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EUROfusion

Shutdown Dose Rate Assessments due to Water Contamination in EU-DEMO Primary Heat Transfer Systems

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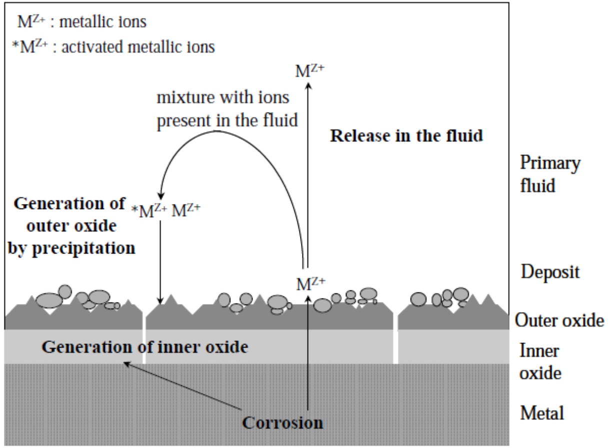
Background

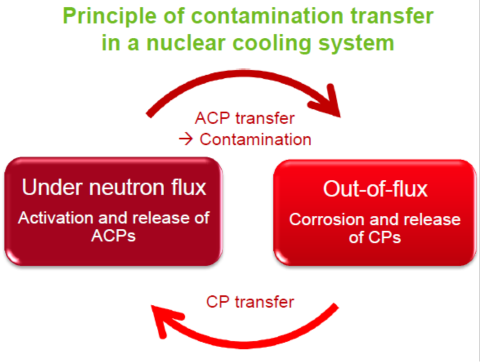
"Since the beginning of the development of water-cooled nuclear power reactors, it has been known that the materials in contact with water release some of their corrosion products into the water."

*"The growth of **gamma radiation fields** around the surfaces of out-core materials was noted from the beginning of the development of nuclear power reactors."* (From IAEA-TECDOC-1672)

From IAEA TEC-DOC 1672



Courtesy F. Dacquait



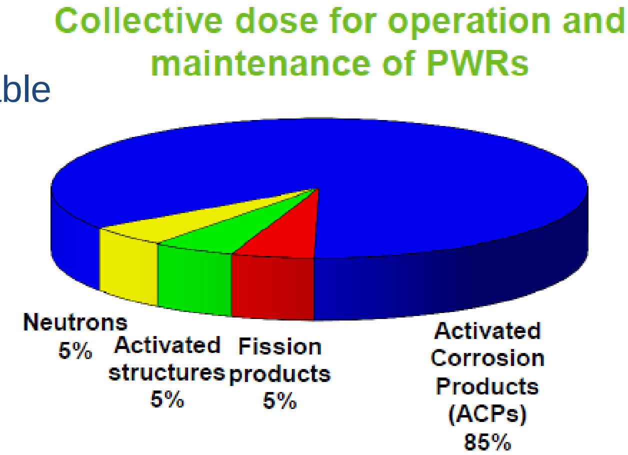
System walls exposed to water release corrosion products into the coolant. They are transported into the vessel where they can deposit and become **activated**. In-core or in-vessel activated corrosion products are released into the coolant. They could be **incorporated in the ex-vessel surfaces and generate radiation fields.**

Background (cont'd)

Water Contamination: The Activated Corrosion Products problem in Water Cooling Systems

The ACP determination is fundamental in safety analyses and source term quantification in Fusion Power Plants for the following reasons:

- **Occupational dose.** Important gamma emitting radionuclides are contained in form of deposit, inner oxide, particle in suspension, and ions in solution.
- **Maintenance plan definition** (e.g. inspectability, filter and resins replacement frequency, etc.)
- **Machine availability**
- **Waste management**
- **Accident consequence estimation** (some ACP are in form of mobilizable source terms)
- **Component qualification.**



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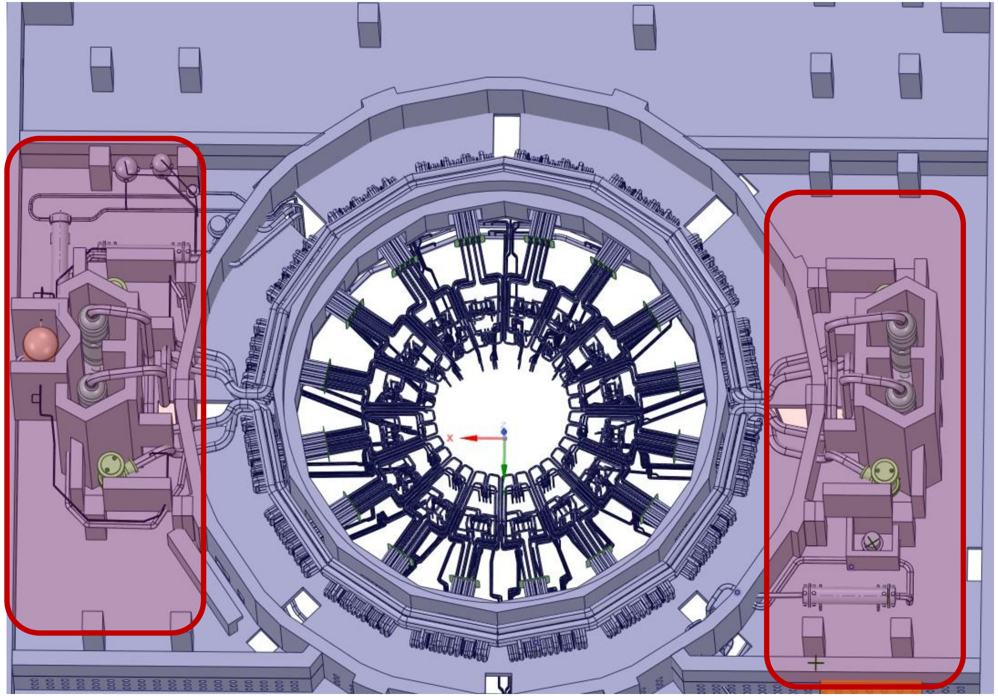
Scope of the activity and expected results



Main goal:

To provide **dose rate maps** around the most important components of EU-DEMO Primary Heat Transfer System (e.g. Divertor, Breeding Blanket).

Heat Exchangers, Steam Generators, Cold and Hot legs, Pumps etc. (requiring preventive and scheduled maintenance)

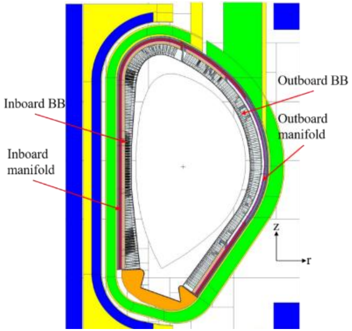
Time considered:
At the end of each maintenance shut-down + relevant cooling times.

Methodology

The methodology relies on a 3 main steps scheme:

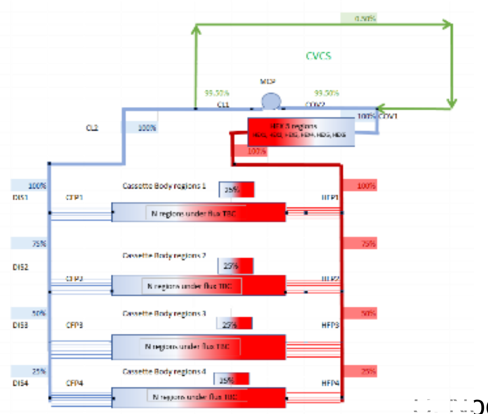
1. Activation reaction rate calculation
2. OSCAR-Fusion modelling and calculation for ACP estimation
3. Gamma transport with MCNP 6.2 + pipe_source patch

Activation Reaction Rate calculation, generally calculated using Monte Carlo means.

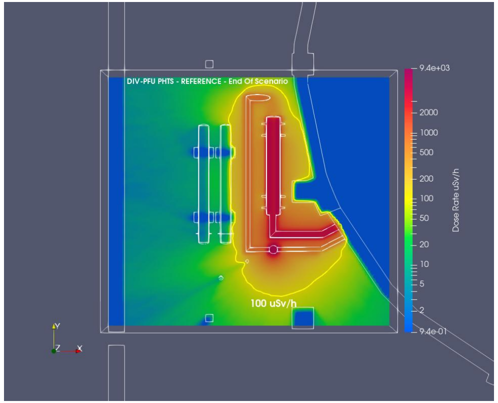


OSCAR-Fusion:

- Input: RR+TH+Chem+Geo etc.
- Output: ACP inventories per component



Gamma Transport for SDDR maps, e.g. MCNP



Methodology (cont'd)

- **Integral reaction rates** must be calculated for OSCAR-Fusion for activation reactions.
- They should be **representative of the RR in the water cooling pipes** under neutron flux.
- **Several methodologies** are used in the fusion community (single RR tallies in MCNP, two steps i.e. $\sum \phi \times \sigma$, production rates from FISPACT, etc.)

Integral RR

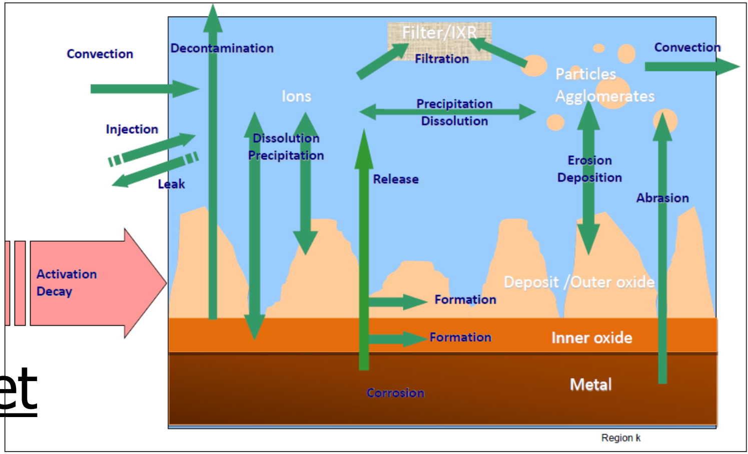
- RR are included in the **NUCLEO database** of OSCAR-Fusion
- OSCAR-Fusion solves the **Bateman equation** together with the mass balance equation for material transport and component contamination
- Requires **thermal-hydraulics, chemistry, geometrical, operational, and technological modelling** of the system

ACP

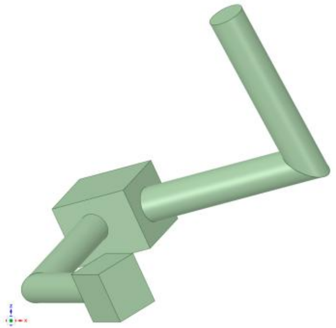
- ACP are processed with **ActiGamma** to have gamma lines and intensities.
- The pipe_source patch is used to define "**tagged pipes**"
- **Gamma emitting surfaces and volumes** are defined according to the surface activity provided by OSCAR-Fusion
- The gamma transport is executed by MCNP.

Computational Tools

- ✓ **OSCAR-Fusion V1.4a:** tOol for Simulating ContAmination in Reactor, derived from OSCAR -> originally developed for **PWRs** by **CEA** in collaboration with EDF and Framatome. Validation based the French nuclear fleet (~430 EMECC campaigns)

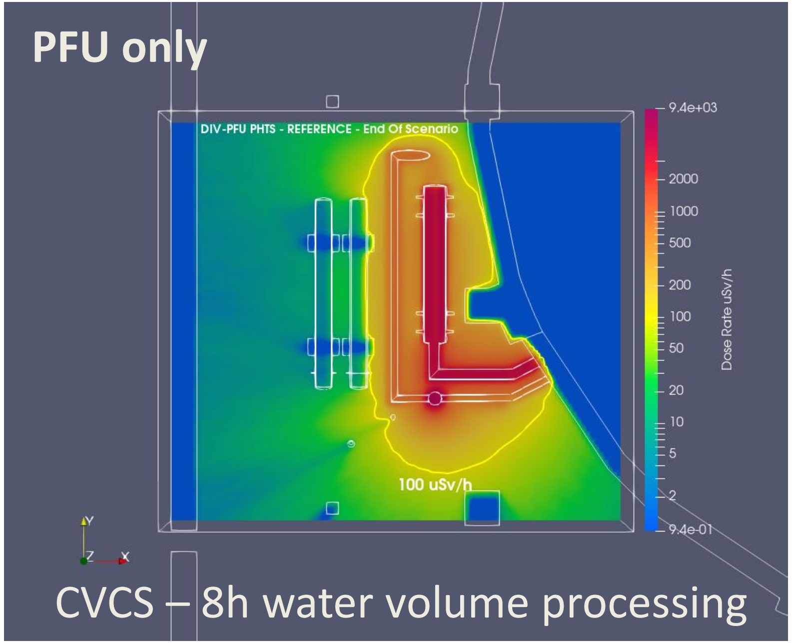


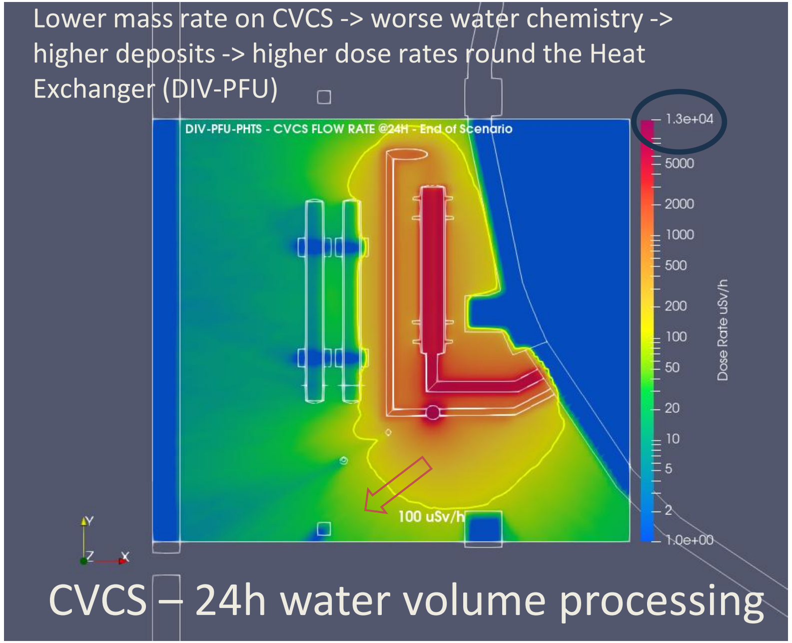
- ✓ **Pipe_source patch for MCNP 6.2:** developed by **UKAEA**. Sampling from either cylindrical, right-angled-parallelepipeds (cubes) or curved corners.



Preliminary Results

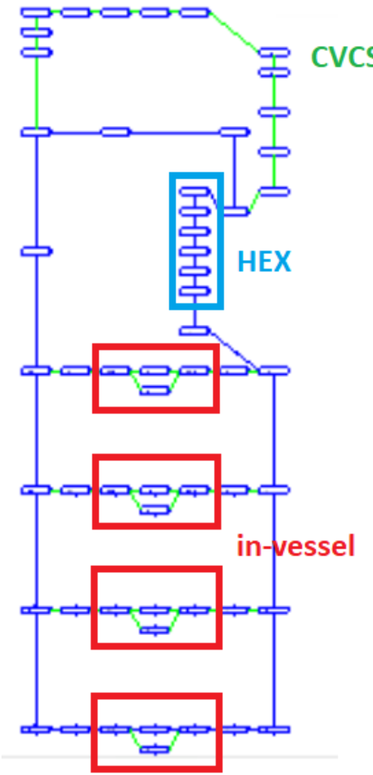
- Parametric results have been produced for the DIV-PHTS of EU-DEMO at the end of each Maintenance shut-down.
- The effect of the design choices, especially on the CVCS has been investigated.
- Important dose rates levels have been calculated, but results are still preliminary.





Main Issues:

- A **three-steps calculation scheme** is quite **complicated and error-prone**. Python scripting has been adopted to automatize the whole process.
- **Error propagation is an issue**. Biases from nuclear data, corrosion laws etc. combine together and propagates in a long calculation chain.
- **MCNP+OSCAR+MCNP** is a **CPU time-consuming** calculation chain. **Far away from what is done in nuclear industry** (e.g. **NARMER** a point-kernel+build-up radiation protection code used in France, derived from MERCURE and developed by CEA)
- OSCAR and MCNP **modelling is extremely time consuming**. A feature that is not suitable to an evolving design, which might require parametric calculations.



Outlook and Conclusions

- A three-steps calculation scheme based on **MCNP and OSCAR-Fusion** has been put in place to **estimate shut-down dose rates** around the most important components of the PHTS of EU-DEMO.
- Preliminary **results are produced on the DIV-PHTS**.
- Developments and calculations on the BB-PHTS are ongoing (ACP results are produced).
- Intrinsic water activation results can also be used (e.g., from ACABLoop, results provided by M. Garcia)
- The issues linked to the **complexity of the methodology** and error propagation have been highlighted.
- Future work will examine the possibility to use simplified MCNP models or point-kernel codes.

Acknowledgements

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FNM Organizing Committee here in Madrid.

Thank you for your attention

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