ELSMOR

Towards European Licensing of Small Modular Reactors

# Safety of SMRs: transients and Severe Accidents analysis

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# *Outline*

- Short introduction to nuclear safety

- Transients & Severe Accidents (SA) modeling
  - ✓ Physical phenomena to consider
  - ✓ Modeling the eSMR design with MAAP_EDF
  - ✓ DBC scenarios to be modeled in ELSMOR WP5.2
  - ✓ SA scenario to be modeled in ELSMOR WP5.3
  - ✓ Preliminary results of a SBO & LOCA calculations for the eSMR design

- Conclusions

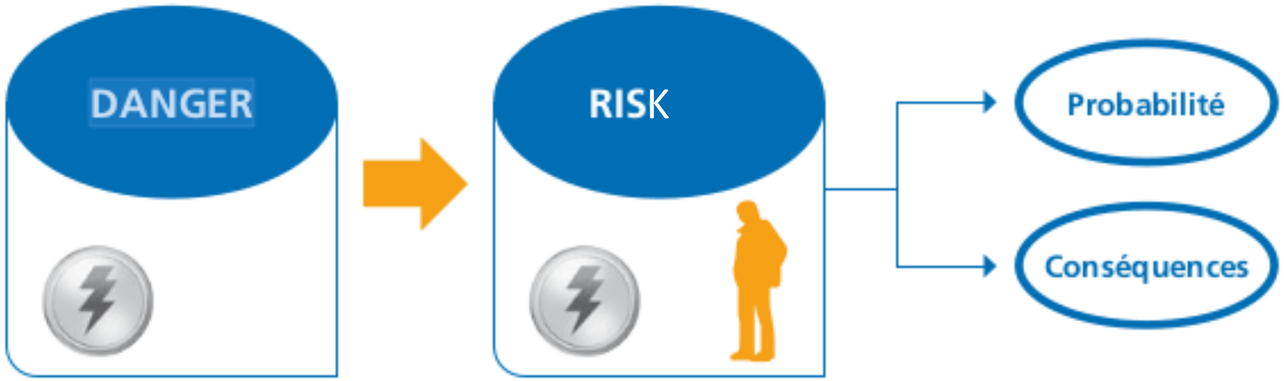
# *Short introduction to nuclear safety*

- Do you know what a **risk** is? Is this equivalent to a **danger**?
- Is it dangerous to do skydiving?  Is it risky?

→ A risk is an exposition to a danger or a damaging event during a situation or activity. It is defined by the probability of this dangerous or damaging situation:

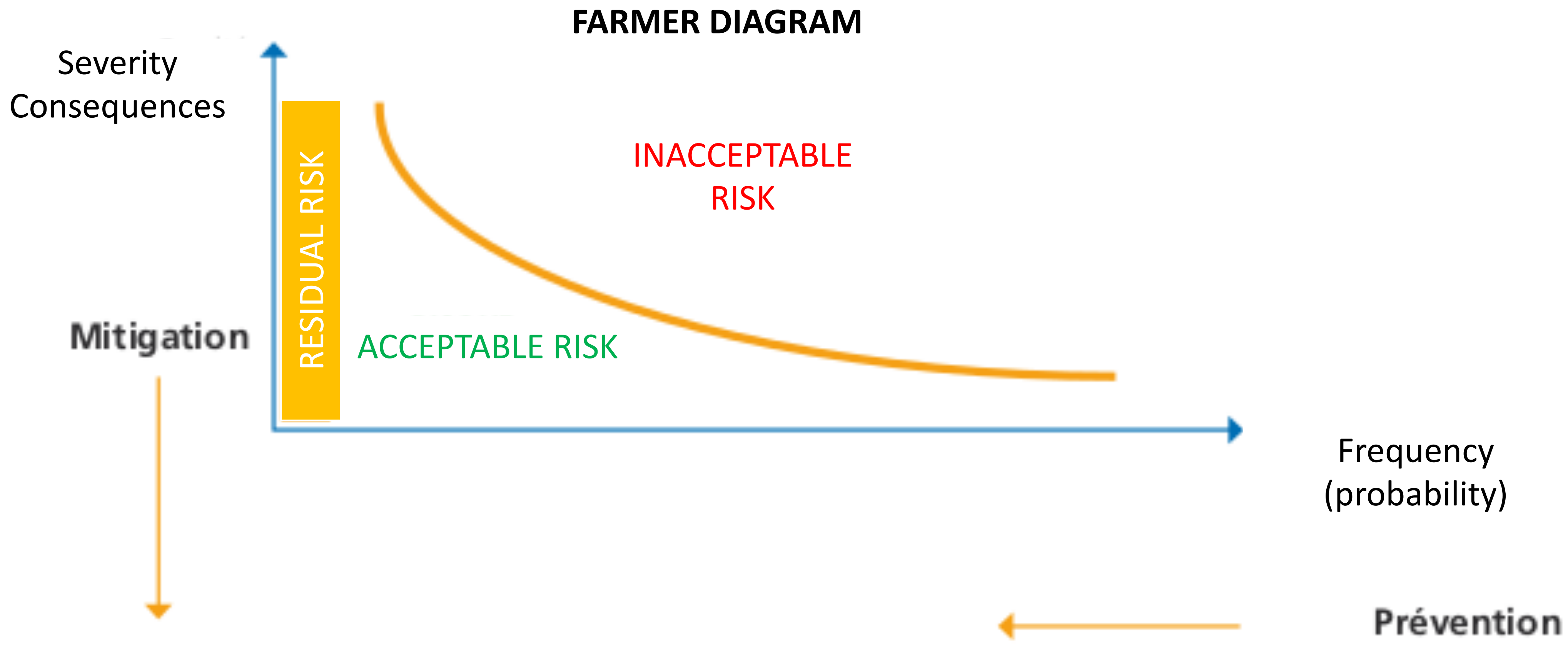
**Risk = Probability * Consequences**

# *Short introduction to nuclear safety*




→ A given **danger** is hence associated to a risk through a **probability** and the **impact of its consequences**

# *Short introduction to nuclear safety*

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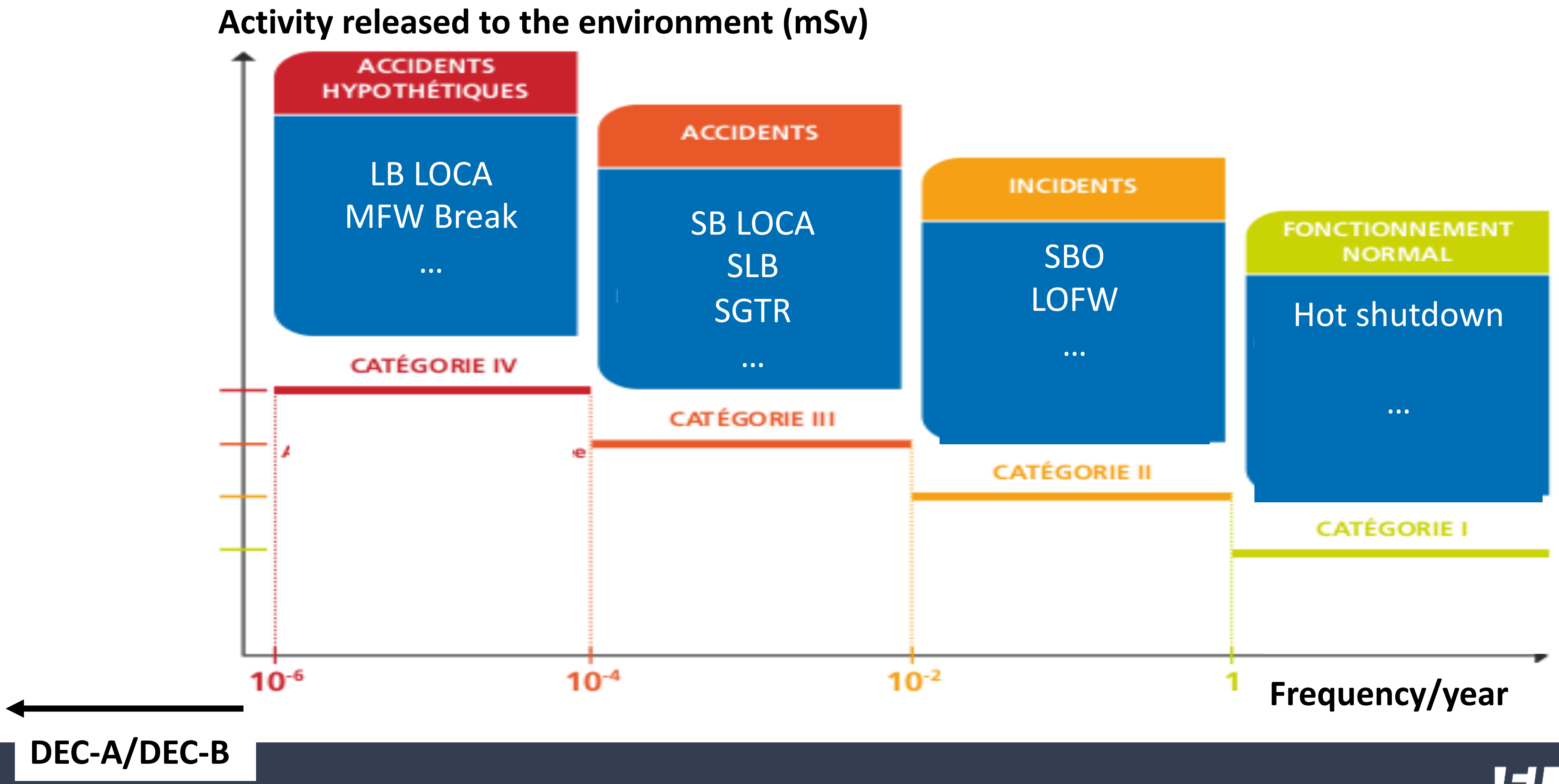
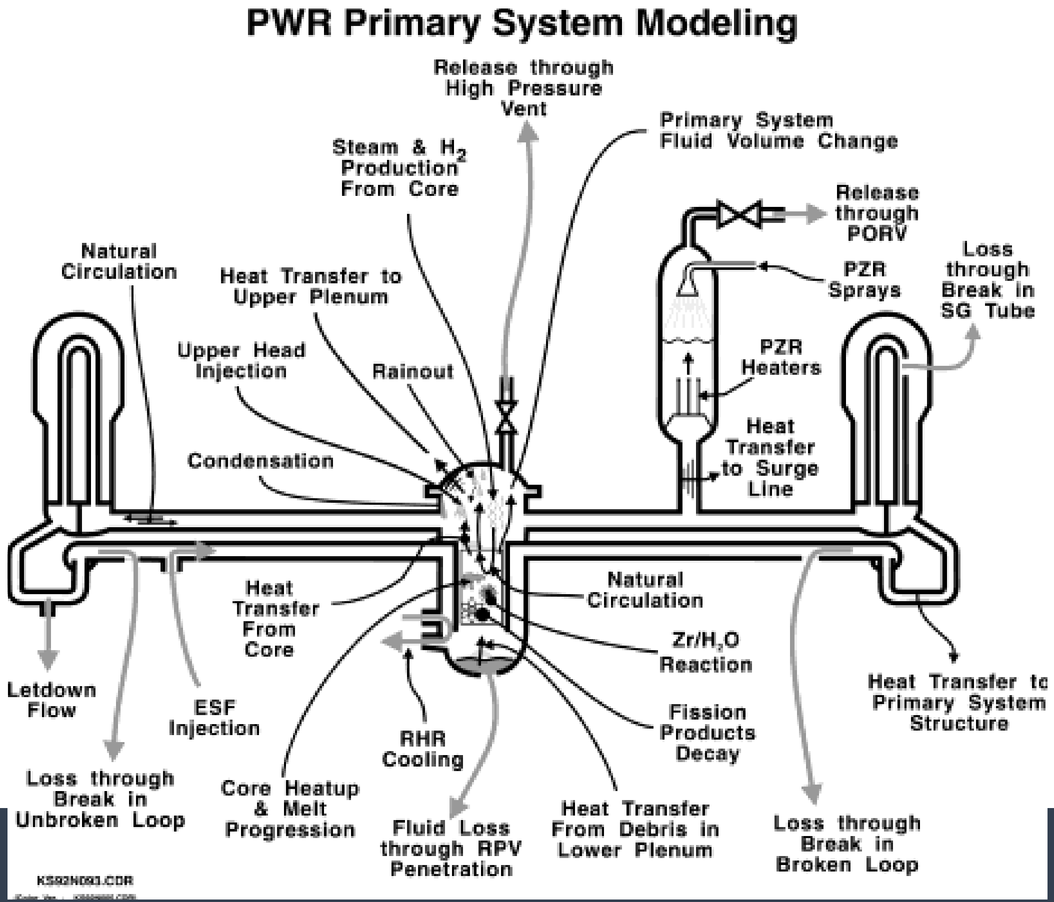
# *Short introduction to nuclear safety*

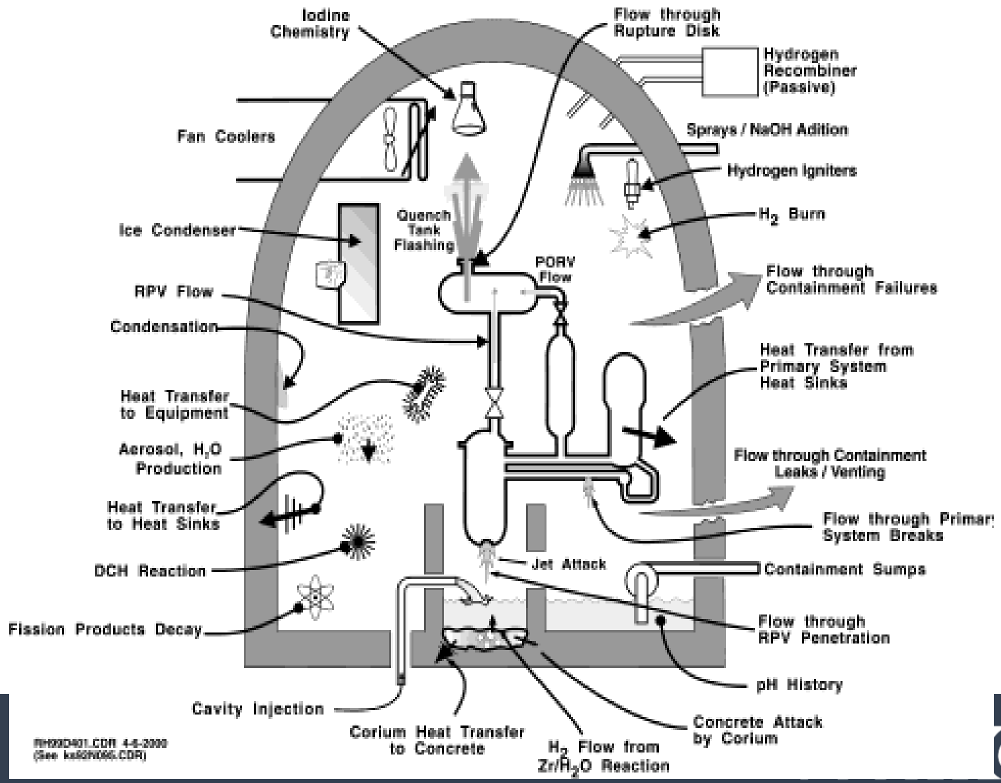


# *Transients & Severe Accidents modeling*

## *Physical phenomena to consider*

- In order to model an accident (potentially leading to a SA) in a SMR or PWR many physical phenomena must be modelled both in the **RCS/Secondary circuit** and the **containment**



# *Transients & Severe Accidents modeling*

## *Physical phenomena to consider*

- The main **physical phenomena to consider** in a transient analysis (not exhaustive list):
  - ✓ The **T/H in the RCS** and **Secondary circuit** (heat transfers, natural circulations…),
  - ✓ The **T/H** in the **containment** (convection, condensation…),
  - ✓ The **core degradation & melting**,
  - ✓ The **Zr oxidation** at high temperature creating $H_2$,
  - ✓ Potential **energetic $H_2$ burn** (leading to a loss of the containment),
  - ✓ The **fission product releases** from **the core to the containment and environment**,
  - ✓ The possibility of a **reactor vessel breaching** at high pressure (creating a Direct Containment Heating leading to a loss of containment),
  - ✓ The **thermochemistry** and **thermal exchanges** in the **lower head for the IVMR** (In Vessel Melt Retention),
  - ✓ The **iodine chemistry**
  - ✓ The **aerosol deposition** in the containment
  - ✓ …

# *Transients & Severe Accidents modeling*

## *Physical phenomena to consider*

- Each **physical model has to be validated** against experiments or a code-to-code comparison (on a validated code) to ensure it is valid

- Some models may interact with others. In order to make sure all those couplings are well taken into account; different levels of validation have to exist:
  - ✓**Separate effects** benchmarking activities (e.g., BETHSY, LIVE,…)
  - ✓**Integral benchmarking** (e.g., Phébus experiments, CORA…)
  - ✓**Reactor cases** (e.g., TMI-2, Fukushima…)

→ A lot of **R&D is necessary** to ensure that a code can model a transient in a SMR leading or not to a Severe Accident. Not all the physics are perfectly known, and research is going on (particularly for SA)

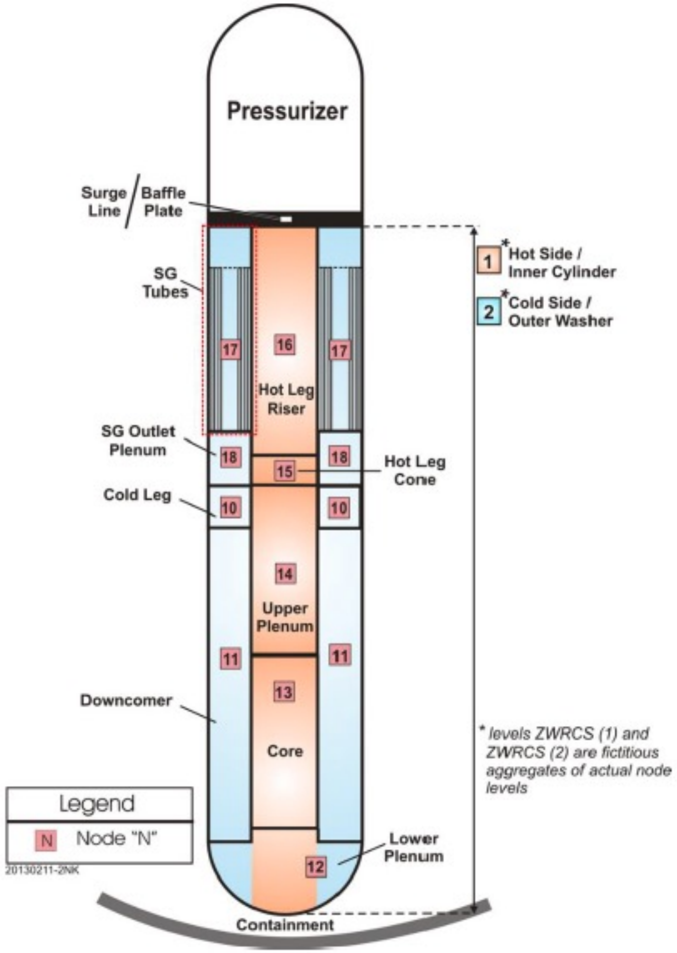
# *Transients & Severe Accidents modeling*

## *Modeling the eSMR design with MAAP_EDF*

- **MAAP** (Modular Accident Analysis Program) is an **EPRI code** that enables to model both transients and SA in PWRs and SMR.

- EDF updates the source code to make it fit to his needs. The EPRI code has been updated (SG model, meshing) in order to be able to model the **ELSMOR eSMR**. The version used is **MAAP_EDF**.

- On the right is presented the **MAAP_EDF RCS meshing** of the eSMR design: the meshing appears as coarse but a code-to-code comparisons against CATHARE (French detailed T/H code – equivalent of RELAP) show a good agreement for different transients

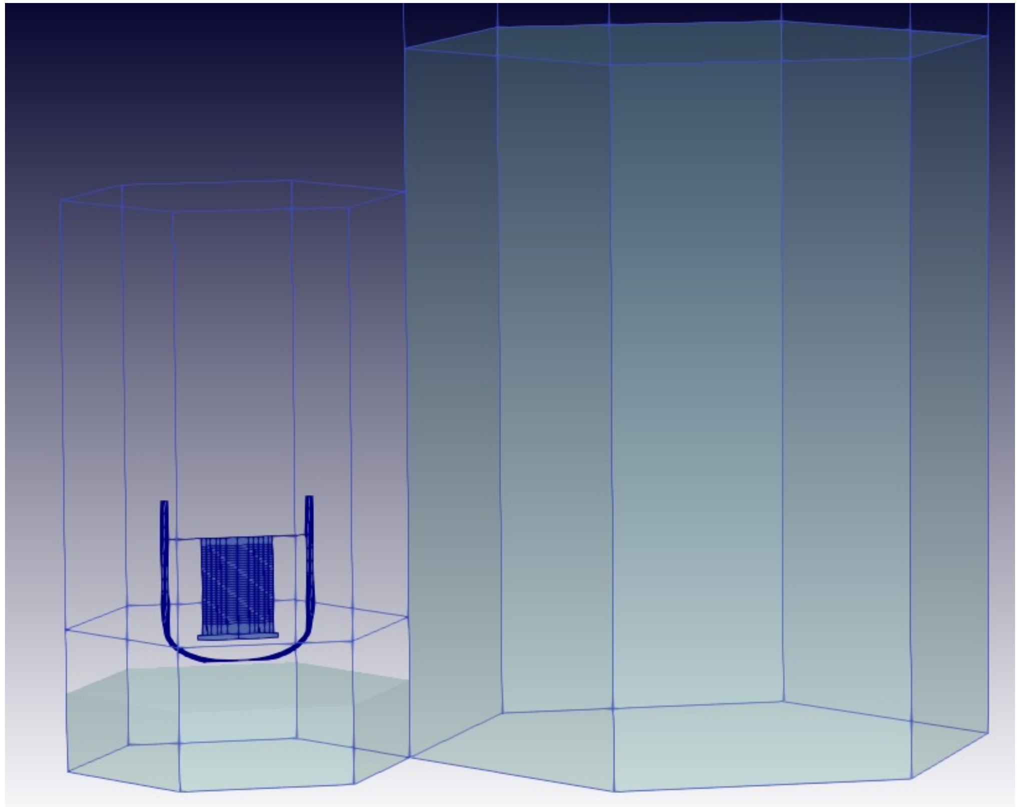



*MAAP_EDF RCS modeling of the eSMR design*

# Transients & Severe Accidents modeling

## *Modeling the eSMR design with MAAP_EDF*

- MAAP enables to model the transient physics both in the **RCS (Reactor Coolant System) and in the containment**.
- In particular, the phenomena occurring in the **containment of the eSMR are extremely** important such as the condensation of hot steam from the RCS in case of a SA
- The eSMR design has **a relatively small free volume in the containment,** which is **challenging** in terms of **physical modelling** (high variation rates of steam, $H_2$, $N_2$ concentrations)



*Vessel and Containment view of the MAAP_EDF eSMR design*

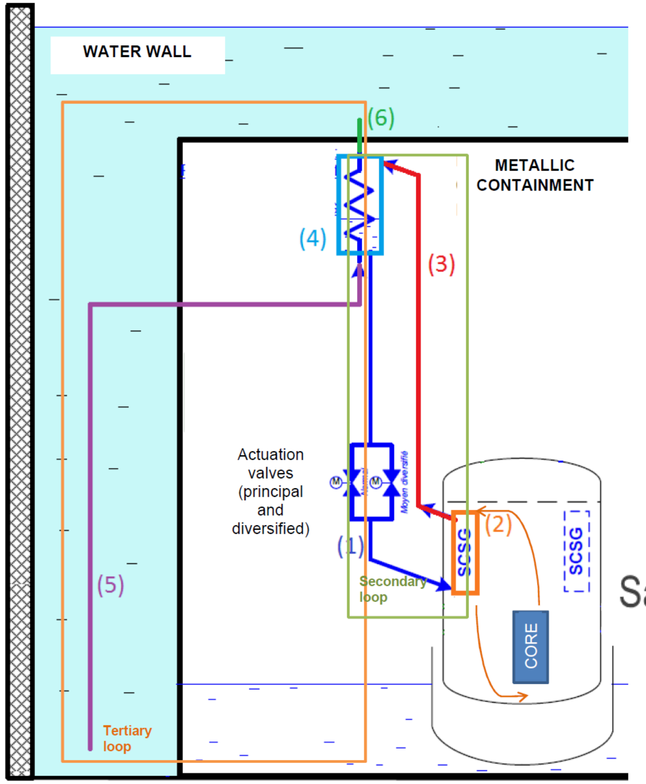
# Transients & Severe Accidents modeling

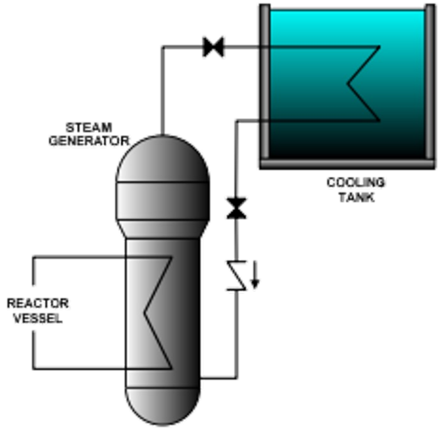
## *DBC scenarios to be modeled in ELSMOR WP5.2*

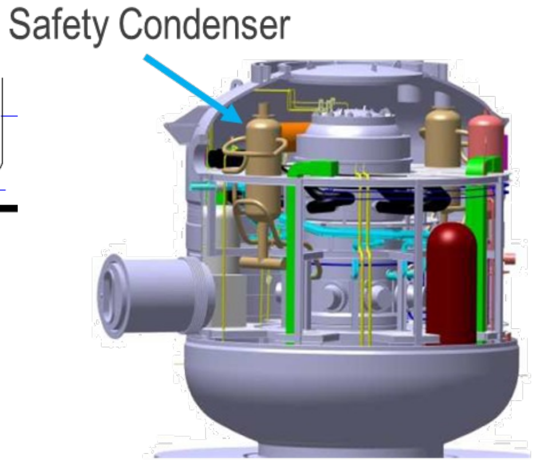
- **Two different transients** are to be considered in the frame of **ELSMOR WP5.2**:
  - ✓ A **SBO** transient (Station Blackout)
  - ✓ A **LOCA** transient (Loss of Coolant Accident)

→ For those two transients it is assumed that **one safety condenser (out of 2) is available** to cool the RCS thanks to the thermal inertia of the water wall

→ No SA is expected at least for some days after the initiator event due to the large amount of water in the water wall



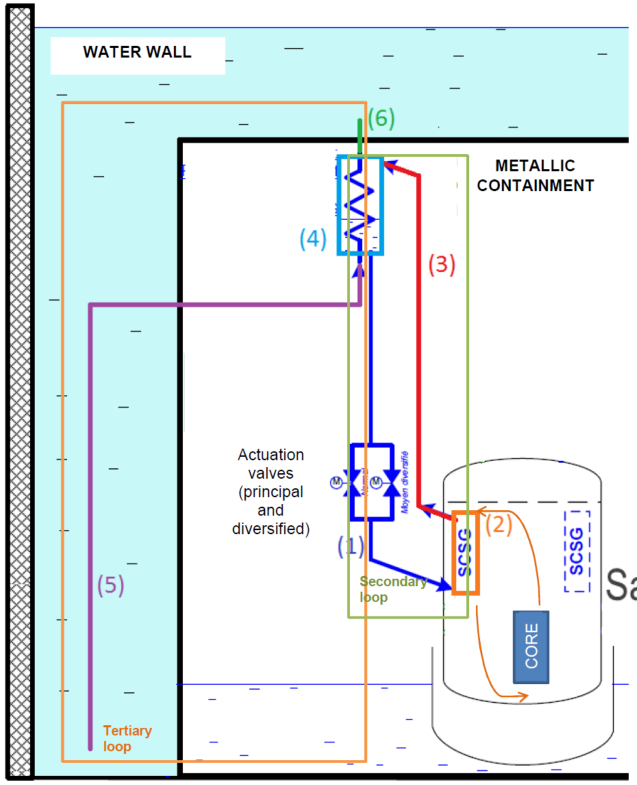



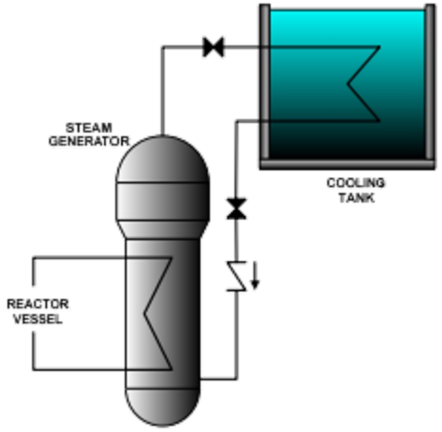



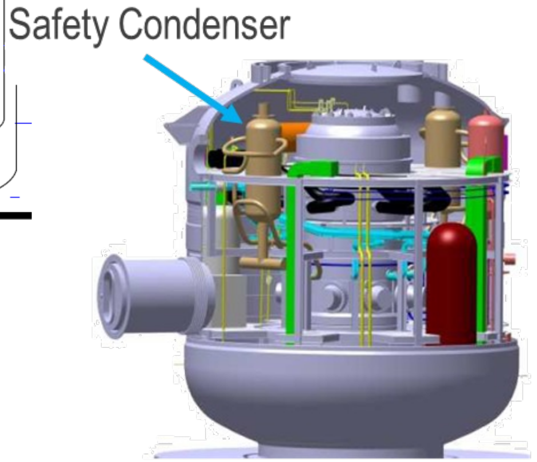
# *Transients & Severe Accidents modeling*

## *DBC scenarios to be modeled in ELSMOR WP5.2*

- **SBO** (Station Blackout):
  - ✓Loss of the **main cooling system**
  - ✓The **Reactor Scram** is reached immediately after the SBO is initiated
  - ✓Use of **the safety condenser** (RRP) to:
    - Cool down the primary circuit (decay heat removal)
    - Depressurize the primary circuit
  - ✓**Physics to address:**
    - Natural convection for the primary circuit
    - Natural convection for the secondary circuit
    - Natural convection for the tertiary circuit



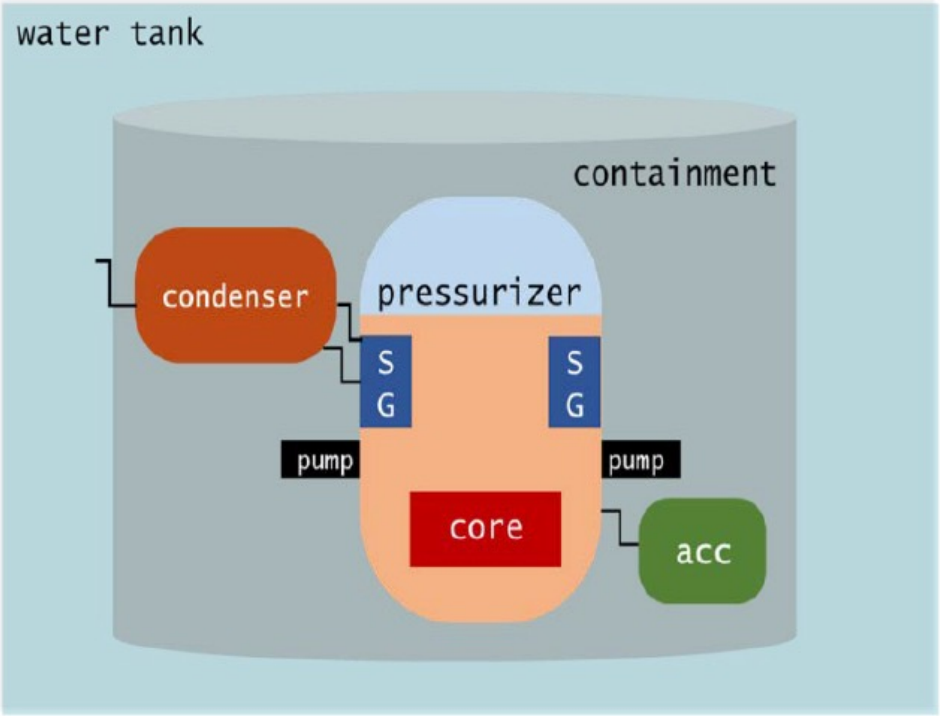



# *Transients & Severe Accidents modeling*

## *DBC scenarios to be modeled in ELSMOR WP5.2*

- **LOCA** (Loss Of Coolant Accident):
  - ✓ Initial **break opening** close to the SG (P/S)
  - ✓ Loss of the **main cooling system**
  - ✓ The **Reactor Scram** is reached on **a high pressure** in the containment
  - ✓ The break leads to the **RCS depressurization** and some steam/water released in the containment (increase of pressure in the containment)
  - ✓ The **accumulators may discharge** depending on the pressure reached in the RCS

  - ✓ **Physics to address:**
    - Natural convection for the primary circuit
    - Natural convection for the secondary circuit
    - Natural convection for the tertiary circuit
    - Break flow vs Containment Pressure
    - Steam condensation on the containment walls
    - Impact of the containment pressure on the break flow
    - Accumulators' discharge



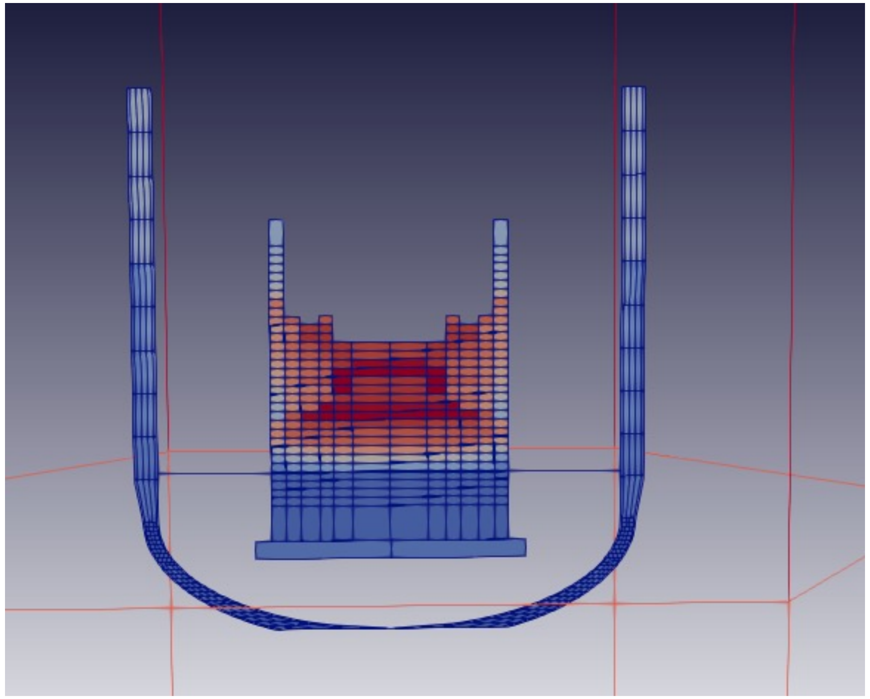
# *Transients & Severe Accidents modeling*

## *SA scenario to be modeled in ELSMOR WP5.3*

- In the same way as for the WP5.2, **two different transients** are to be considered in the frame of **ELSMOR WP5.3**:
  - ✓ A **SBO** transient (Station Blackout)
  - ✓ A **LOCA** transient (Loss of Coolant Accident)

→ For those two transients it is assumed that **no Safety Condenser** is **available**: since no cooling of the RCS is available **a core degradation is expected** as the water from the RCS will evaporate. The onset timing of the core degradation is a key parameter

→ **Containment pressure and temperature** will increase due to the creation on **non condensable and hot gases** in the containment ($H_2$)

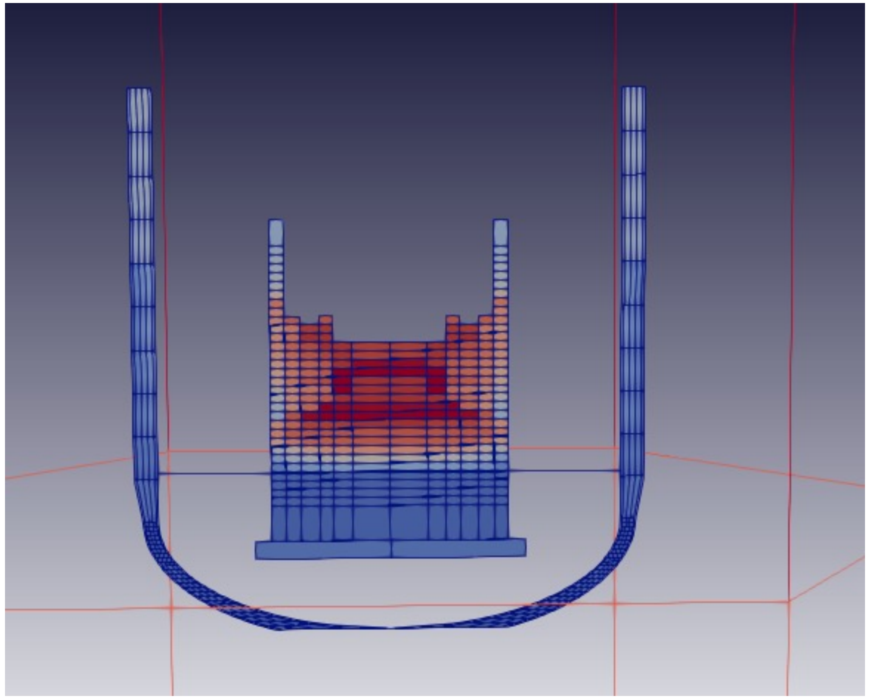


*MAAP_EDF view of a core degradation*

# *Transients & Severe Accidents modeling*

## *Preliminary results of a SBO & LOCA calculations for the eSMR design*

- **SBO** (Station Blackout): **Phase 1**
  - ✓Loss of the **main cooling system**
  - ✓The **Reactor Scram** is reached immediately after the SBO is initiated
  - ✓The **PORVs** are solicited due to the pressure increase (hysteresis)
  - ✓ The **operator** realizes a **depressurization of the primary circuit** through the PORVs, one hour after the scram
  - ✓**An injection of clear water** from the water wall is assumed when the Pressure in the RCS is lower than 100 bar – **lasting around 12 hours (assumed battery life)**



*MAAP_EDF view of a core degradation*

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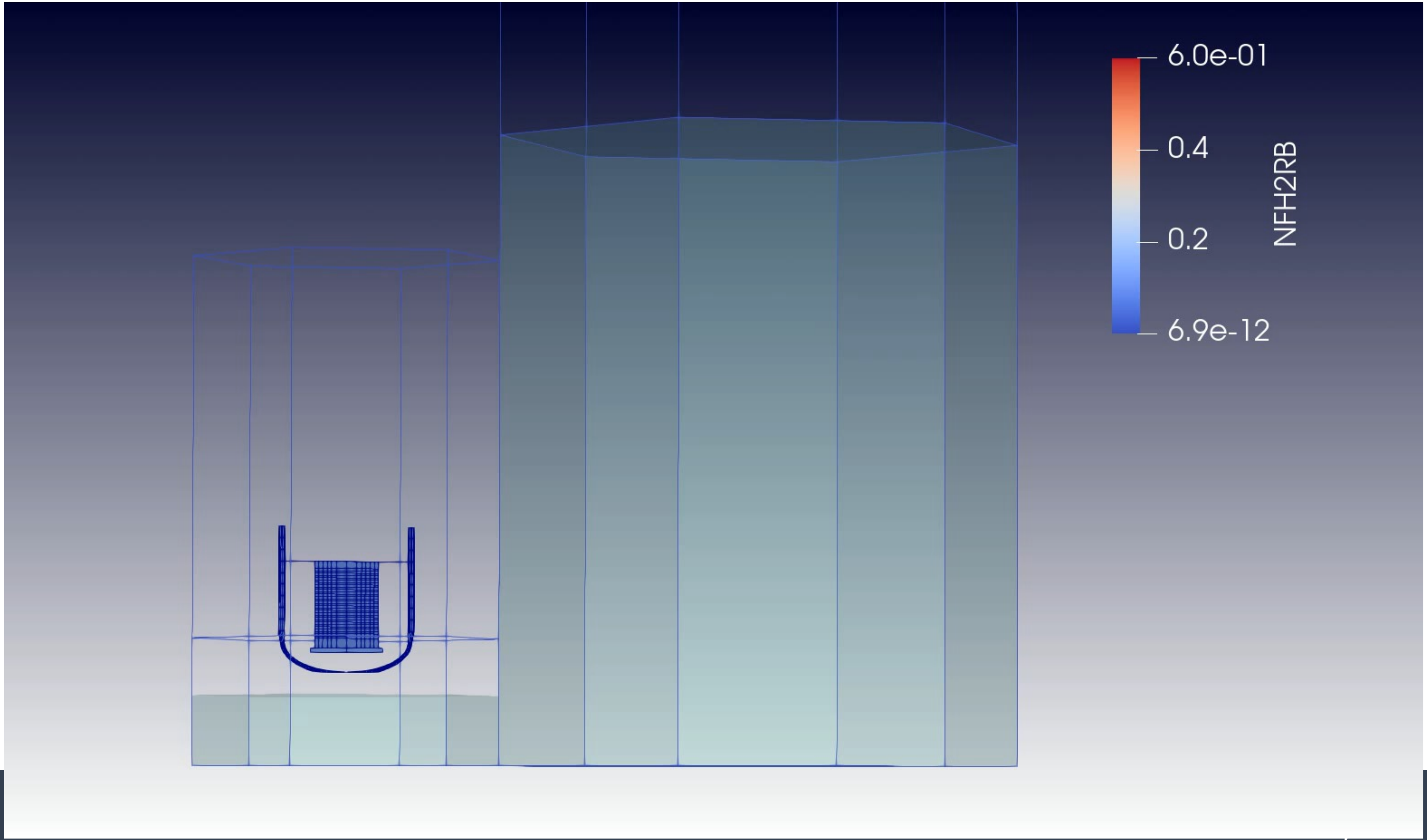
## *Preliminary results of a SBO & LOCA calculations for the eSMR design*

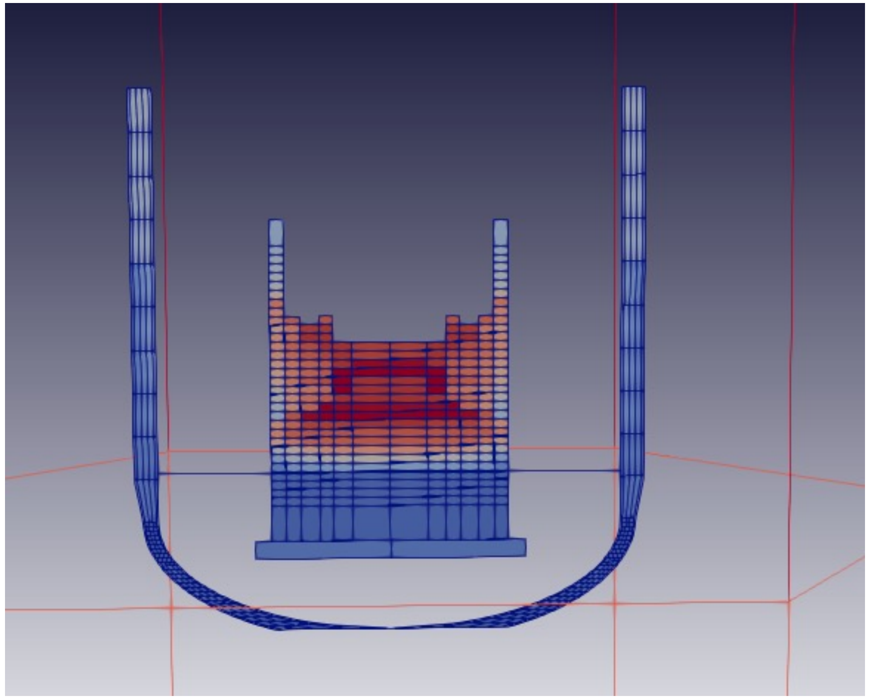
**SBO** (Station Blackout): **Phase 1**



# *Transients & Severe Accidents modeling*

## *Preliminary results of a SBO & LOCA calculations for the eSMR design*

- **SBO** (Station Blackout): **Phase 2**
  - ✓ After the water injection stops, since there is no cooling, the water contained in the RCS is evaporated
  - ✓ The **Core uncovers and starts to heat up**
  - ✓ **$H_2$ is generated** from the Zr-Water interaction
  - ✓ The **core melts and relocates** in the lower head
  - ✓ The **water outside the vessel** enables cooling the vessel lower head and no vessel failure is calculated by MAAP_EDF



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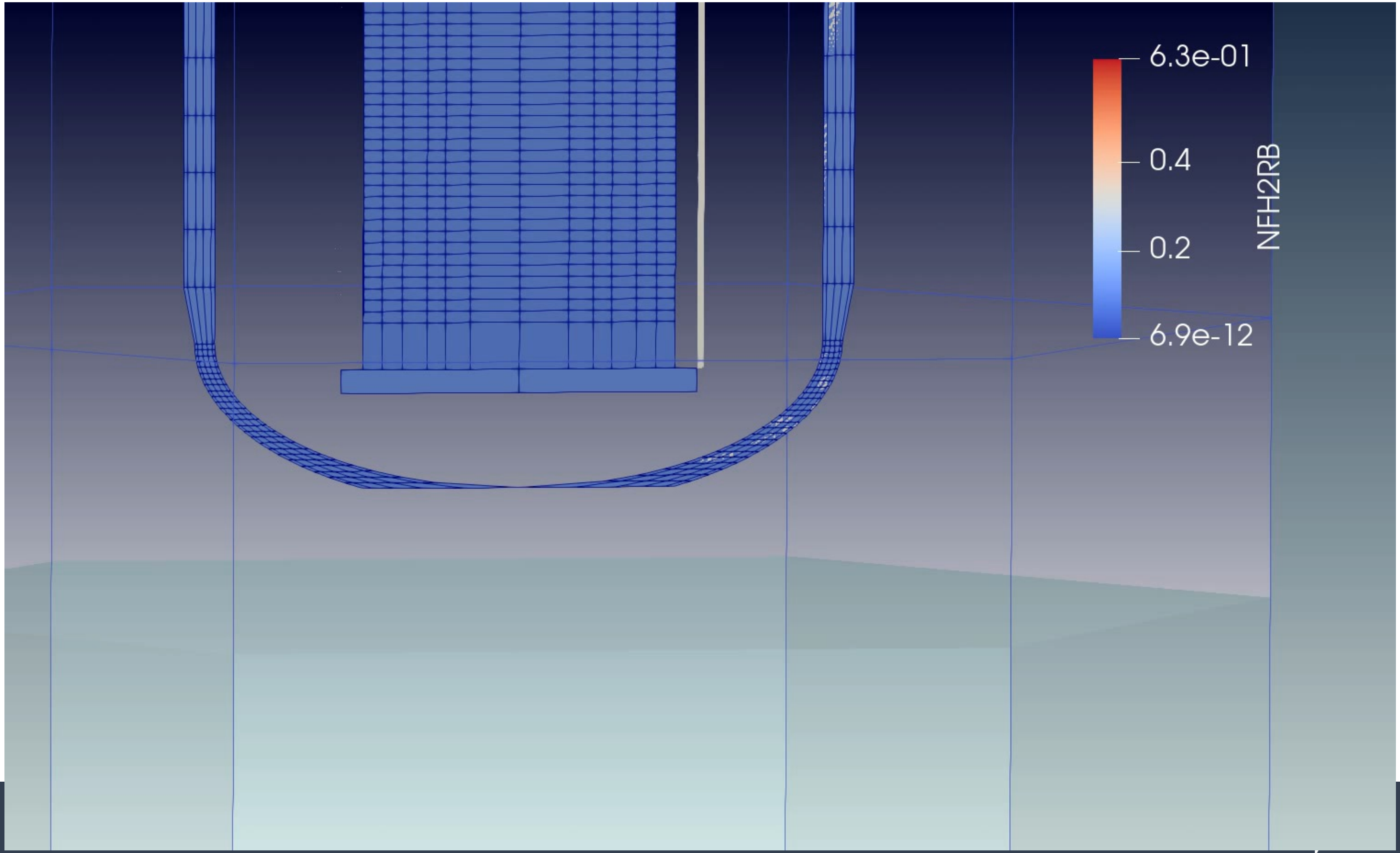
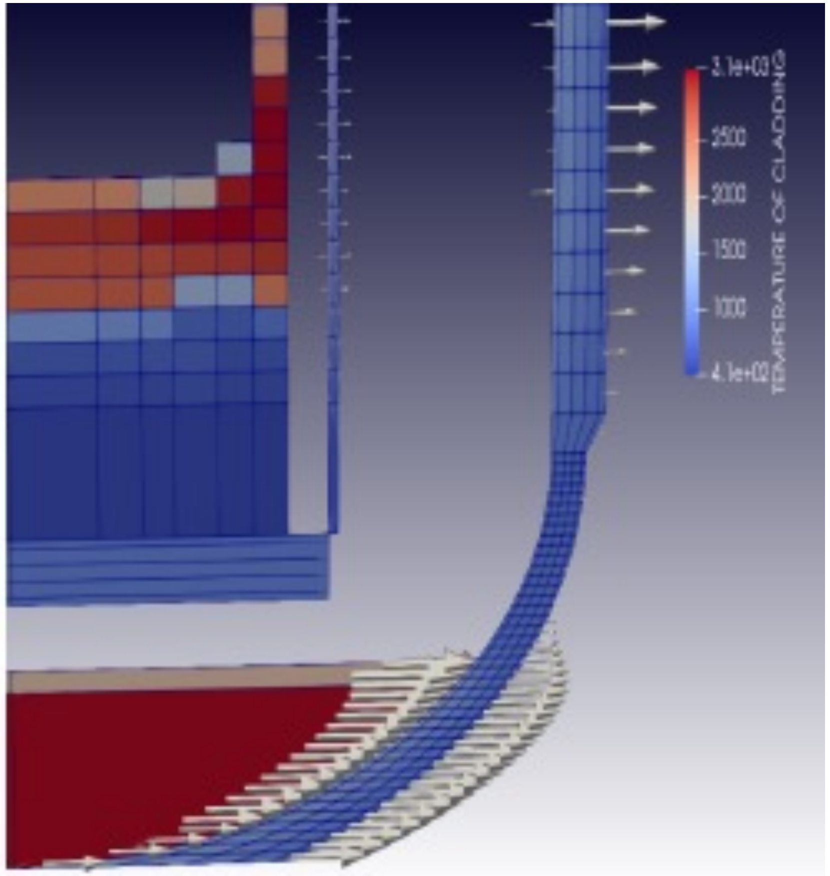


# *Transients & Severe Accidents modeling*

## *Preliminary results of a SBO & LOCA calculations for the eSMR design*

- **LOCA** (Loss of Coolant Accident): **Phase 1**
  - ✓ Loss of the **main cooling system**
  - ✓ The **Reactor Scram** is reached on a high pressure in the containment
  - ✓ The **operator** realizes a **depressurization of the primary circuit** through the PORV, one hour after the scram
  - ✓ The **accumulators** inject in the primary circuit
  - ✓ **An injection of clear water** from the water wall is assumed when the Pressure in the RCS is lower than 100 bar – **lasting around 12 hours (assumed battery life)**



# *Transients & Severe Accidents modeling*

## *Preliminary results of a SBO & LOCA calculations for the eSMR design*

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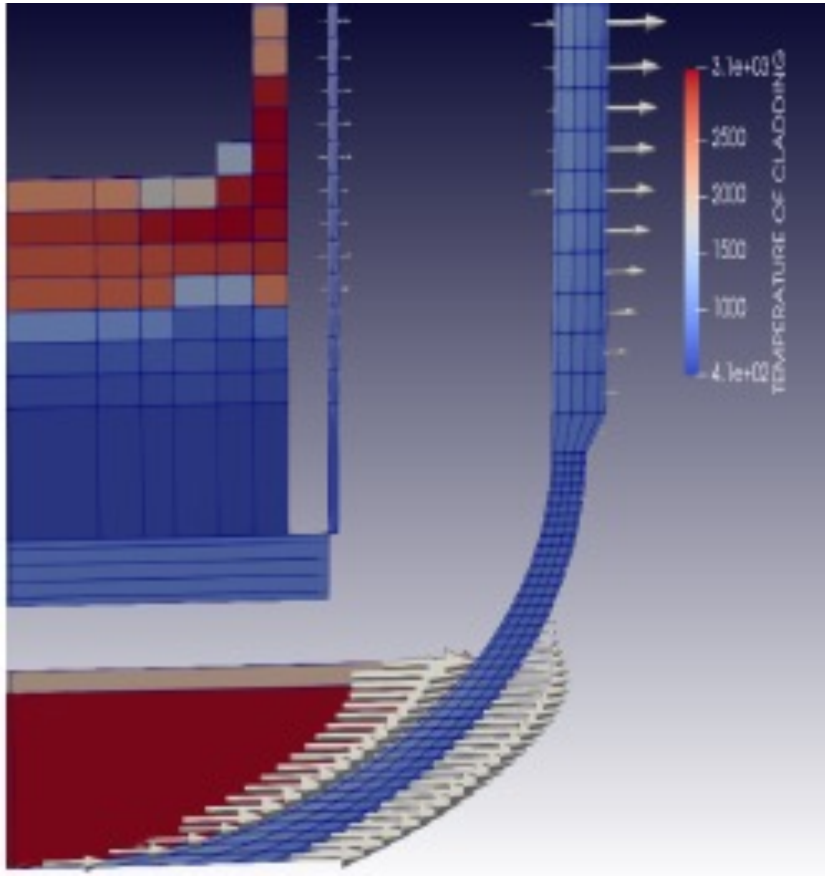
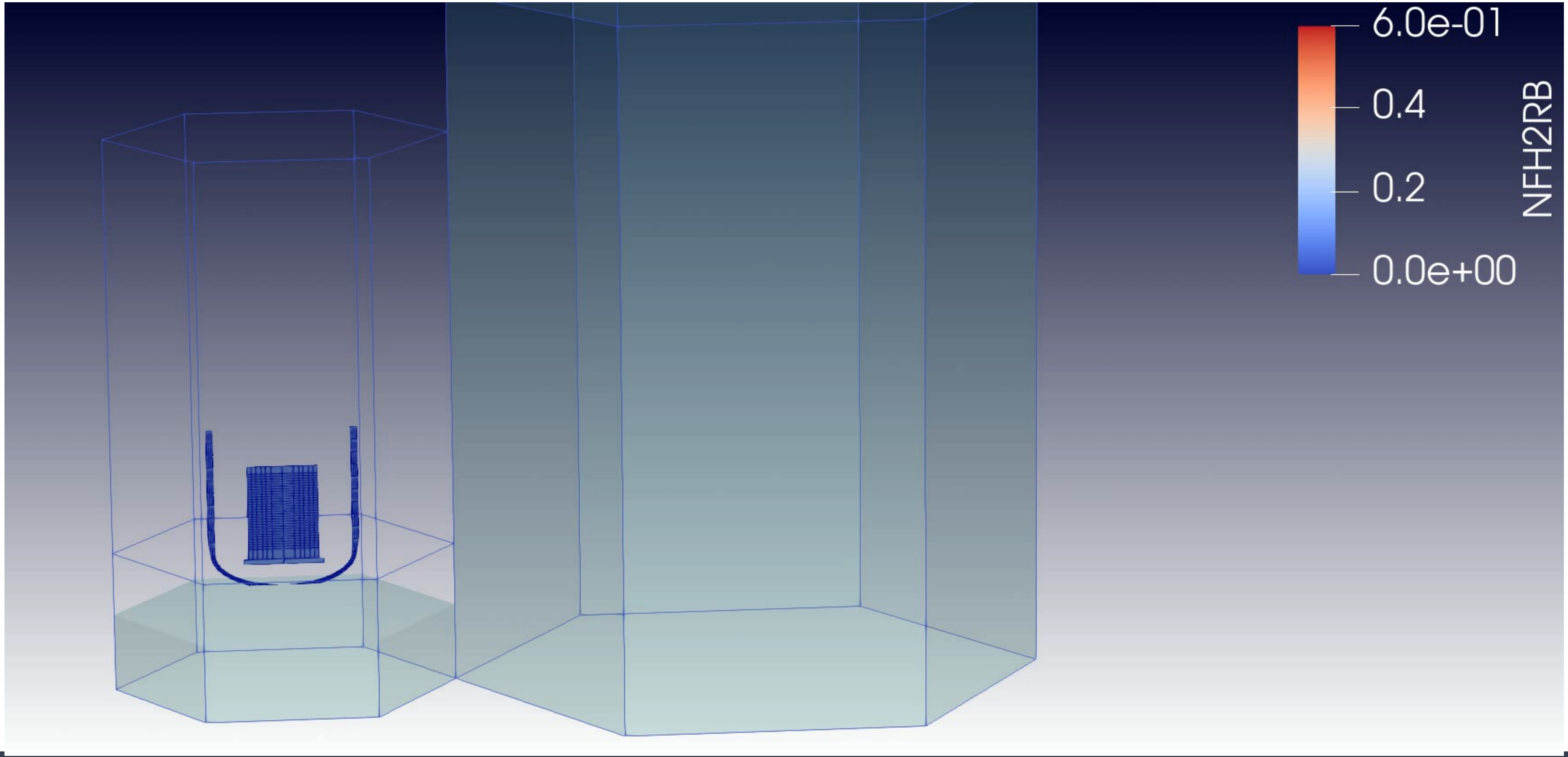


# *Transients & Severe Accidents modeling*

## *Preliminary results of a SBO & LOCA calculations for the eSMR design*

**LOCA** (Loss of Coolant Accident): **Phase 1 &2**



# Conclusions

- The modeling of **accidental transients with validated codes** is a key element to certify the **safety of a reactor design**
- The **SA are evaluated natively for SMR designs** (contrarily to older reactors) with their set of passive systems
- The modeling of the eSMR design is challenging because less validated than the large scale PWRs (correlations to adapt…)
- Simulation results of **SA** are inputs for **Probabilistic Safety Analyses**
- Simulations show possible core degradation for LOCA &SBO but **no LERF** (IVR)
- Some **R&D is necessary** in the field of **accidental transients and SA modeling for SMR** as done in the frame of the ELSMOR or the SASPAM-SA European Projects

*Thank you for your attention !*

*Questions ?*

# ELSMOR

*Towards European Licensing of Small Modular Reactors*

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