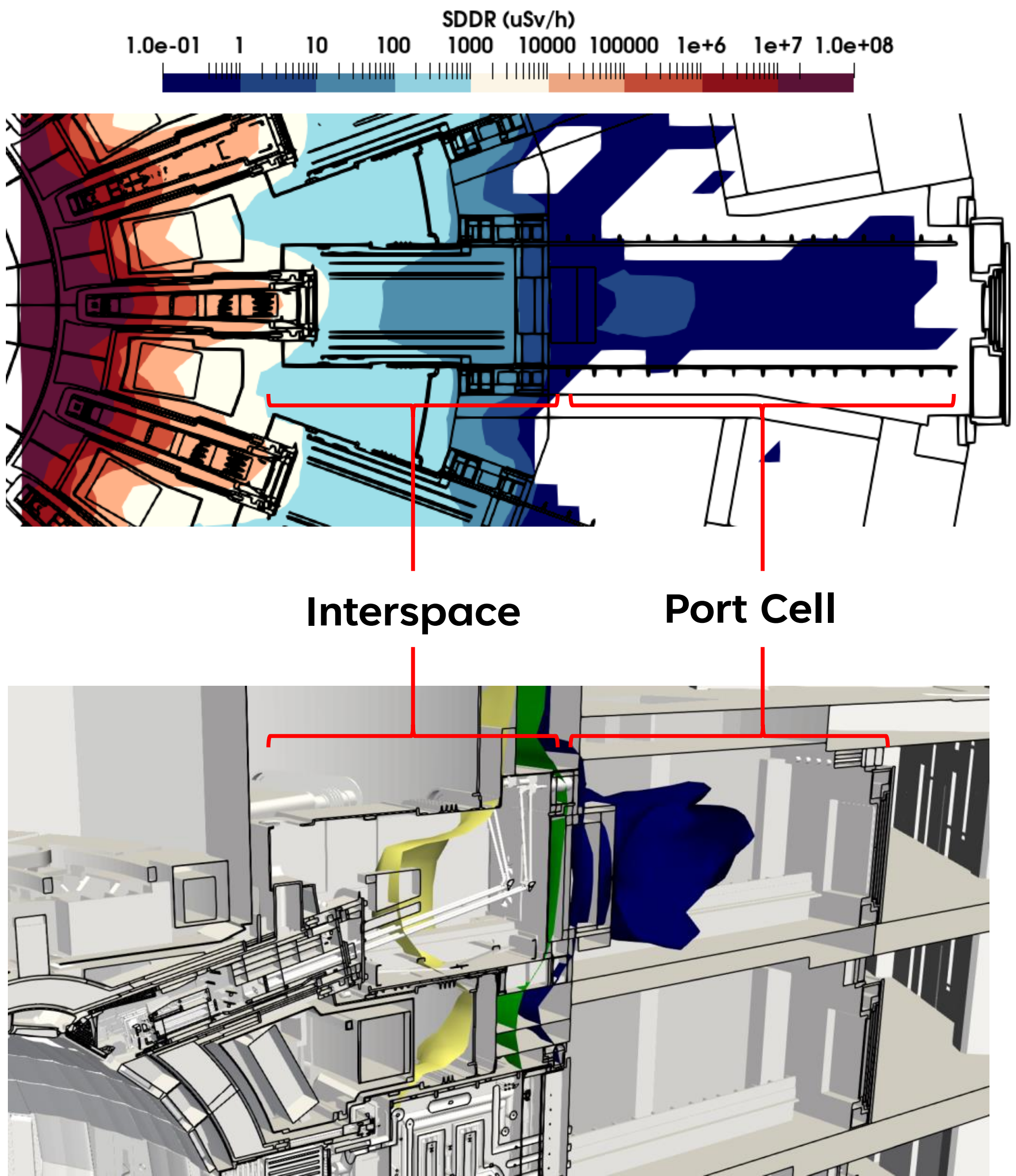
Accumulated dose

Isosurfaces displayed

Dose rate

Map

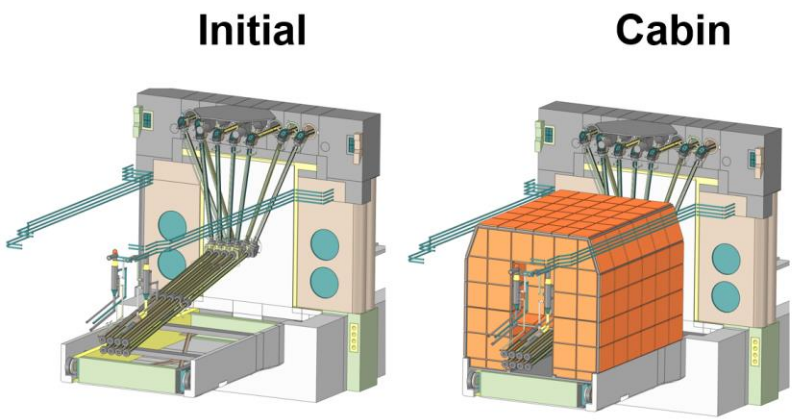
Example I: Upper port #16



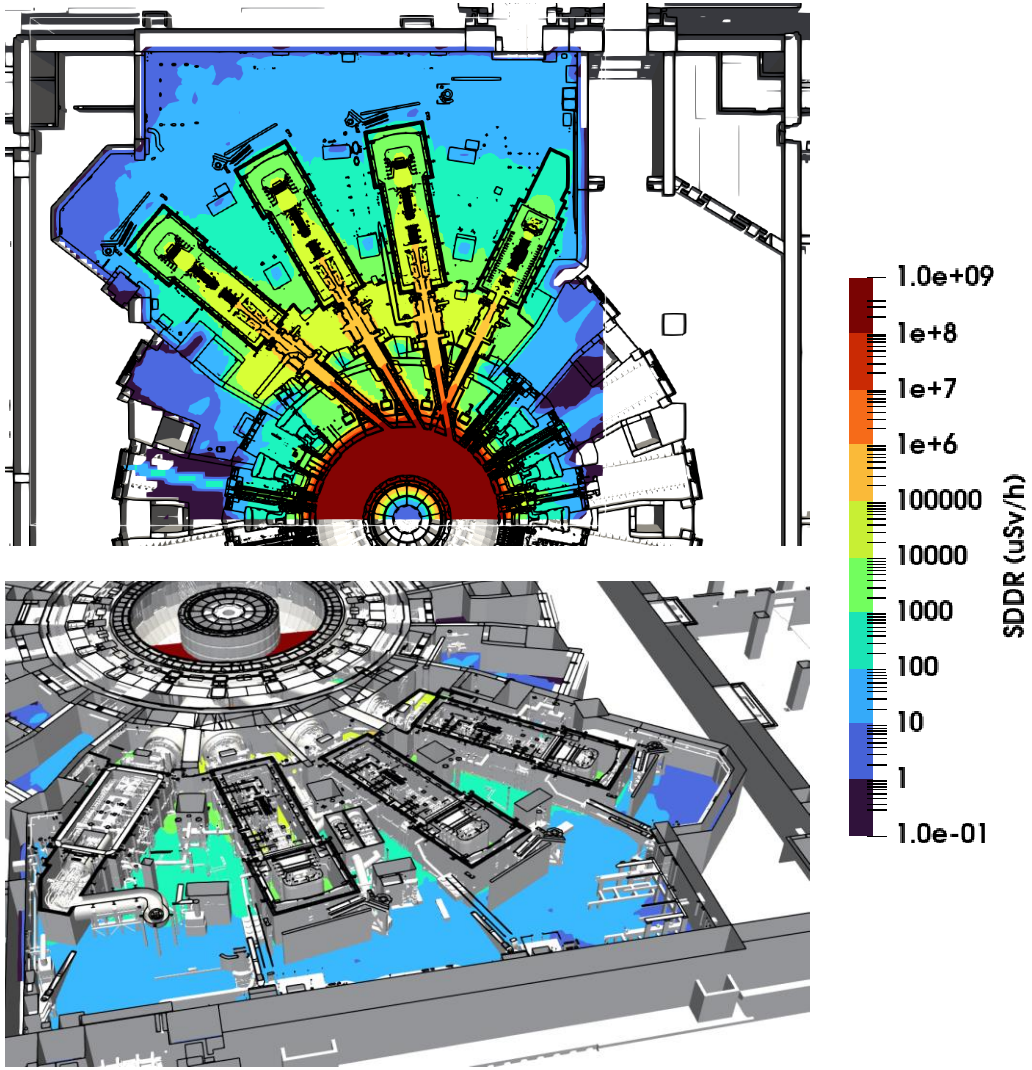
14 Dose Reduction Measures:

- Inspections behind the bioshield
- Eliminate the helium bottles
- Eliminate the inspection requirements
- Implementation of shielding cabin
- …

Factor x6 reduction in the ORE



Example II: Neutral Beam Cell



9 Dose Reduction Measures:

- Thicken the lead front walls
- Alternative gamma shielding
- Reduction of the Co impurities
- Local shielding of the RH preparation area
- Relocation of the SVS boxes
- Remote inspection of PHTS valves
- Move LAC to lower dose rate area
- Remote inspection of UP feedthroughs
- Refine the ACPs inventory

Factor x3 reduction in the ORE

Example III: Upper Pipe Chase

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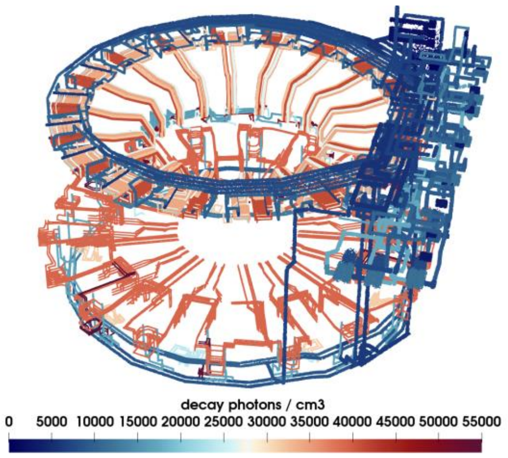
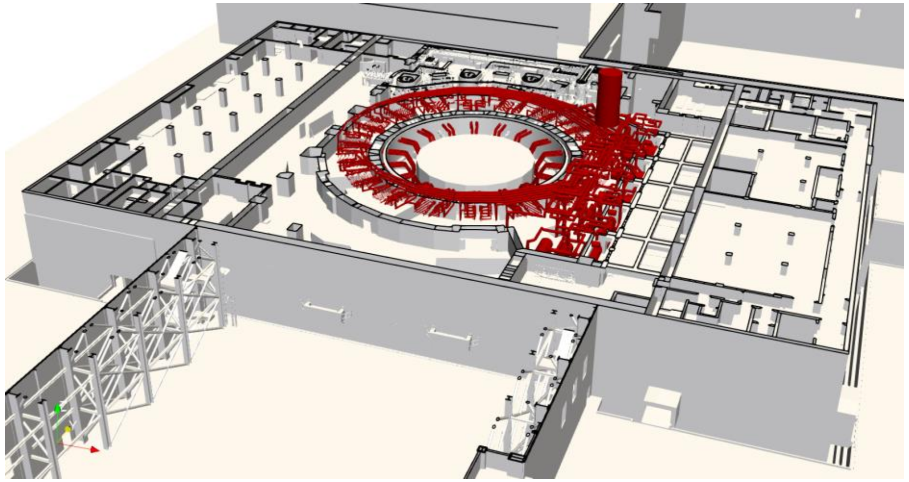
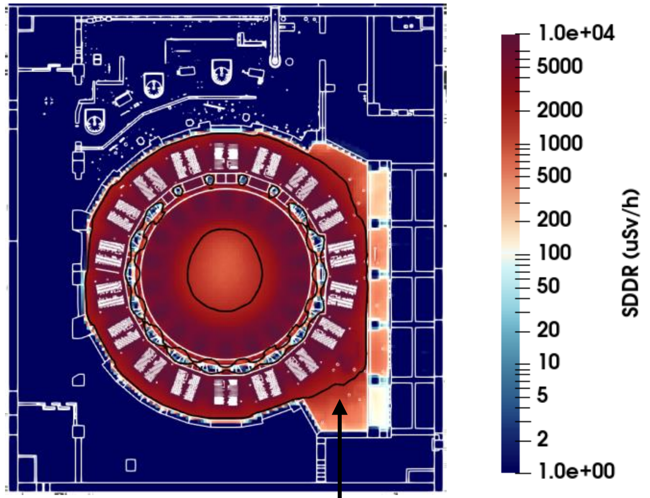
Activated Corrosion Products radiation source







2000 µSv/h

17 Dose Reduction Measures:

- Chemical cleaning of the IBED Heat Exchanger
- Add shielding around heat exchangers
- Reduce pump shaft length
- IBED Pump vibration monitoring
- …

Despite the work done, high SDDR is observed, still with large uncertainty

→ SDDR > 2000 µSv/h leads to inconclusive ORE estimate

→ Workforce has been created to reduce the uncertainty due to Activated Corrosion Products and a roadmap is established

Conclusions

Key points of the integrated ALARA approach implemented at ITER since 2019:

- A guiding thread with "ALARA states" for dose prediction, formalization of iterations, and optimization has been implemented
- Formalized ALARA states (reports, DRM, DRM tracker) in workshops with stakeholders
- A zone-based approach including a "future operator" perspective allows for building a common approach for interventions in a nuclear environment.

Despite efforts dose rate often exceeds the targeted constraints near the machine. ITER's collective dose still need to be optimized, and the ALARA approach continued.

Reflections are ongoing on the optimization of the ITER scientific program incorporating the main outcomes from the integrated ALARA approach implemented in this work

Thank you!