



Enhancing the safety of concrete structures for long term operation

Annual Nuclear Conference: Life After 60 – Long Term Operation of
Nuclear Power, Stockholm, 22.1.2025

Miguel Ferreira, ACES Project Coordinator
VTT Technical Research Centre of Finland Ltd.

Table of content

ACES Overview

What knowledge GAPS?

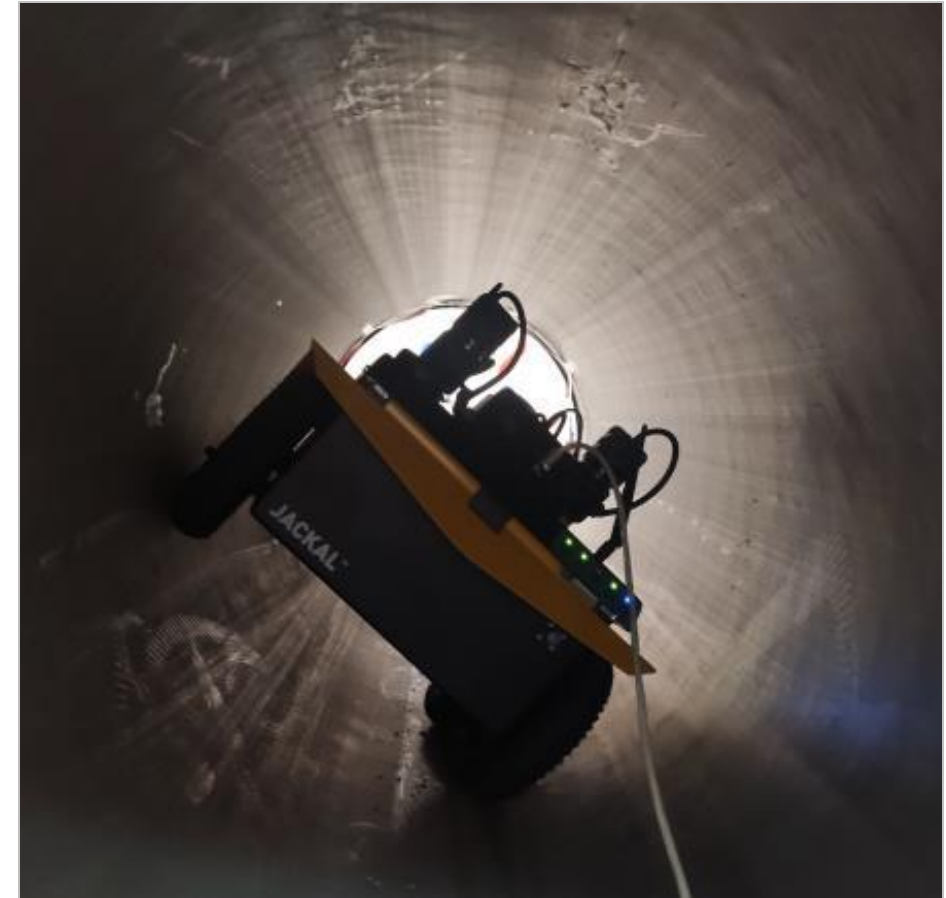
Corrosion of embedded liners in concrete

Internal swelling reactions of concrete

Creep and shrinkage of prestressed
concrete during operation and accidents

Effects of prolonged irradiation of the CBS

ACES Final Project Workshop



Robotic platform and measuring device manipulator prototype development (WP2, CEA)

ACES

Towards improved Assessment of safety performance for long-term operation of nuclear Civil Engineering Structures



- **Duration:** 57 months (September 2020 – May 2025), EC extension approved 1.2024.
- **Budget:** 5.4 M€ total, of which EC contribution of 3.99 M€
- **Call:** Euratom NFRP 1 (2019): Ageing phenomena of components and structures and operational issues (RIA)
- SNETP/NUGENIA awarded ACES the “NUGENIA Label” (2019NUG0070)

ACES – Work packages

- **WP1 – State-of-the-art of quantitative assessment of ageing of concrete SSC**
SCK•CEN, Diederik Jacques (diederik.jacques@sckcen.be)
- **WP2 – Corrosion assessment of embedded liners in concrete**
ZAG, Andraž Legat (andraz.legat@zag.si)
- **WP3 – Characterization, prediction and monitoring of ISR in concrete**
IRSN, Christophe Marquie (christophe.marquie@irsn.fr)
- **WP4 – Delayed strains of containment in operational & accidental conditions**
EDF, Jean-Luc Adia (jean-luc.adia@edf.fr)
- **WP5 – Assessing the performance of irradiated concrete.**
CTU, Petr Štemberk (stemberk@fsv.cvut.cz) & ORNL, Yann Le Pape (lepapeym@ornl.gov)
- **WP6 – Dissemination, communication and training**
CVR, Zbyněk Hlaváč (zbynek.hlavac@cvrez.cz)
- **WP7 – Project management – VTT, Miguel Ferreira (miguel.ferreira@vtt.fi)**

End Users Group

- 1) TVO (Finland, NPP)
- 2) EDF DI (France, NPP)
- 3) Ringhals (Sweden, NPP)
- 4) Oskarshamn (Sweden, NPP)
- 5) EPRI (USA, TSO)
- 6) STUK (Finland, Regulator)
- 7) Kajima Corporation (Japan, TSO)
- 8) Tecnatom/Westinghouse (Spain, TSO)
- 9) IETcc-CSIC (Spain, TSO)
- 10) NNEGC Energoatom (Ukraine, NPP)
- 11) US NRC (USA, Regulator)
- 12) SVTI (Switzerland, TSO)
- 13) GRS (Germany, TSO)
- 14) SWECO (Finland, Consultant)
- 15) ČEZ, a.s. (Czechia, NPP)
- 16) FORTUM (Finland, NPP)
- 17) SÚJB (Czechia, Regulator)
- 18) CSNC (Canada, Regulator)
- 19) URSJV (Slovenia, Regulator)
- 20) Electronuclear (Brazil, NPP)

**5th EUG Seminar –
14.3.2025**

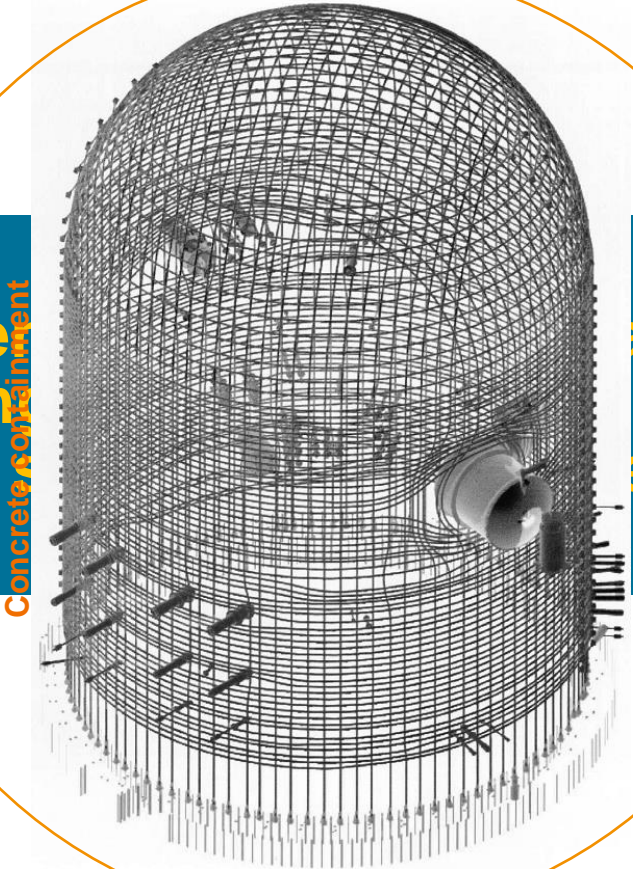
What knowledge GAPS?

ny-rad
Neutron and gamma radiation effects

ISR
Internal swelling reactions (ASR & DEF)

Advance the assessment of structural integrity by addressing knowledge gaps of NPP

Cor.
Embedded liner corrosion



Advance the assessment of civil engineering technology gaps for safe concrete infrastructure

NDE
Non-destructive evaluation

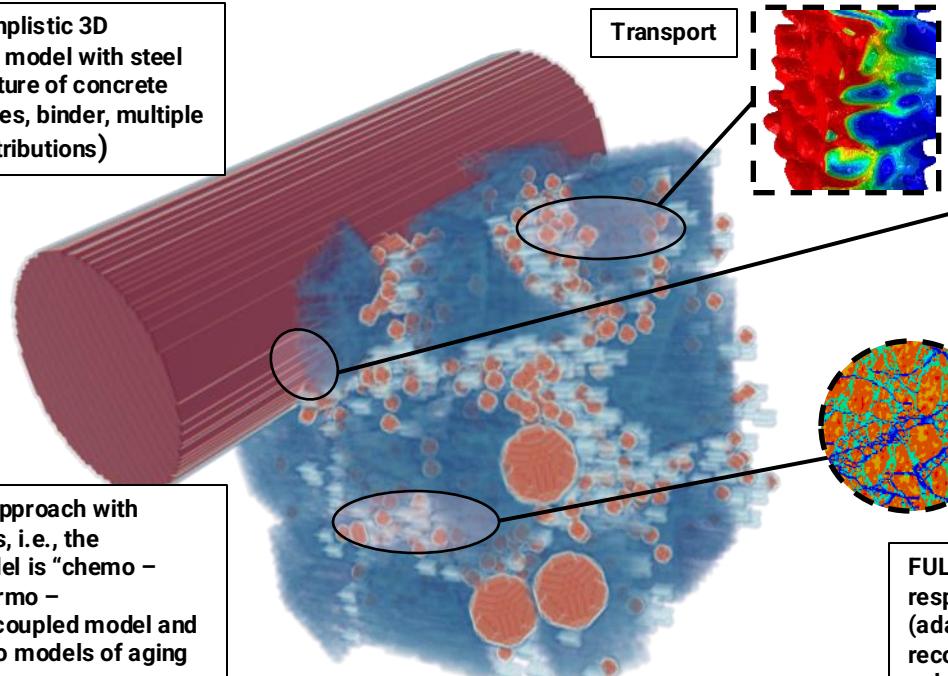
AM
Ageing management

C&S
Creep and shrinkage

How to assess the corrosion of embedded liners in concrete?

- Mechanisms and models of steel corrosion (WP2)
 - Chloride-induced corrosion of SCCP; Crevice corrosion mechanisms of steel liner in containment; Phenomenological modelling of steel corrosion

Section of a simplistic 3D microstructural model with steel and microstructure of concrete (aggregate, pores, binder, multiple spatial size distributions)



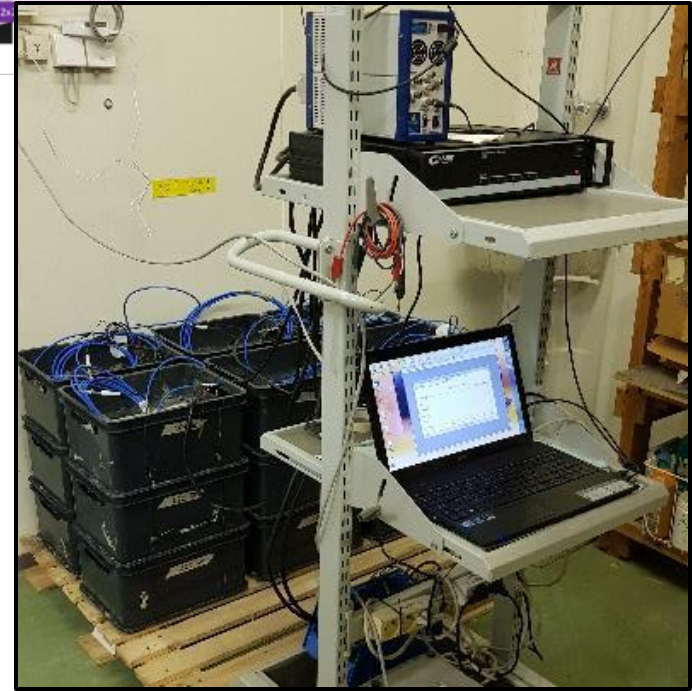
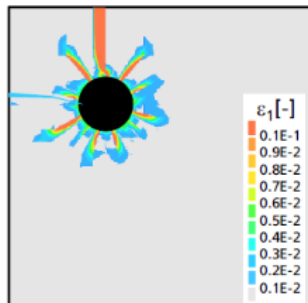
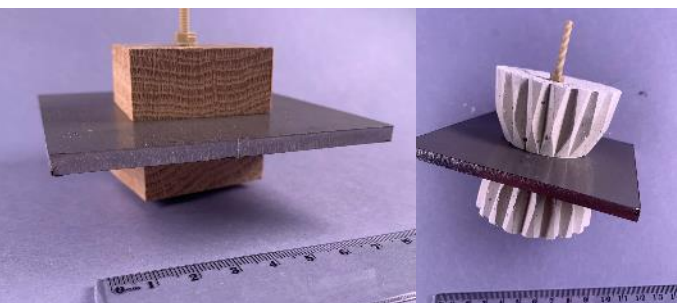
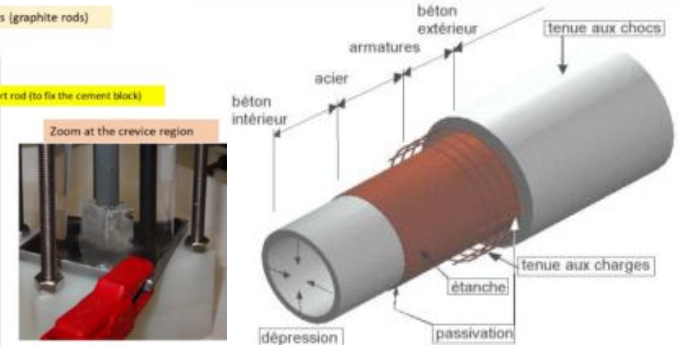
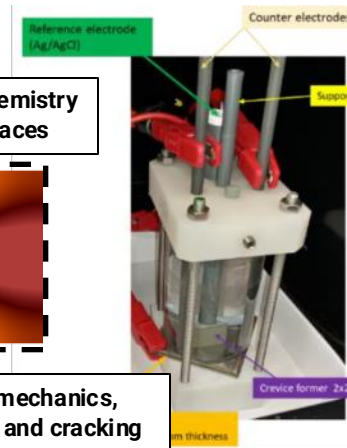
Multiphysical approach with microstructures, i.e., the underlying model is "chemo - transport - thermo - mechanically" coupled model and will be linked to models of aging and degradation.

Transport

Electrochemistry and interfaces

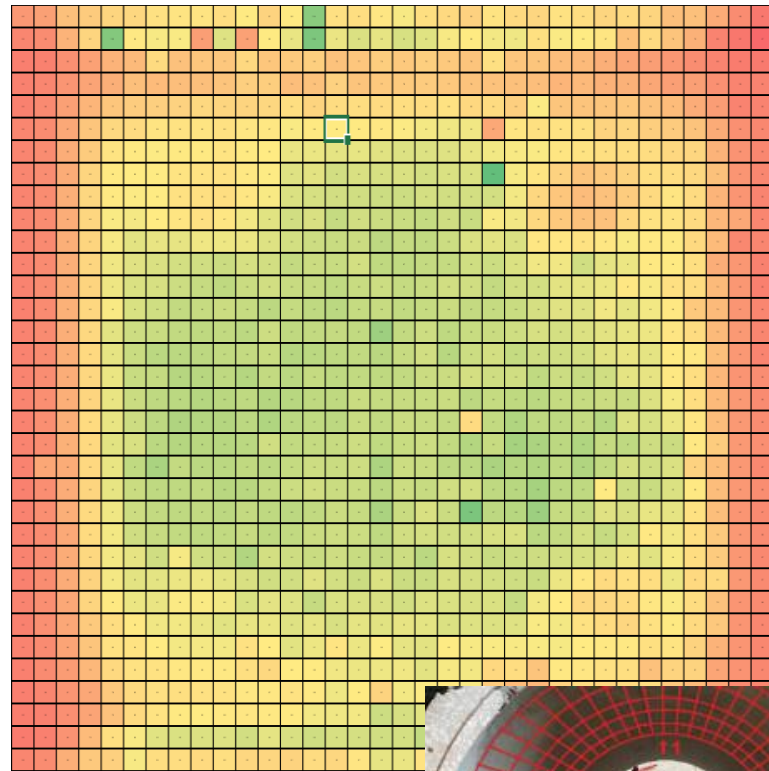
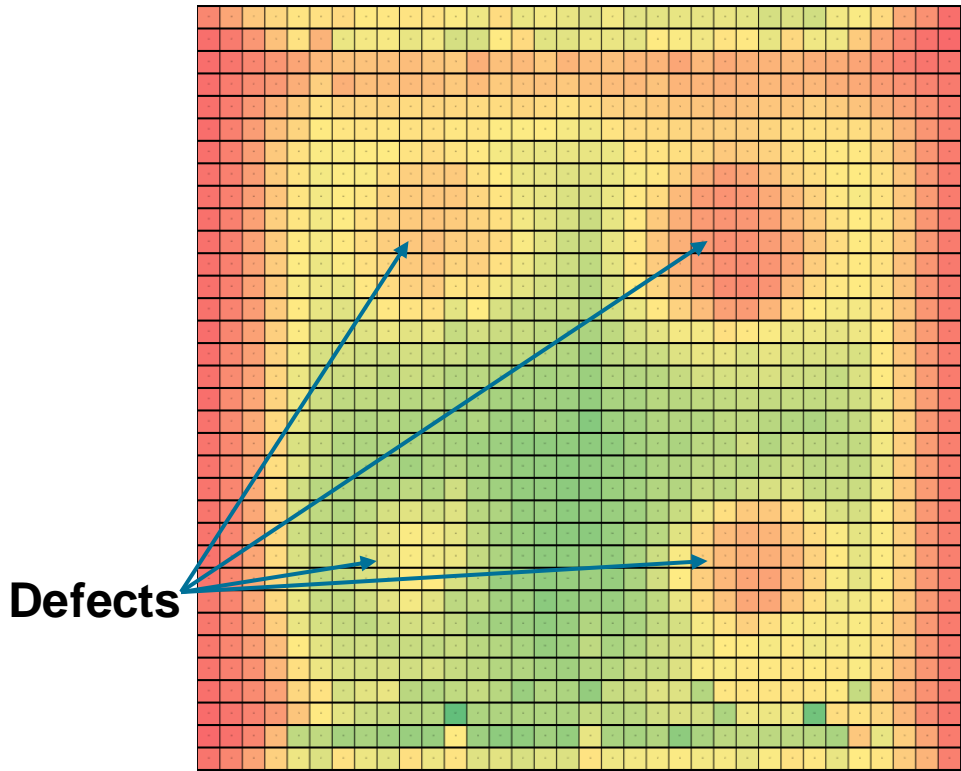
Thermomechanics, damage and cracking

FULL coupling between the respective mechanisms (adaptive model reconstruction during solution)

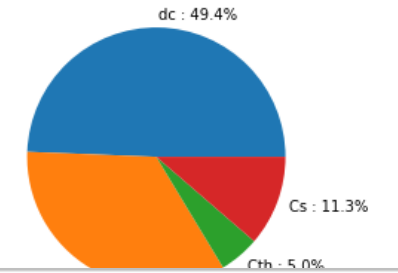


How to assess the corrosion of embedded liners in concrete?

- Probabilistic assessment of corrosion and corrosion inspection (WP2)

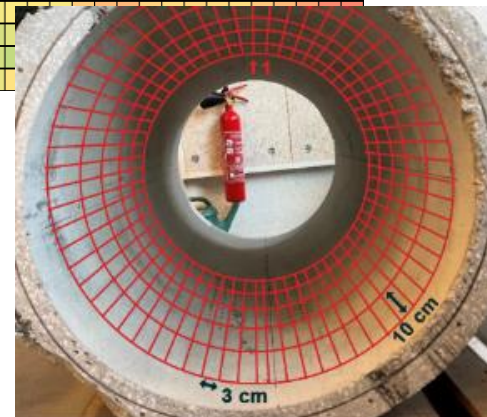
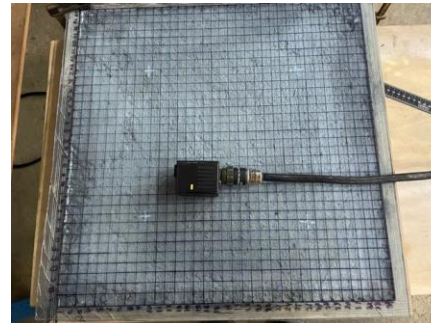
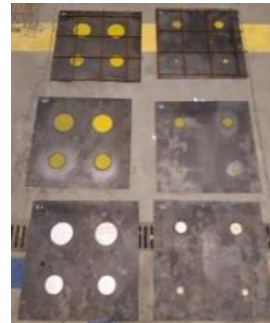
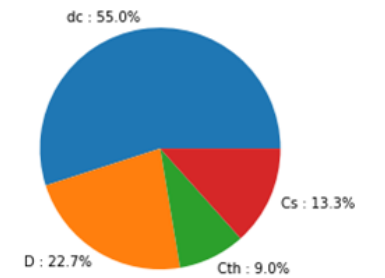


Taylor expansion importance factors - corrosion initiation time



probability of corrosion at $T_i = 30$ years : 0.092

Importance Factors from Design Point - corrosion_exceedance

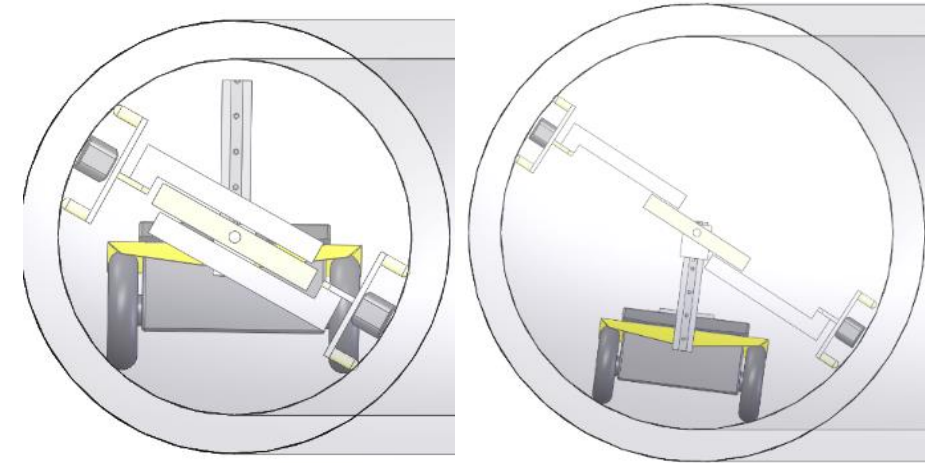
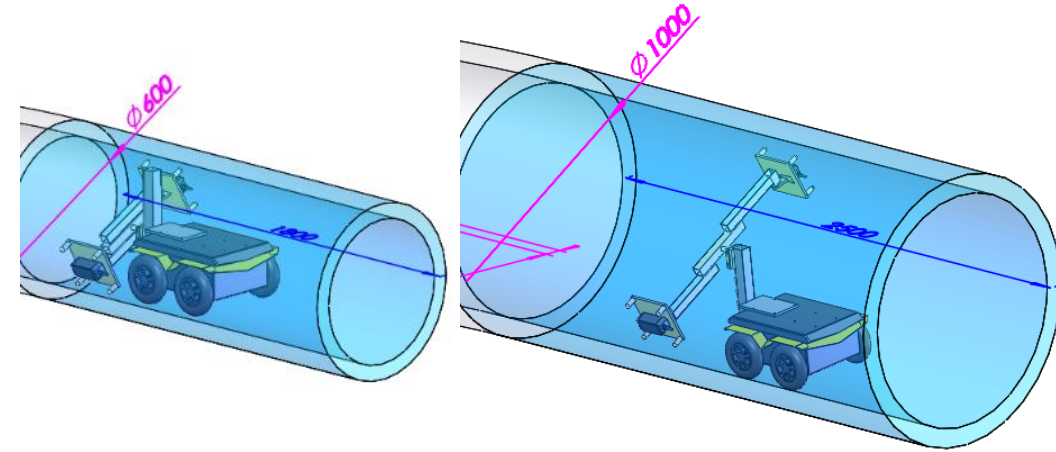


How to assess the corrosion of embedded liners in concrete?

- Robotics diagnosis (WP2)

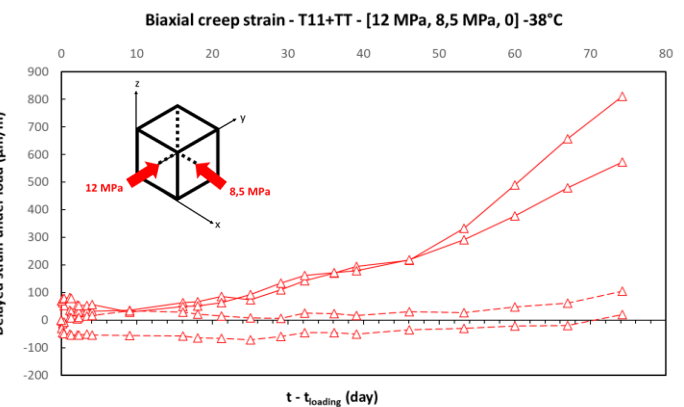
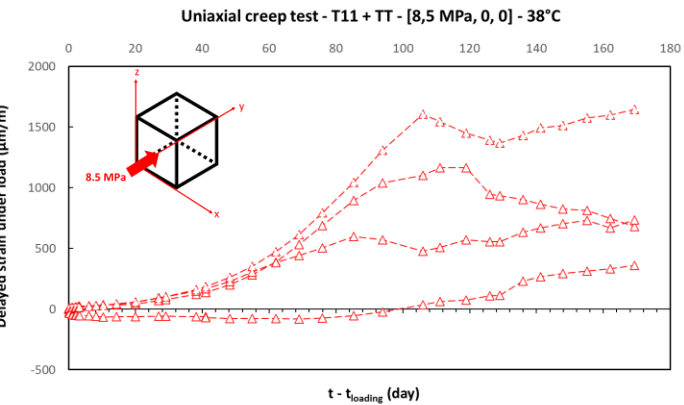
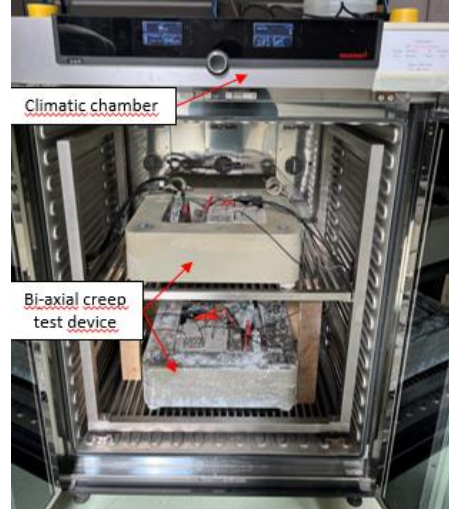
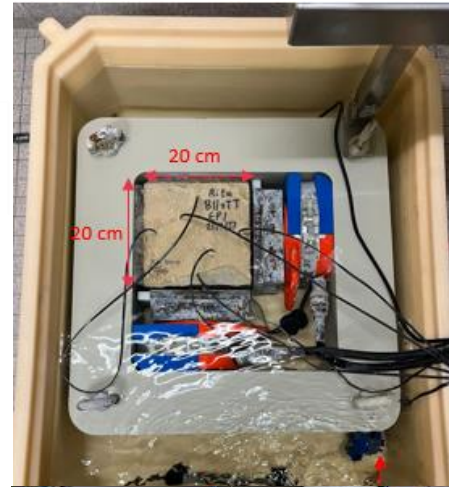
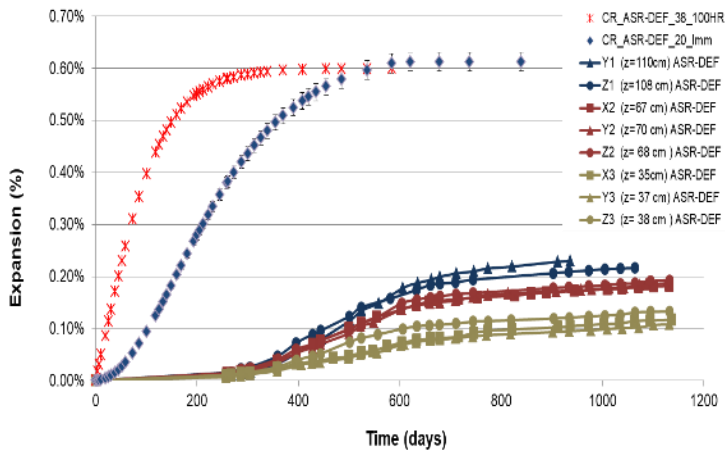
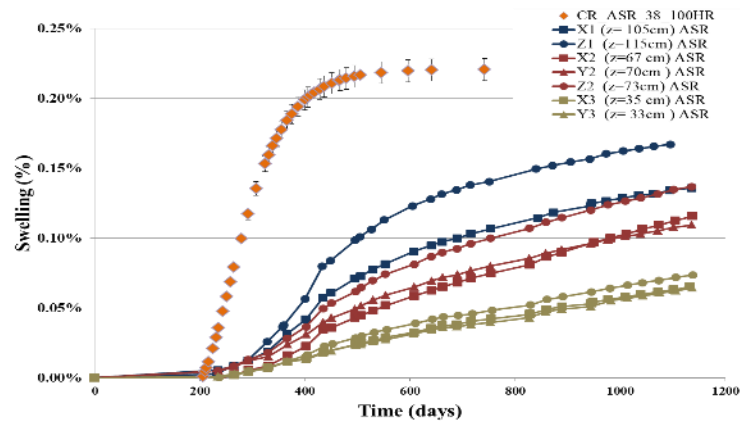
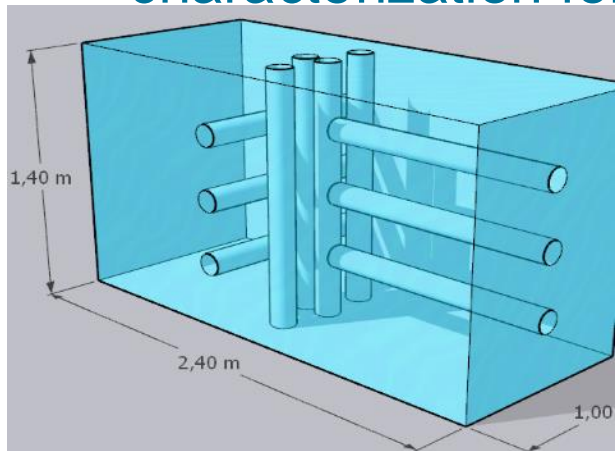


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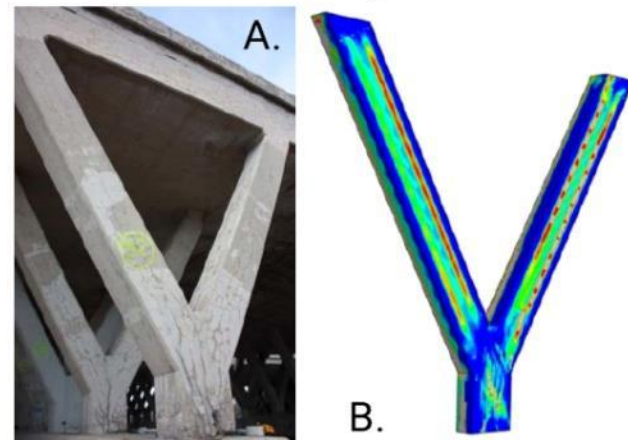
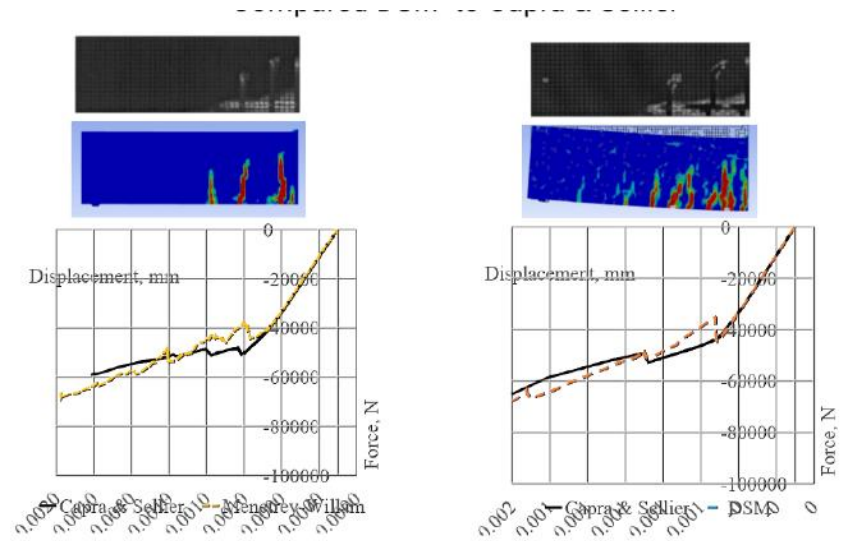
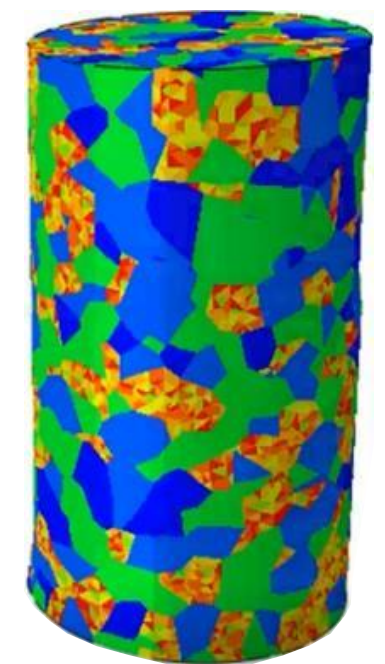
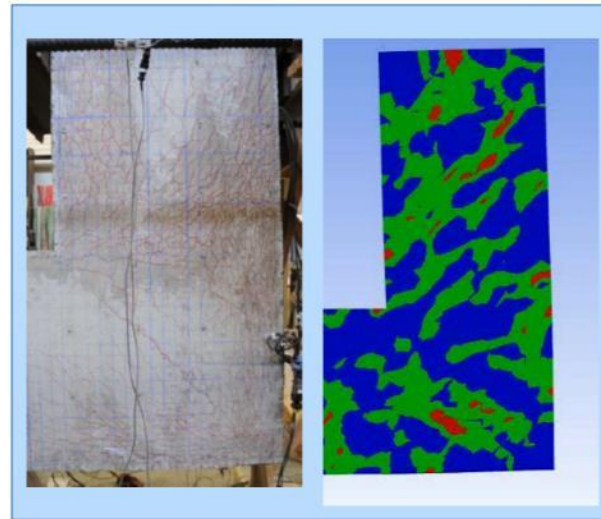
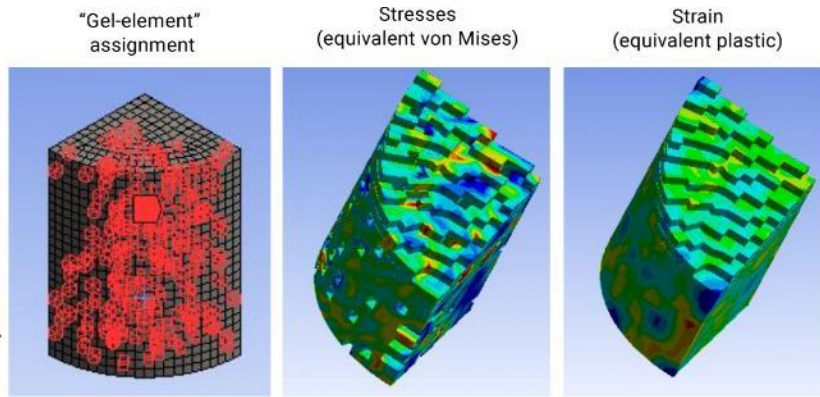
How do Internal Swelling Reactions of concrete impact the performance of the structure?

- Characterization of ISR reactions (WP3)
 - Laboratory to large-scale correlation of ISR; Interaction if ISR with biaxial loading; ISR characterization for modelling



How do Internal Swelling Reactions of concrete impact the performance of the structure?

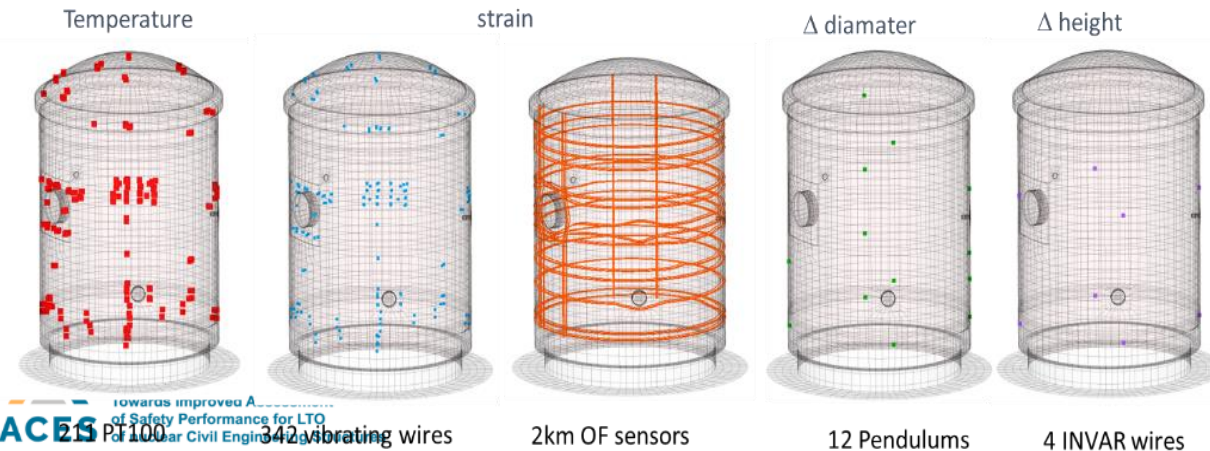
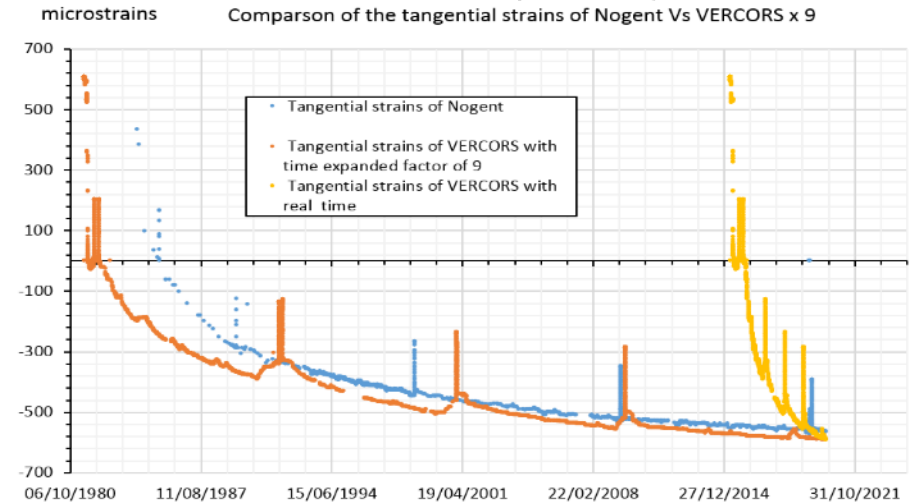
- Multi scale modelling - Macroscale models, Structure scale models (WP3)



How to improve prediction of moisture, strain and stress of prestressed concrete during operation and accidents?

- VERCORS Benchmark 3 - monitoring and material characterization (WP4)

Measured variable	Sensor type	VeRCoRs mock-up	EDF fleet
temperature	PT100 probes	>200	30
strain	vibrating wires	>300	50
diameter variation	plumb-lines	4	4
length variation	invar wires	4	4
rebar strain	strain gages	80	-
water content	TDR	20	-
water content	Pulse	20	-
strain+temperature	optic fiber (OF)	2km	-



6 Dynamometers for instrumented tendons (VW6 + GLOTZL)

- 1 meteorological station
- For the ambient air measure : 10 thermometers, 10 relative humidity sensors,
- 1 atmospheric pressure gage,
- 1 flow meter
- 2 km of optic fiber
- 31 TDR (Time Domain Reflectometry) sensors
- 30 « pulse » sensors (permeability measurement)
- 160 strain gauges on rebars

Temperature PT100 (211)

12 Pendulums

Embedded strain sensors (326)

How to improve prediction of moisture, strain and stress of prestressed concrete during operation and accidents?

- Effect of temperature on drying and strains - Behaviour of VERCORS concrete at temperatures 20-150°C (WP4)



Accidental situation

Intrados :
 $T = 150\text{ °C}$; $RH = 100\%$,
 $P = 5,2\text{ bar}$
 Extrados :
 $T = 25\text{ °C}$ ↑ ; $HR = 55\%$ ↓
 $P = 1\text{ bar}$

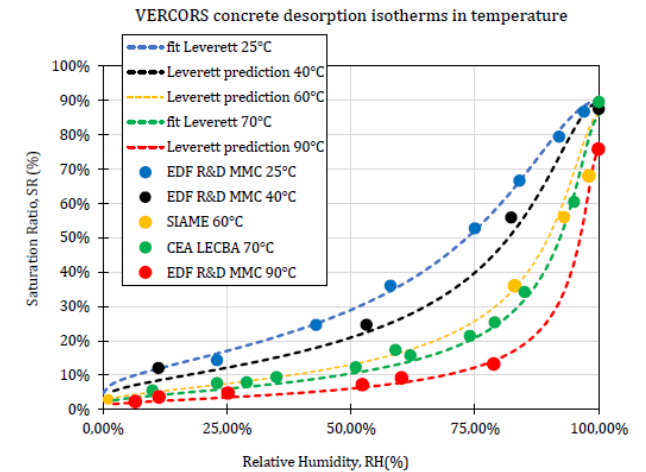
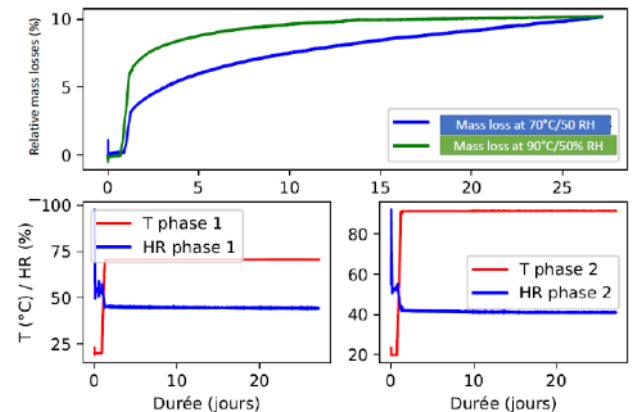
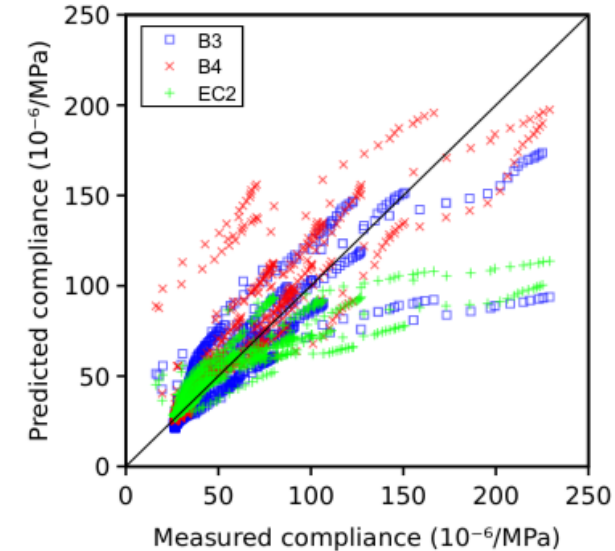
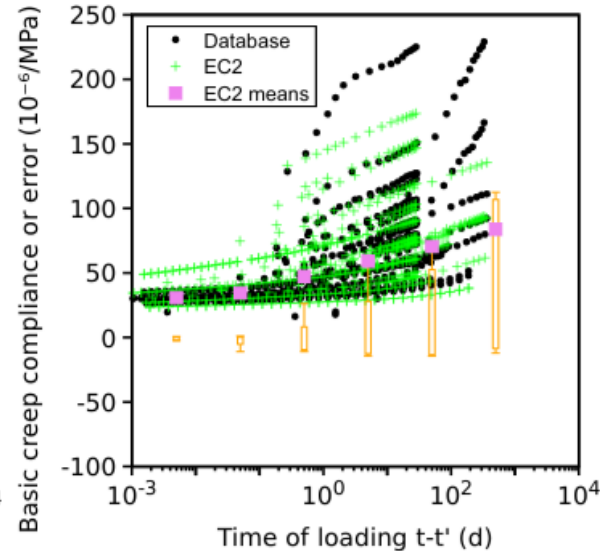
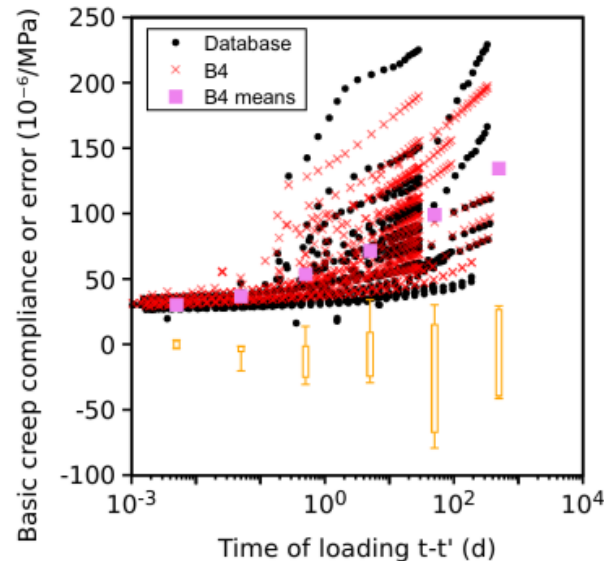
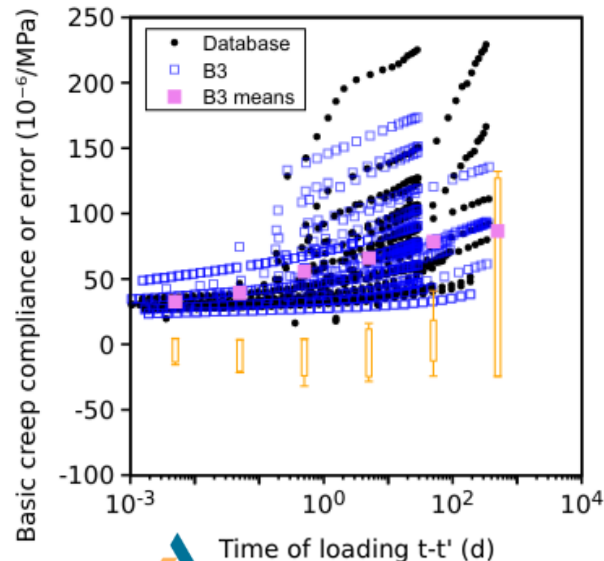


Fig9: First desorption isotherms of VeRCoRs concrete

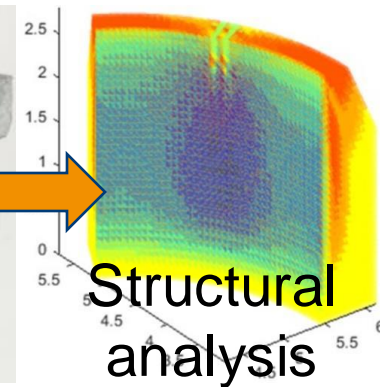
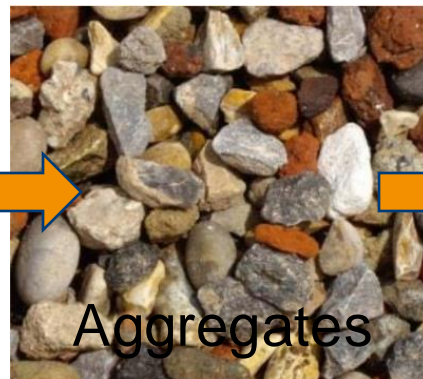
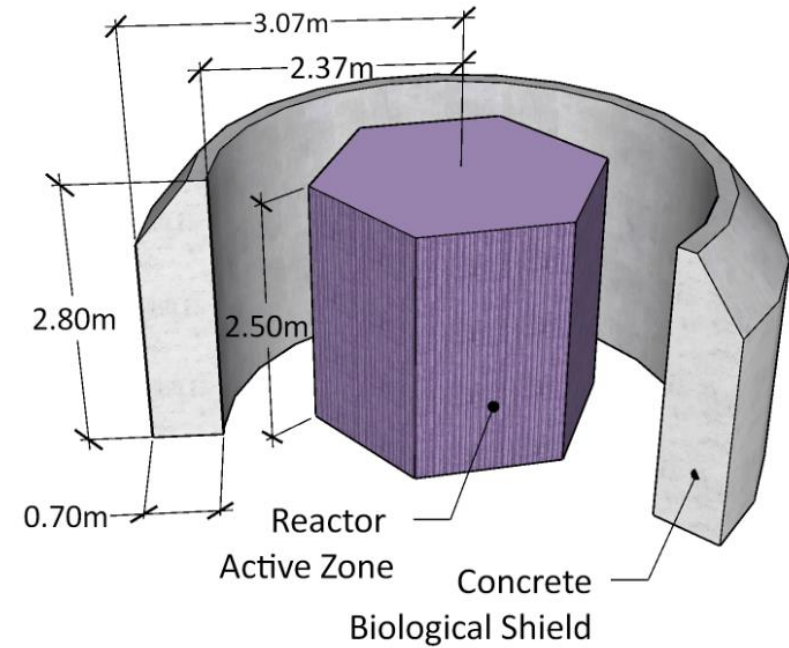
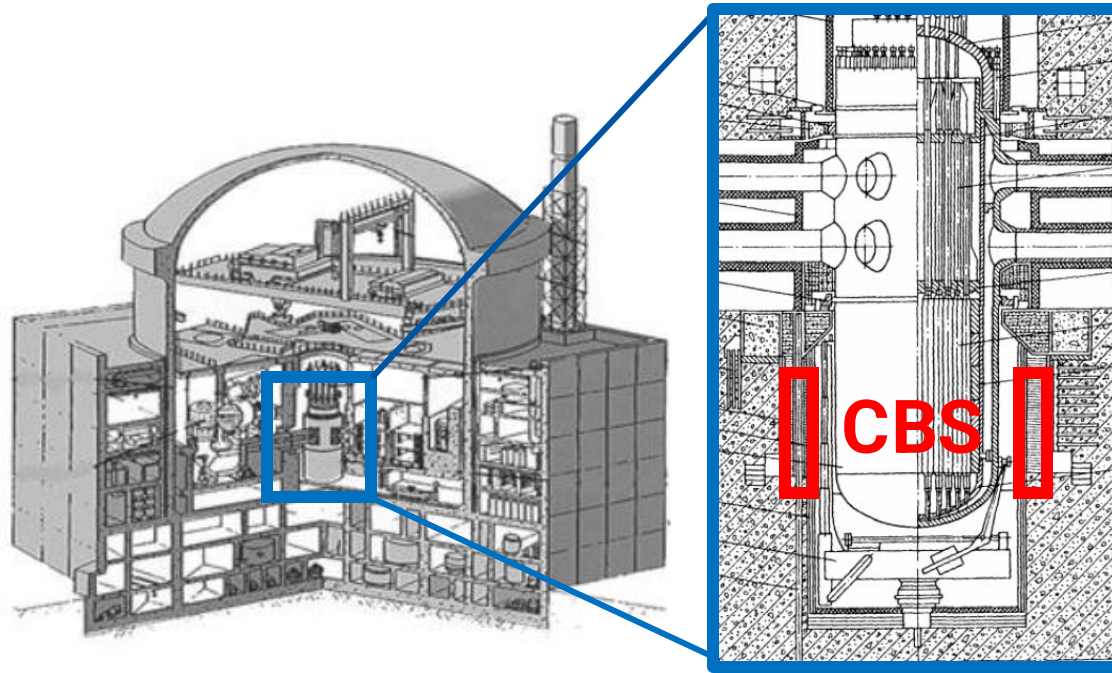


How to improve prediction of moisture, strain and stress of prestressed concrete during operation and accidents?

- Predicting creep & shrinkage from mix design (WP4) – predicting mechanical behavior of CCB when no shrinkage/creep tests are available
 - Available tools: Codes (B4, FIB Code model, ...), Micromechanics tools (Vi(CA)2T developed at EDF, MOSAIC code developed at ORNL), other custom tools (e.g. at SCK-CEN)
 - Need for improving the validation of these tools and apply them to CCB concrete

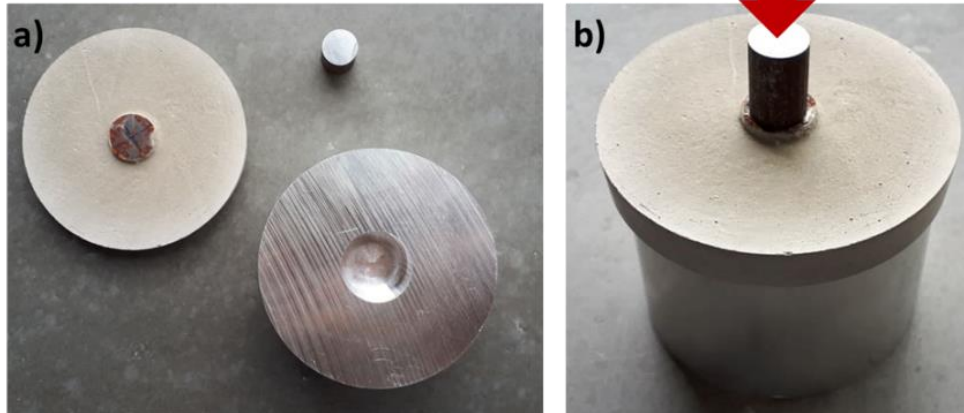


How to improved assessment of the effects of prolonged irradiation of the CBS using a holistic approach ?



How to improved assessment of the effects of prolonged irradiation of the CBS using a holistic approach ?

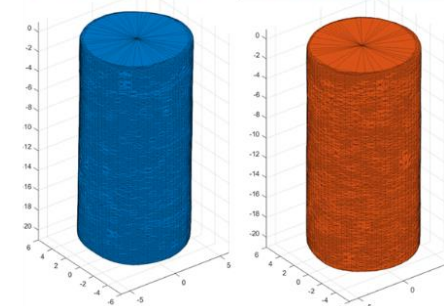
- Gamma irradiation – concrete/reinforcement and rock



#	Rock
1	Serpentenite CZ
2	Soapstone FL
3	Granite FL
4	Diabase FL
5	Quartz A1 FR
6	Calcite A2 (grey) FR
7	Quartz A2 (black) FR
8	Granite A6 FR
9	Barite (white) SK
10	Barite (dark) SK



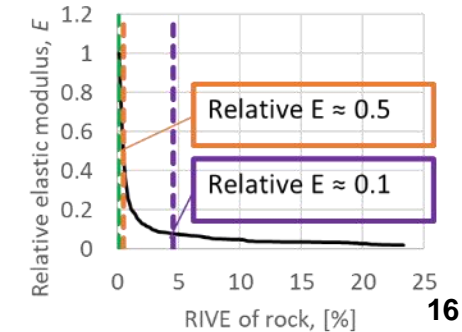
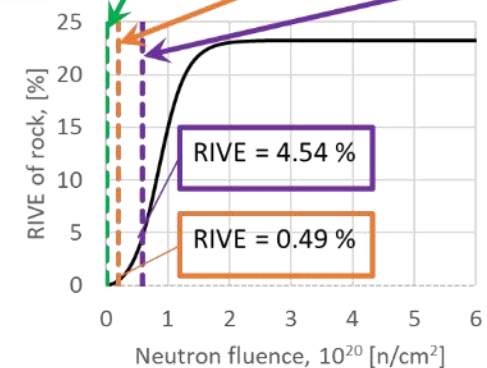
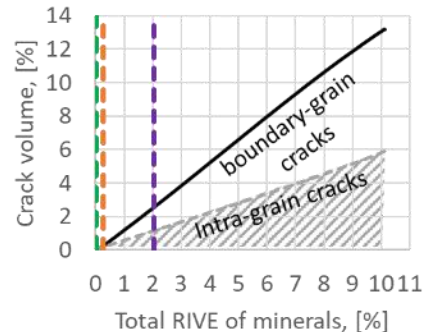
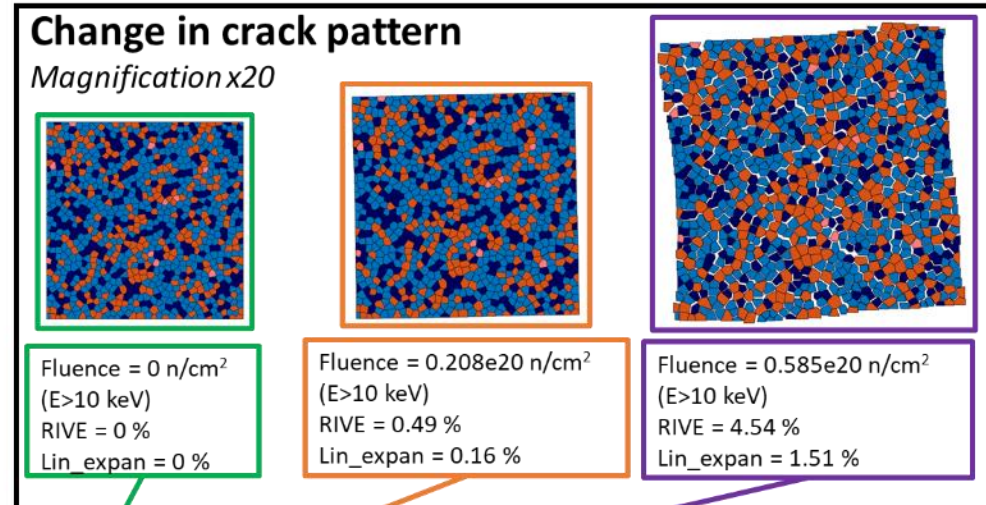
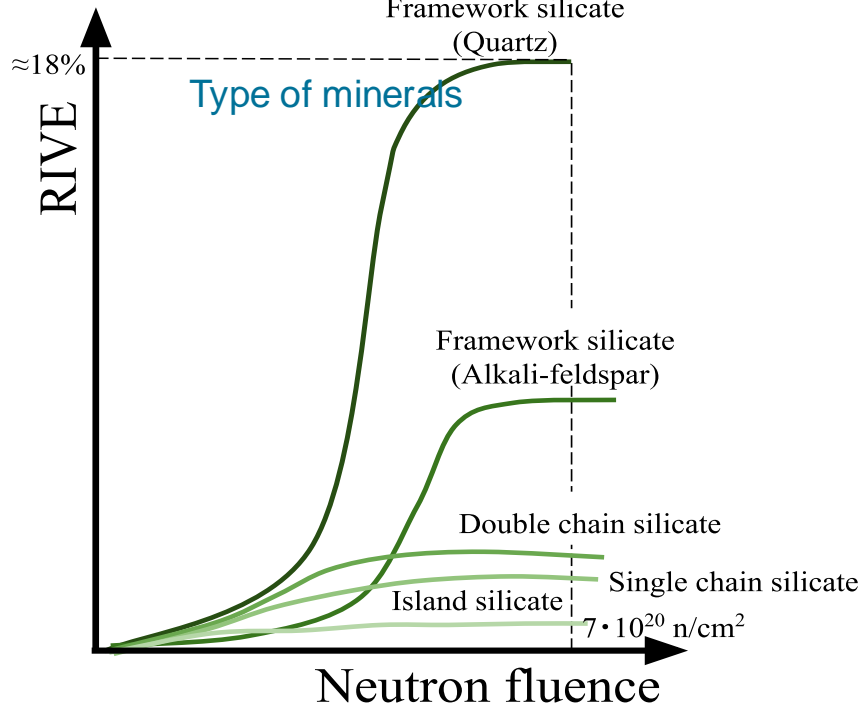
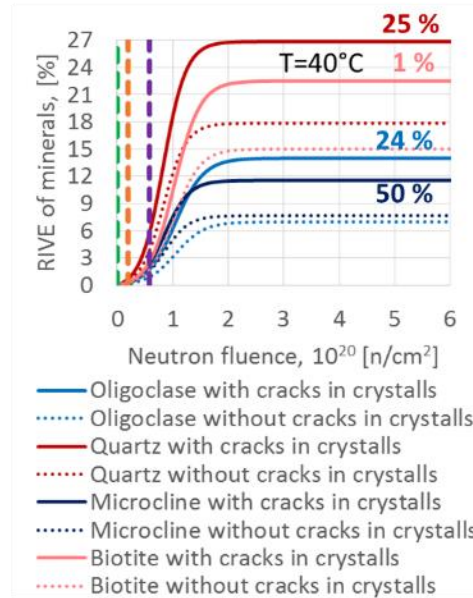
PRE-irradiation V=1538.730 mm³ POST-irradiation V=1560.138 mm³



How to improved assessment of the effects of prolonged irradiation of the CBS using a holistic approach ?

- Modelling meso-scale to structural analysis (WP5)

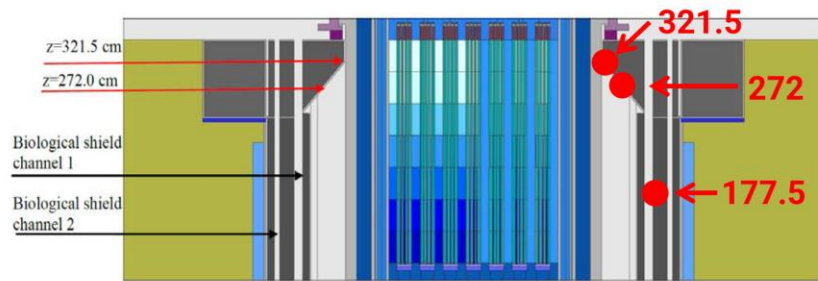
RIVE of aggregates



How to improved assessment of the effects of prolonged irradiation of the CBS using a holistic approach ?

- Modelling meso-scale to structural analysis (WP5)

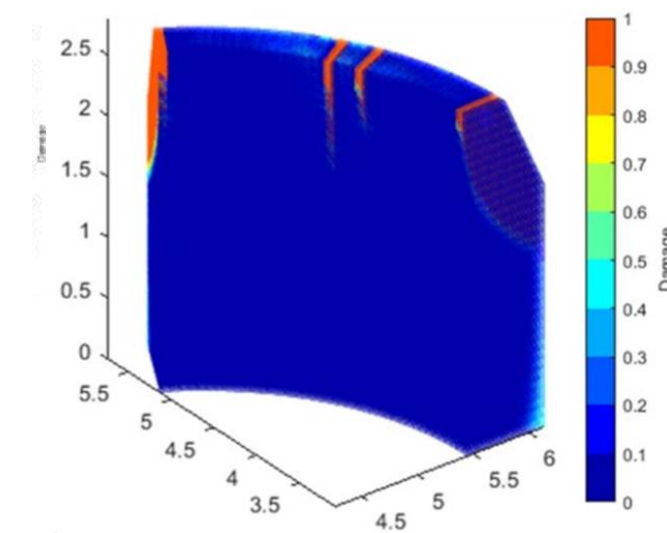
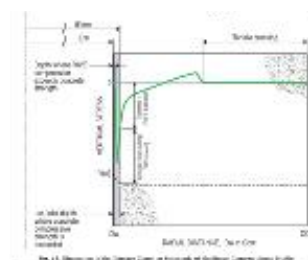
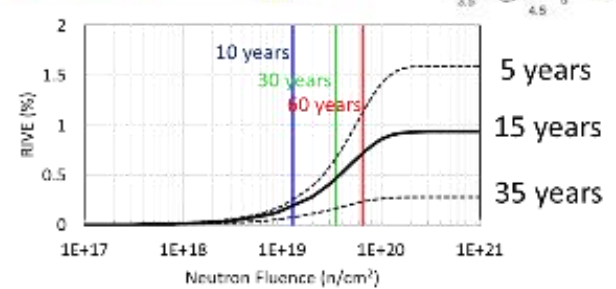
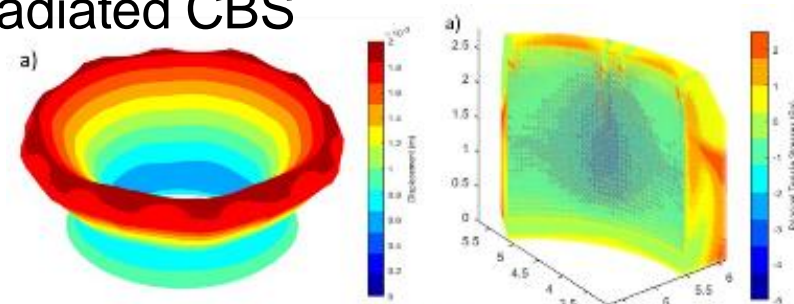
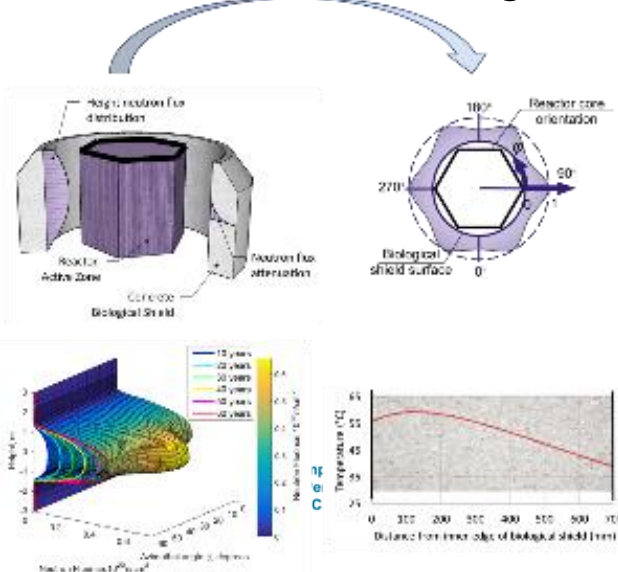
Radiation, thermal and moisture fields



	$z=272$ cm	$z=321.5$ cm	$z=177.5$ cm
Total neutron flux [1/cm2s]	2.974e+10	2.718e+10	4.078e+10
Thermal neutron flux $E < 0.41$ eV [1/cm2s]	4.650e+09	2.555e+09	7.154e+09
Fast1 $E > 0.1$ MeV [1/cm2s]	8.911e+09	9.752e+09	1.368e+10
Fast2 $E > 1$ MeV [1/cm2s]	7.772e+08	9.096e+08	1.487e+09
Gamma flux [1/cm2s]	1.148e+10	1.016e+10	1.892e+10

- Data from EUG
- Numerical model for neutron transport for VVER 1000 and VVER 440

Structural modeling of irradiated CBS



ACES Final Project Workshop

- Hosts:
 ENGIE Laborelec and SCK CEN
- Location:
 Linkebeek, Belgium
- Date:
 22 – 24 April 2025
- Registration online:
<https://www.eventbrite.be/e/aces-final-project-workshop-tickets-1109224774159?aff=oddtcreator>



Thank-you!

miguel.ferreira@vtt.fi / +358 401 380 546