# FISSION AND FUSION WATER COOLING CIRCUITS: CHEMISTRY, CORROSION MITIGATION AND MATERIALS

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This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarly reflect those of the European Commission.

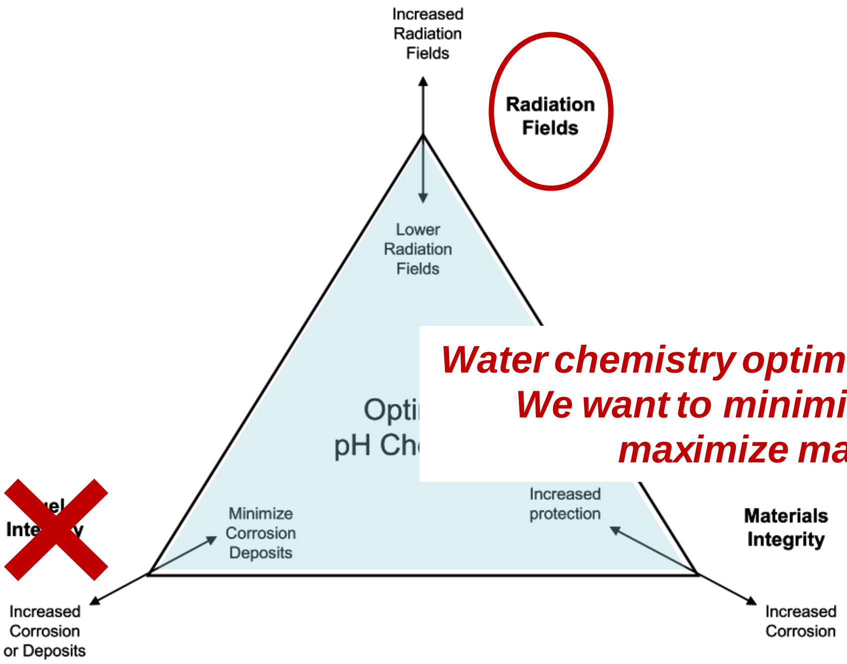
# Fission know-how transfer to fusion

Water chemistry and corrosion mitigation strategies

Activated Corrosion Products simulation

Steels development for Gen IV reactors and fusion

# Water chemistry optimization in fission plants



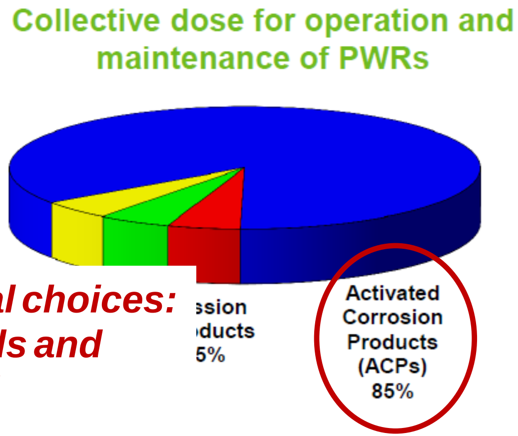

***Water chemistry optimisation + material choices: We want to minimize radiation fields and maximize materials integrity!***

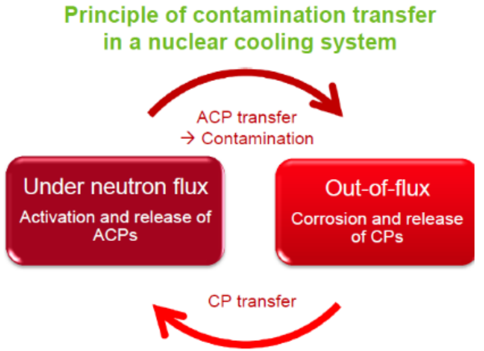
EPRI, Pressurized Water Reactor Primary Water Chemistry Guidelines

7.4

$pH_T$ ↑ corrosion release rates ↓ fuel cladding corrosion ↑

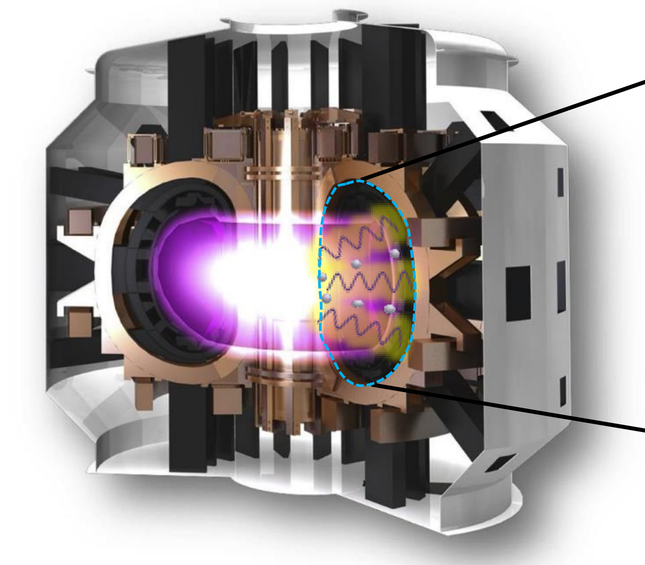
6.9 Li



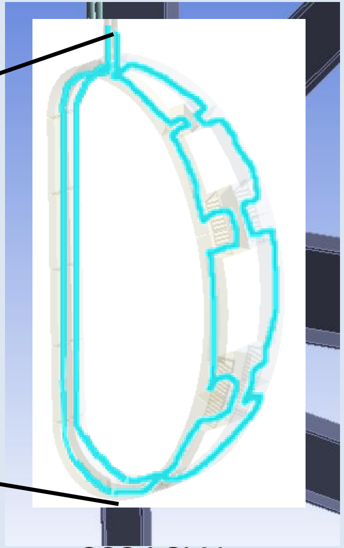
# Fusion experiments: JT60SA, KSTAR, DTT

Vacuum vessel operates as a neutronic shield through the use of enriched boric acid



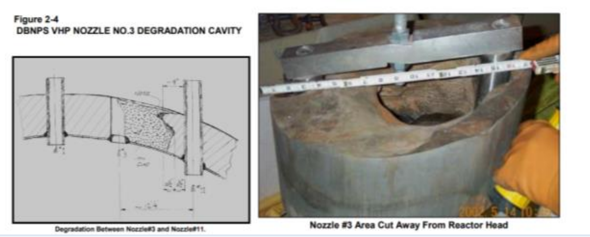
G. Di Gironimo, Fusion Engineering and Design 146, Part B, 2019, 2483-2488

## Water & Borated water in DTT VV



SS316LN

Borated water (8000 ppm B, enriched with 95% of $^{10}B$) 50-80 °C



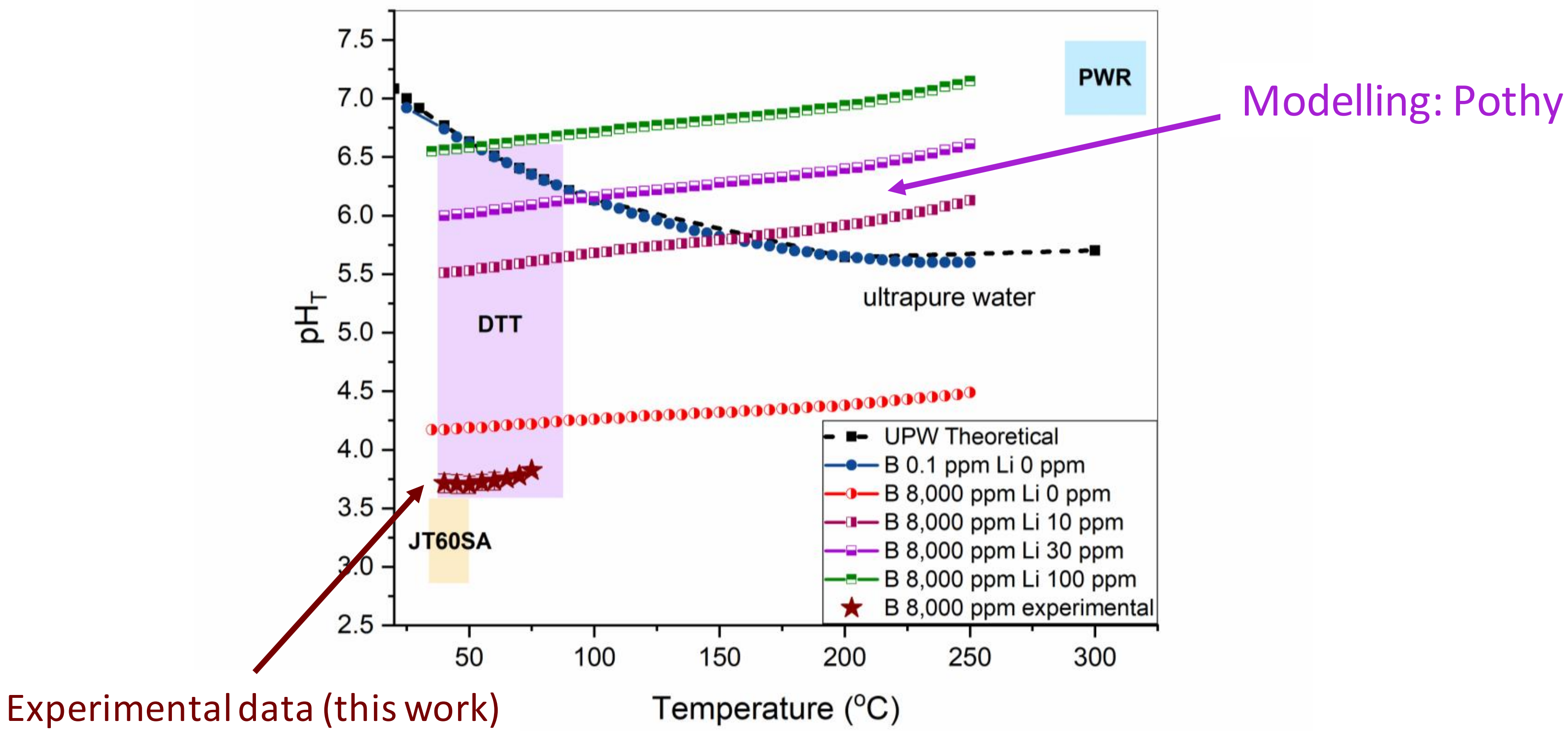

**Borated water corrosion on steels (60 years experience in PWRs/VVERs!)**

Eg: $B(OH)_3 + 2H_2O = B(OH)_4^- + H_3O^+$

$H^+ + e^- = H$

$Fe = Fe^{2+} + 2e^-$ or $Fe^{3+} + 3e^-$

# $pH_T$ borated water: experiments vs modelling

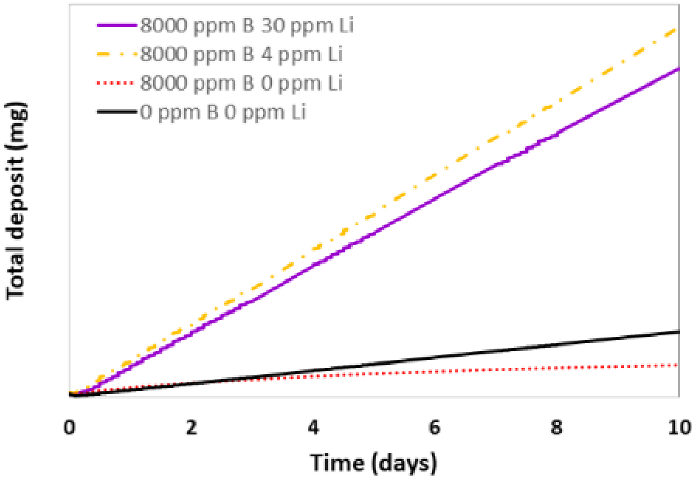


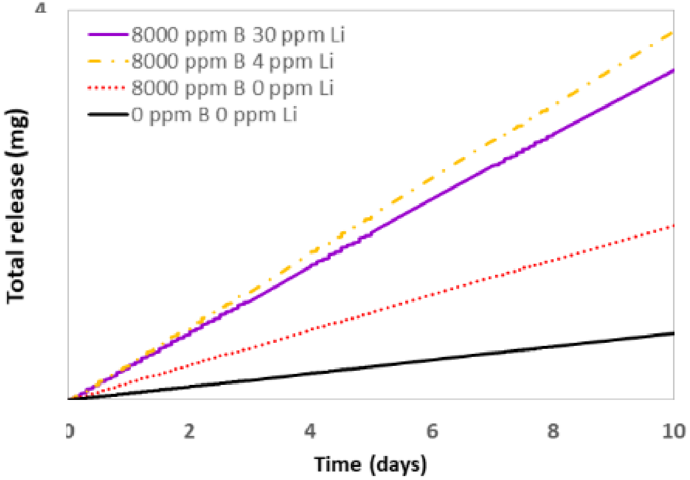

- **Discrepancy between pH stated in JT60SA and DTT (pH stated=4.5) and experimental data (pH=2.8 and 3.6 )**
- Modelling overestimated concentrated borated water solutions $pH_T$

# Releases and deposits in a simulated loop

**8000 ppm B 0 ppm Li** → $pH_{80°C,\ experimental}$ = 3.6 → $pH_{80°C, PACTITER\ v2.1}$ = 4.23 → $pH_{300°C, PACTITER\ v2.1}$ = 4.7

**8000 ppm B 30 ppm Li** → $pH_{80°C, PACTITER\ v2.1}$ = 6.11 → $pH_{300°C, PACTITER\ v2.1}$ = 7.04




- Borated water (no LiOH added) beneficial in minimizing corrosion releases and mass deposits → This seems counterintuitive as adding LiOH increases pH!
- DTT operates at 80 °C and probably will not consider $H_2$ injections (oxidizing conditions may be present)
- PACTITER v2.1 cannot represent oxidizing conditions, its release module is well represented for T> 200°C

# OSCAR Code for predicting ACPs fission/fusion

- Simulation of contamination transfer in nuclear reactor systems during power operation and during cold shutdown (PWR: 20-350 °C - **reducing/oxidizing - acid/alkaline**)
  - ✓ Calculation of masses/activities of CPs/ACPs/FPs/Actinides in solid/liquid/gaseous phases of nuclear circuits as a function of time (normal operation over several decades and transients over minutes/hours)
  - ✓ Development of a calculation code since 70's: **OSCAR** (merge of former PACTOLE and PROFIP in 2008) **O**util de **S**imulation de la **C**ont**A**mination en **R**éacteur

    (t**O**ol of **S**imulation of **C**ont**A**mination in **R**eactor)

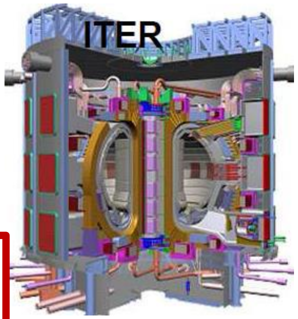
- ✓ **OSCAR** originally developed by CEA for **PWR** in collaboration with EDF and Framatome

  Validation based on a large OPEX unique in the world (~420 EMECC spectrometry campaigns)

  Last version: OSCAR V1.4 released in 2021

- ✓ **Application to ITER:** PACTOLE-ITER (1995) **PACTITER** (1995-2010)

  **OSCAR-Fusion** (2016)




It requires as **input corrosion & releases rates**
(we need to measure them !)

EMECC: Ensemble de Mesure et d'Etude de la Contamination des Circuits (assembly of measuring and study of circuit contamination)

# PWR experience - Dampierre 1

Image of Dampierre-1 nuclear power plant (900 MWe) and its cooling circuit simulation with OSCAR code

https://www.flickr.com/photos/karelh/9531207088

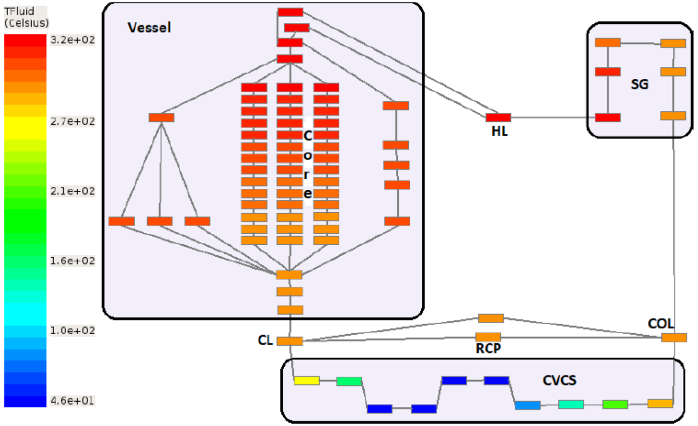
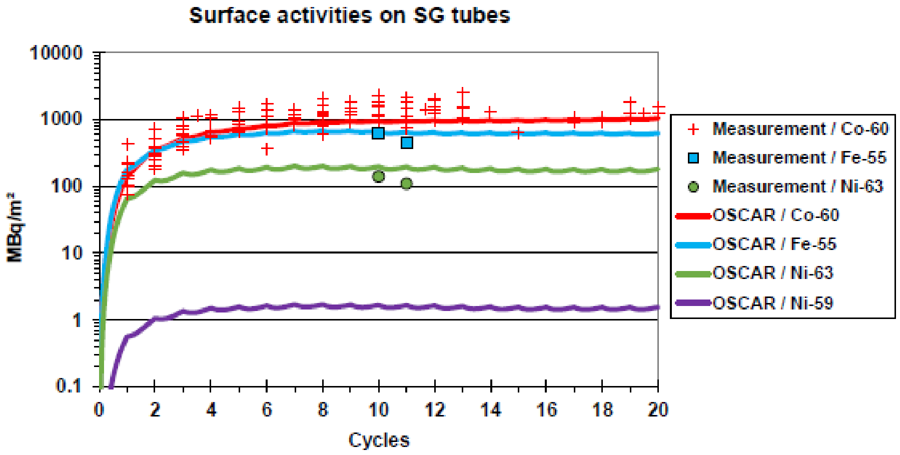


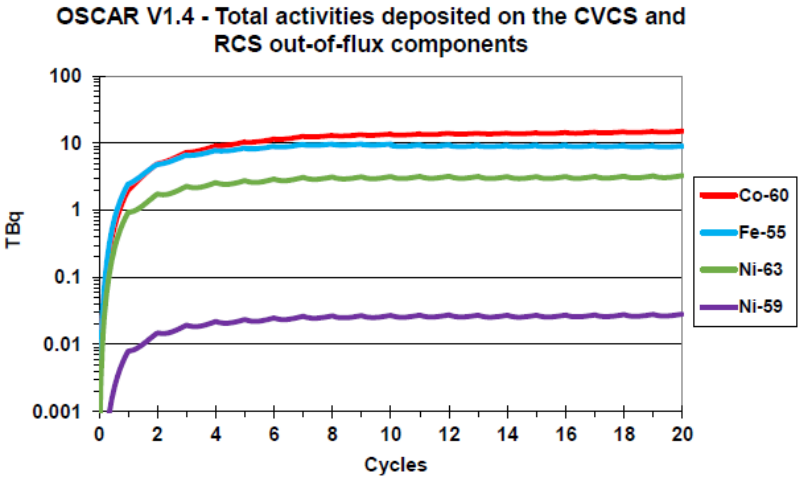

Figure 1. OSCAR - RCS (Reactor Coolant System) and CVCS (Chemical and Volume Control System) nodalization of a typical PWR with a third-core reload fuel management (HL: Hot Leg / SG: Steam Generator / COL: CrossOver Leg / RCP: Reactor Coolant Pump / CL: Cold Leg).

F. Dacquait, "The OSCAR code: a simulation tool to assess the PWR contamination for decommissioning", DEM 2021 – International Conference on Decommissioning Challenges: Industrial Reality, Lessons learned and Prospects, France, Avignon, 2021, September 13|15

# OSCAR simulations ACP vs real data

Simulations of a typical French 900 MWe PWR

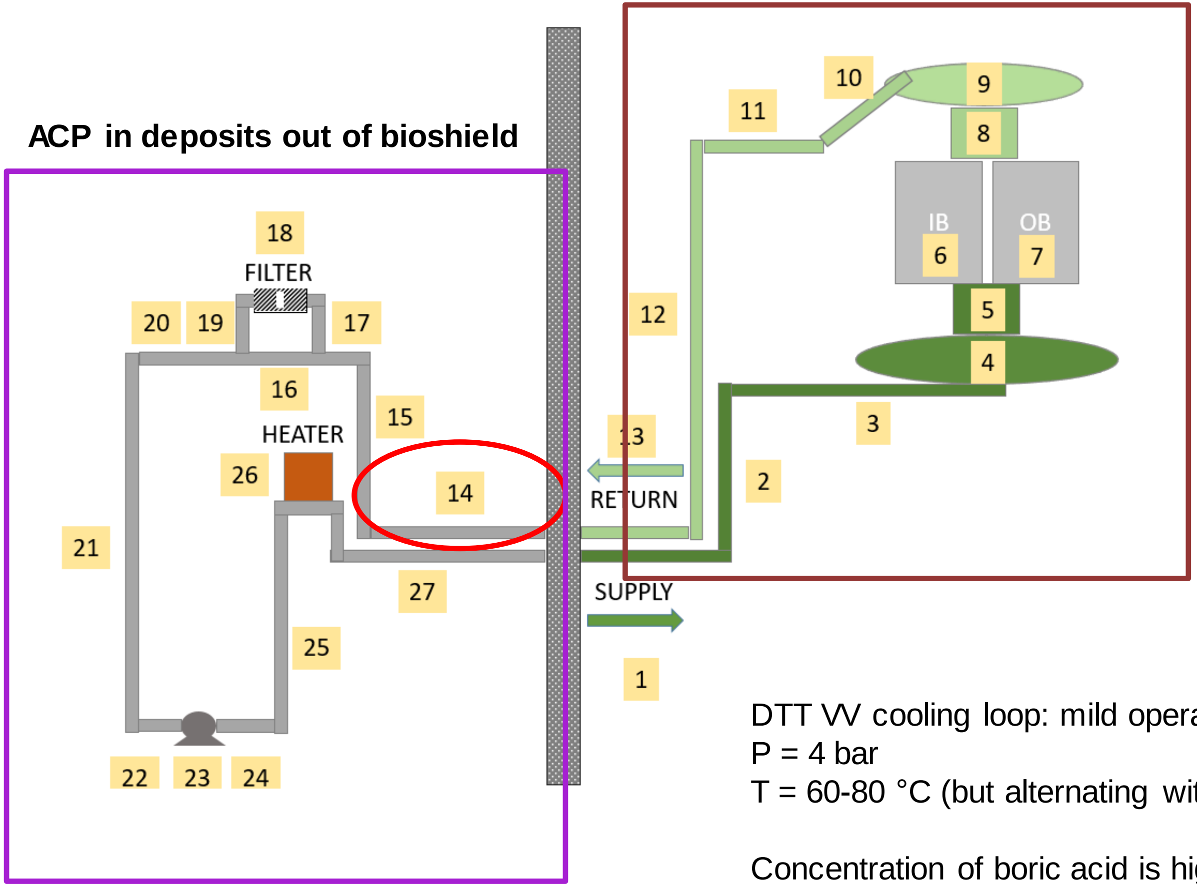


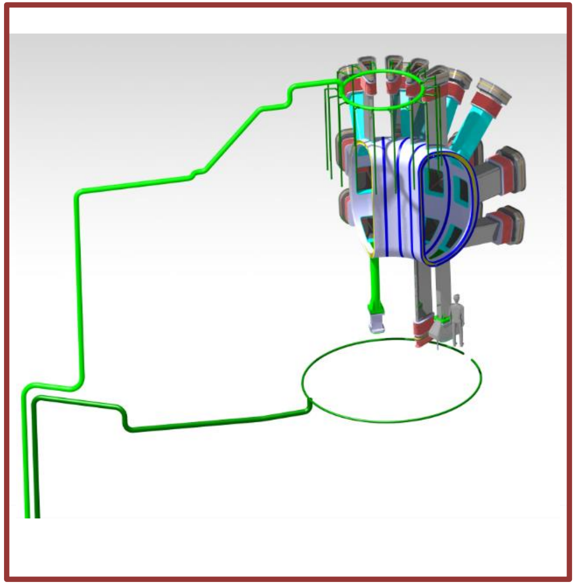




Cycle = fuel cycle = about 300 days

F. Dacquait, "The OSCAR code: a simulation tool to assess the PWR contamination for decommissioning", DEM 2021 – International Conference on Decommissioning Challenges: Industrial Reality, Lessons learned and Prospects, France, Avignon, 2021, September 13|15

# DTT experimental reactor: VV cooling circuit



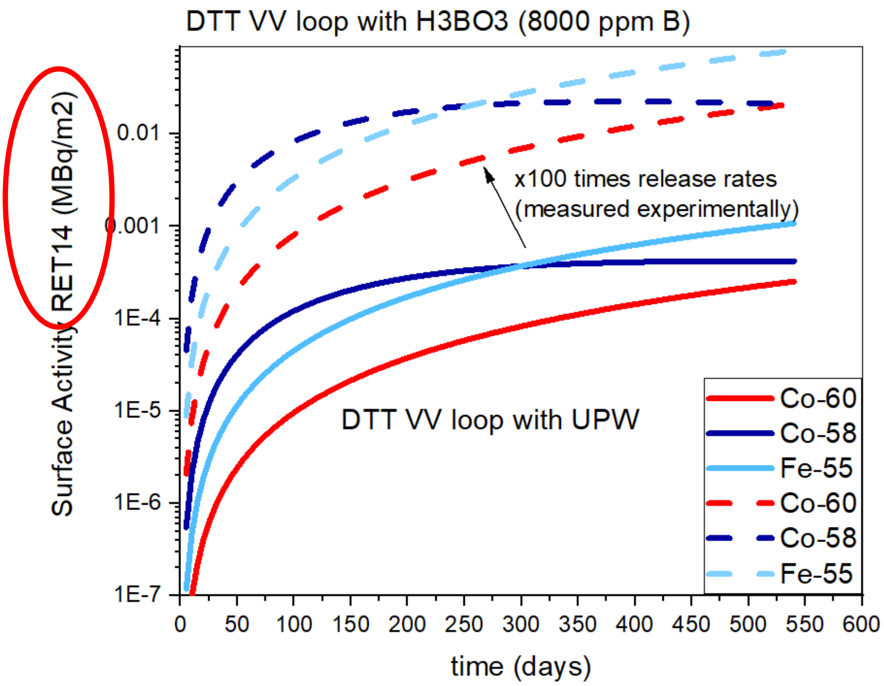



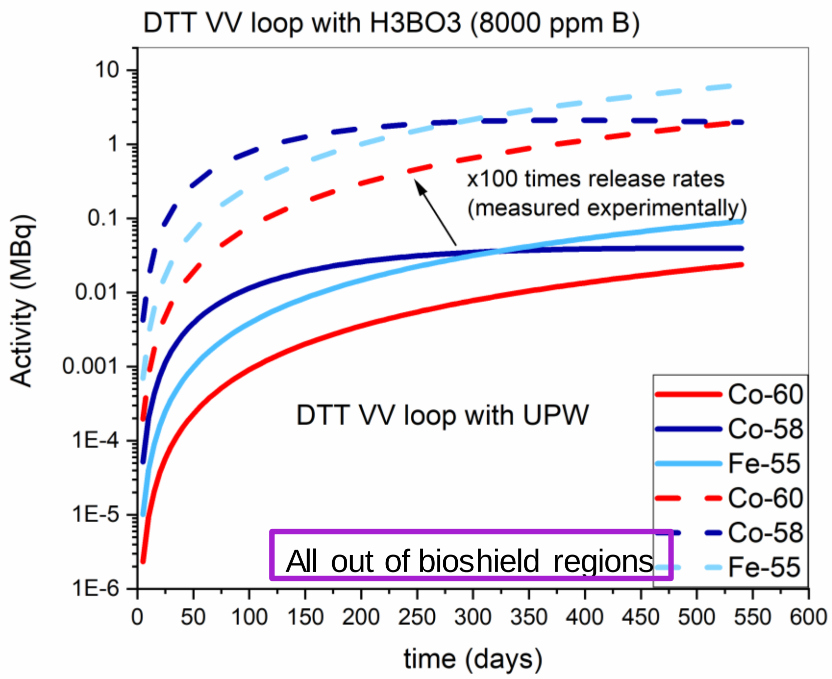
DTT VV cooling loop: mild operating conditions compared to PWRs
P = 4 bar
T = 60-80 °C (but alternating with hot gas 250 ° C)

Concentration of boric acid is high: 8000 ppm B

# ACP in DTT out of bioshield

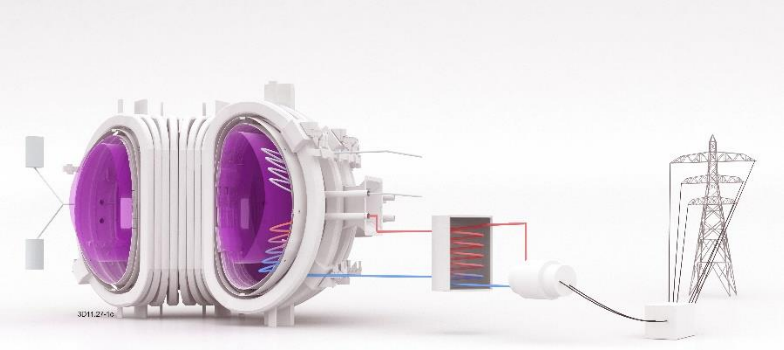
Water chemistry influence on corrosion rate: effect of boric acid on ACP deposition.
OSCAR Fusion (v1.3) cannot simulate water chemistry with large B additions (it was tailored to ITER needs): these simulations run with 1 ppm $O_2$ and 0 ppm $H_2$, no 8000 ppm B can be added

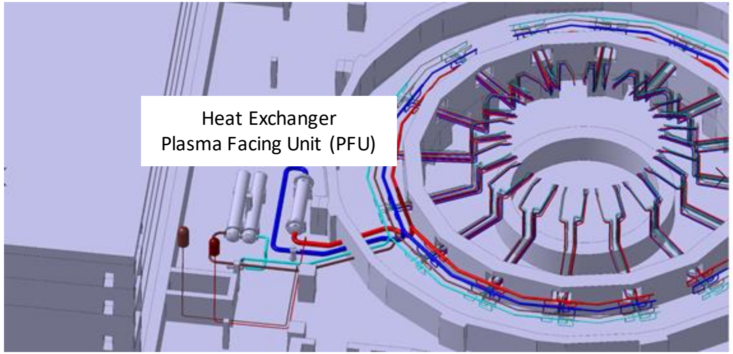


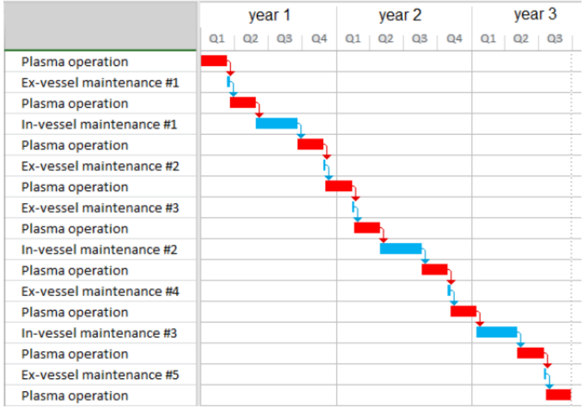

Only ACP in deposits are plotted

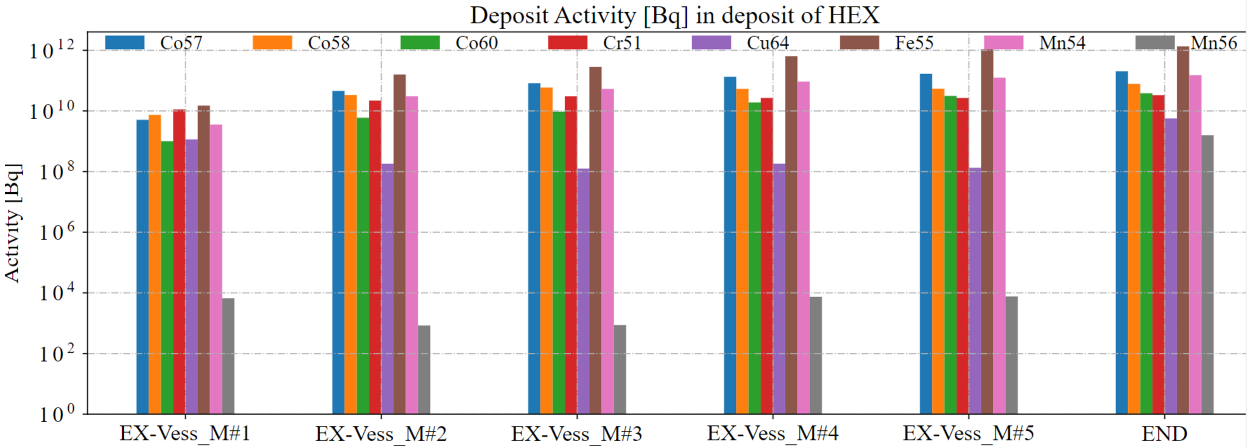
# DEMO: future fusion power plant






In DEMO NPP the ACP inventory for the cooling loop is important



# Ferritic martensitic steels: Gen IV & Fusion

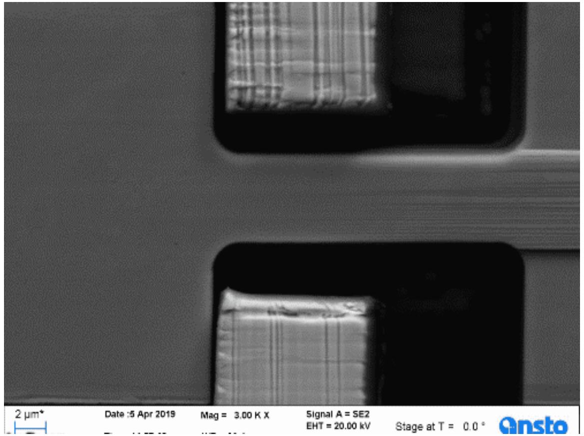
FISSION → Gen IV reactors development for P91 and T91 steels : temperature 600 °C along with a neutron damage of 0.01 dpa/year

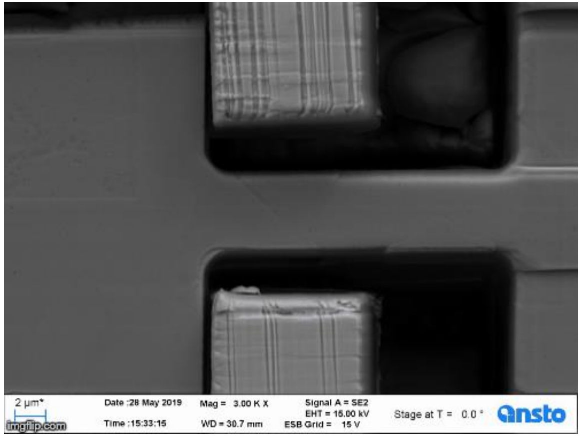
**Reduced activation**: reduce production of long lived radionuclides. Control over Co → $^{60}$Co, replacement of Mo → $^{93}$Mo (with W or V) and Nb → $^{94}$Nb (with Ta)

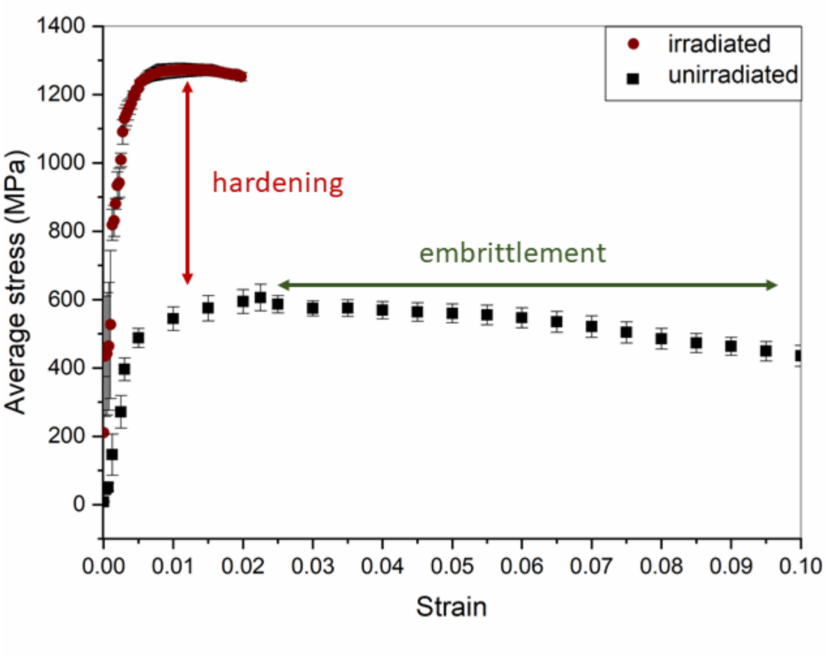
FUSION → EUROFER97 steel to withstand 0.6-6 dpa and at temperatures of 20-600°C is needed

| element | 316LN wt% | FISSION T/P91 wt% | FUSION EUROFER97 wt% |
|---|---|---|---|
| Cr | 16 – 18 | 8 – 9.5 | 8.5 – 9.5 |
| Ni | 10 – 14 | 0.4 | 0.005 |
| Mo | 2 – 3 | 0.85 – 1.05 | 0.005 |
| Mn | 2 | 0.3 – 0.6 | 0.2 – 0.6 |
| P | 0.045 | 0.02 | 0.005 |
| S | 0.03 | 0.01 | 0.005 |
| Si | 0.75 | 0.2 – 0.5 | 0.05 |
| C | 0.03 | 0.08 – 0.12 | 0.09 – 0.12 |
| N | 0.1 | 0.03 – 0.07 | 0.015 – 0.045 |
| W | | | 1 - 2 |
| Ta | | | 0.1 |

# Steels testing at microscale



# Conclusions

- Fission power plants have extensive experience on water chemistry and corrosion mitigation strategies in cooling circuits → this can benefit fusion experimental reactors and future fusion power plants

- Simulation of ACPs is routinely conducted in PWRs for Occupational Radiation Exposure (ORE) monitoring → fusion community is using the same codes for reactor design optimization

- 9% Cr ferritic/martensitic steels have been optimized for Gen IV reactors. Fusion community is developing Reduced Activation FM steels.

- The synergy between the two communities can accelerate the deployment of fusion reactors as well as offering a low activated steel for both communities in the future

# Thanks for listening ! Any questions?

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