



RELAP/MODELICA coupling for safety analysis

09/10/2026



PUBLIC



INTERNAL



RESTRICTED



CONFIDENTIAL

1. Introduction

2. Coupling Validation

3. DEC A: SLBOUT

combined with SGTR and loss of CVCS

1. Introduction

1.1 INTRO

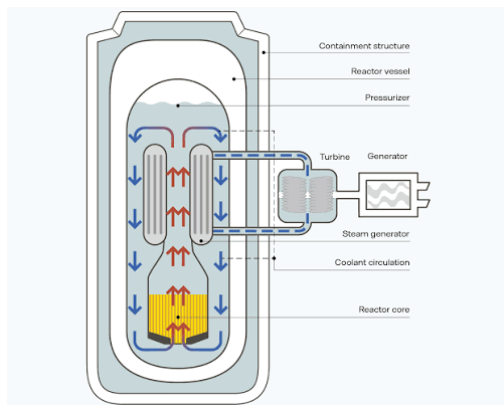
1.2 CERES

1.3 RELAP-MODELICA

INTRO

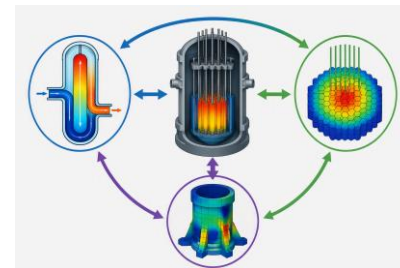
New nuclear designs (SMRs, Gen IV reactors, advanced coolants) are becoming increasingly complex (e.g. new passive system, difficult to predict in classical simulations normally modeled through an excel tool). Moreover, also latest safety studies (e.g. DEC) require higher fidelity and more realistic system behavior prediction.

Regulators and designers request stronger demonstration of plant performance under normal and accidental conditions.



A realistic simulation framework may combine:

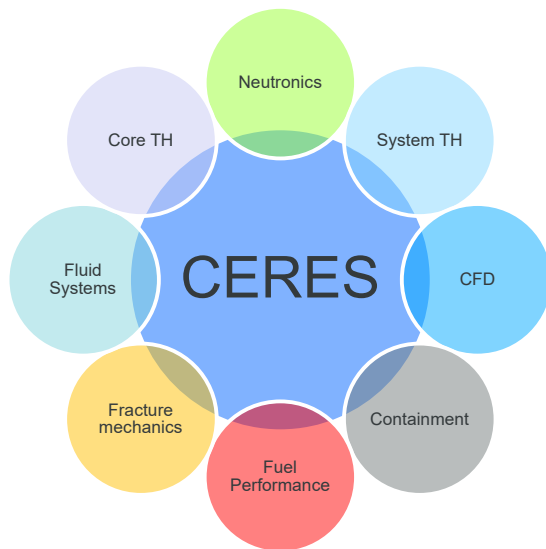
Neutronics ↔
Thermal-Hydraulics ↔
Fuel Performance ↔
Structural Mechanics ↔
I&C and Control Systems



Benefits:

- Improved prediction accuracy
- Better safety demonstration
- Enhanced design optimization
- Reduced uncertainties

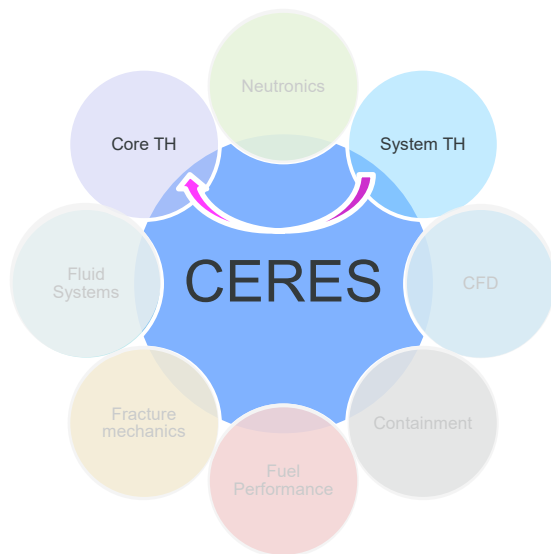
Tractebel has a large tradition of multi-physics calculation



- CERES is based on External Coupling
- The codes are coupled or integrated into CERES not among themselves
- The different codes are integrated into CERES without hard modifications
- Each code requires a python class to be integrated into CERES
- The Python class contains the standard functions that all python classes

RELAP - MODELICA

For the Relap-Modelica coupling:



- Enables 1D system-level sizing of passive systems, as an alternative to full CFD.
- Significantly shorter simulation times than CFD → faster design iterations and sensitivity studies.
- Lower computational cost and reduced dependency on external CFD resources/licenses.
- Scalable approach: same methodology reusable for other passive heat exchanger designs across project

Feature	RELAP5	MODELICA	RELAP5+MODELICA
Primary Circuit TH	Qualified	No	Qualified
Auxiliary Systems	Limited	Full flexibility	Full flexibility
Control Systems	Basic	Advanced	Advanced (for aux sys)
Modularity	Low	High	High (to adapt according the need)

2. COUPLING VALIDATION

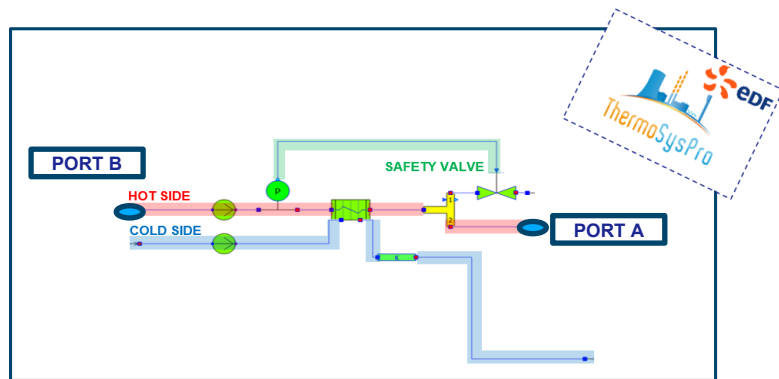
2.1 VALIDATION CASE

2.2 VAIDATION RESULTS

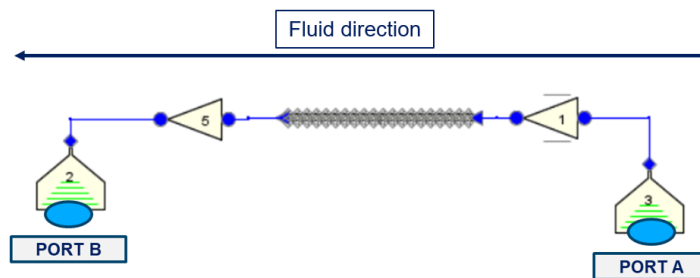
VALIDATION CASE – 1/3

For the coupling validation, a simple model has been selected: a closed loop (hot side) cooled by a cold chain. The hot loop has been split into two parts, one modelled in Modelica and the other in RELAP. At the beginning of the work, the EDF library ThermoSysPro was used (a custom library was developed later).

MODELICA

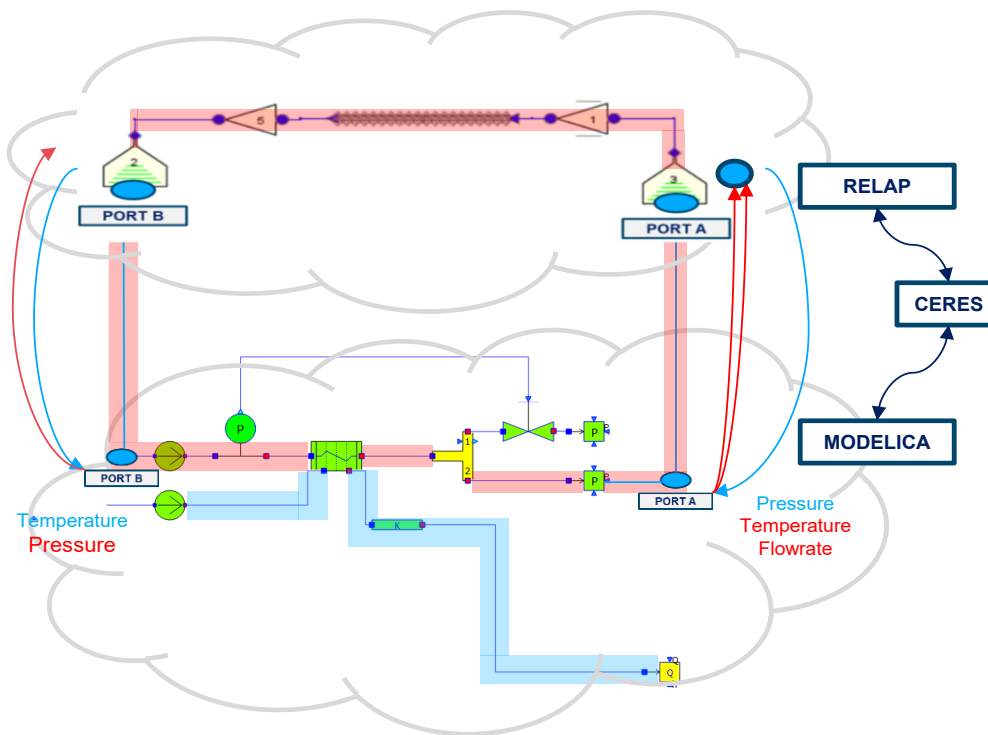
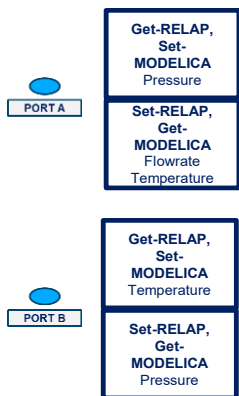
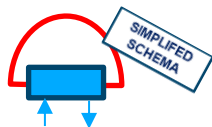


RELAP5-3D

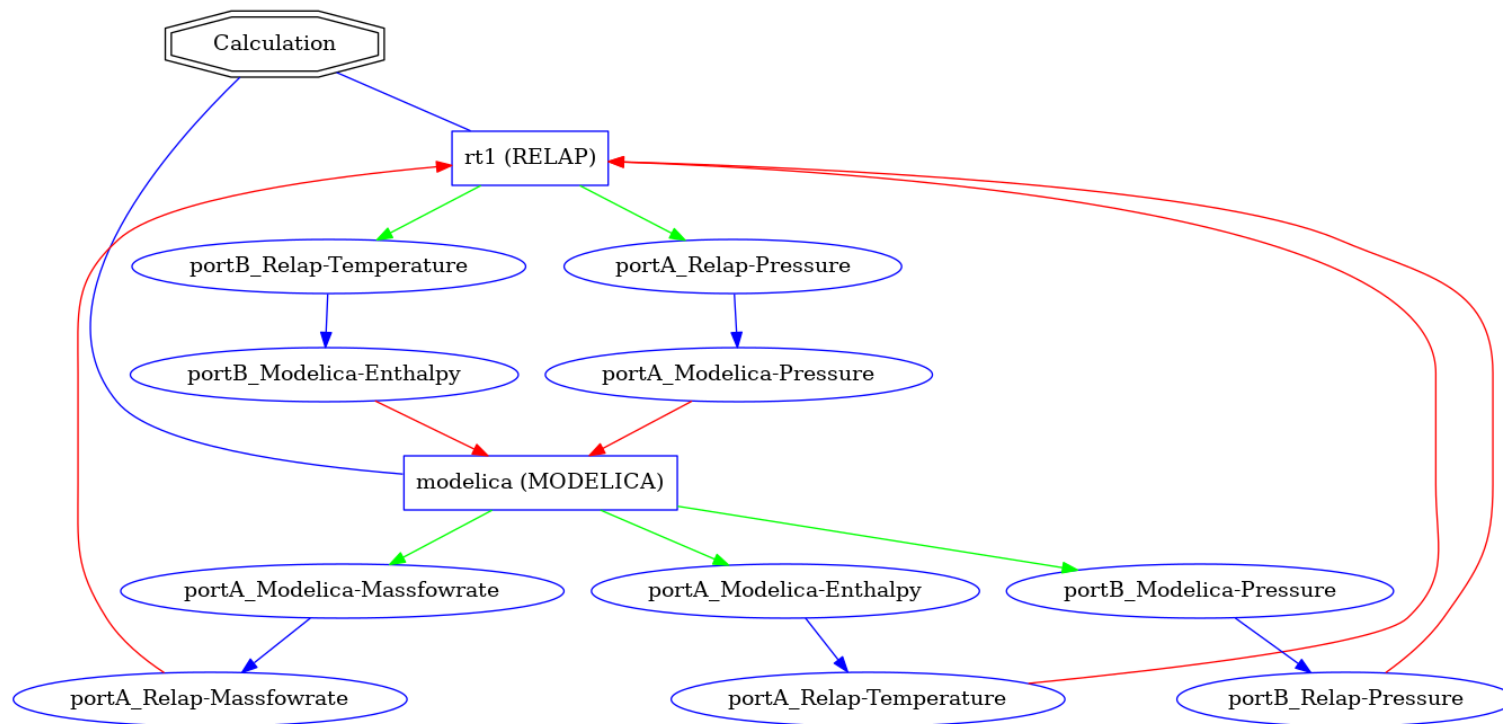


VALIDATION CASE – 2/3

This integration allows for real-time data exchange between RELAP and Modelica

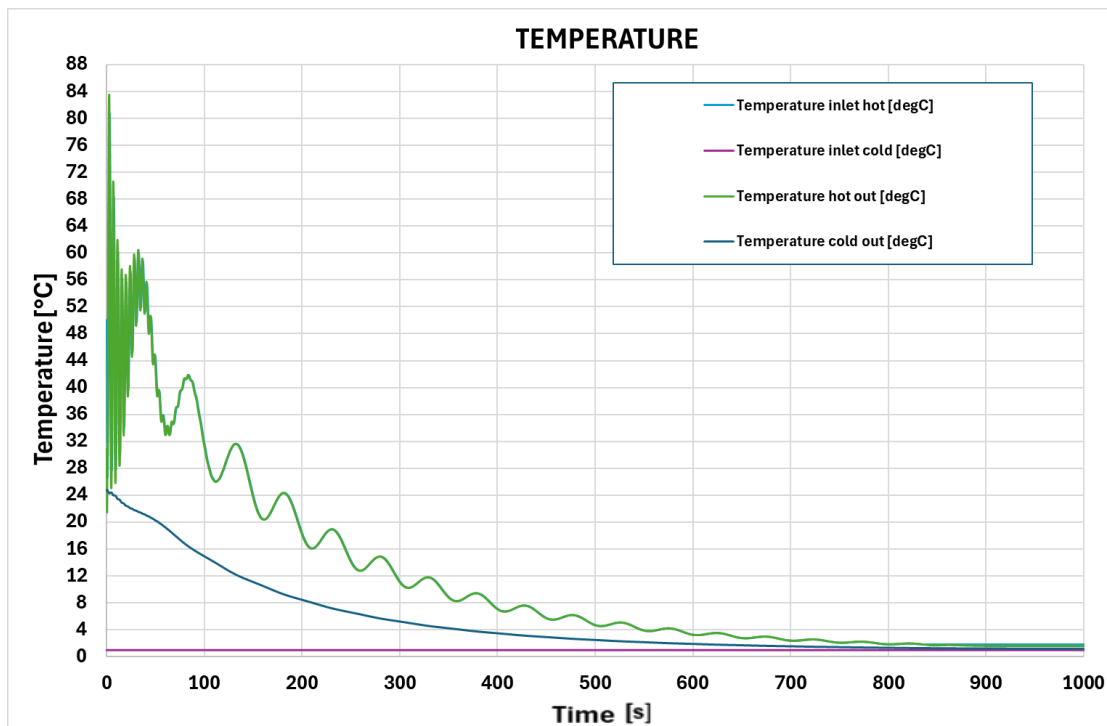


VALIDATION – 3/3



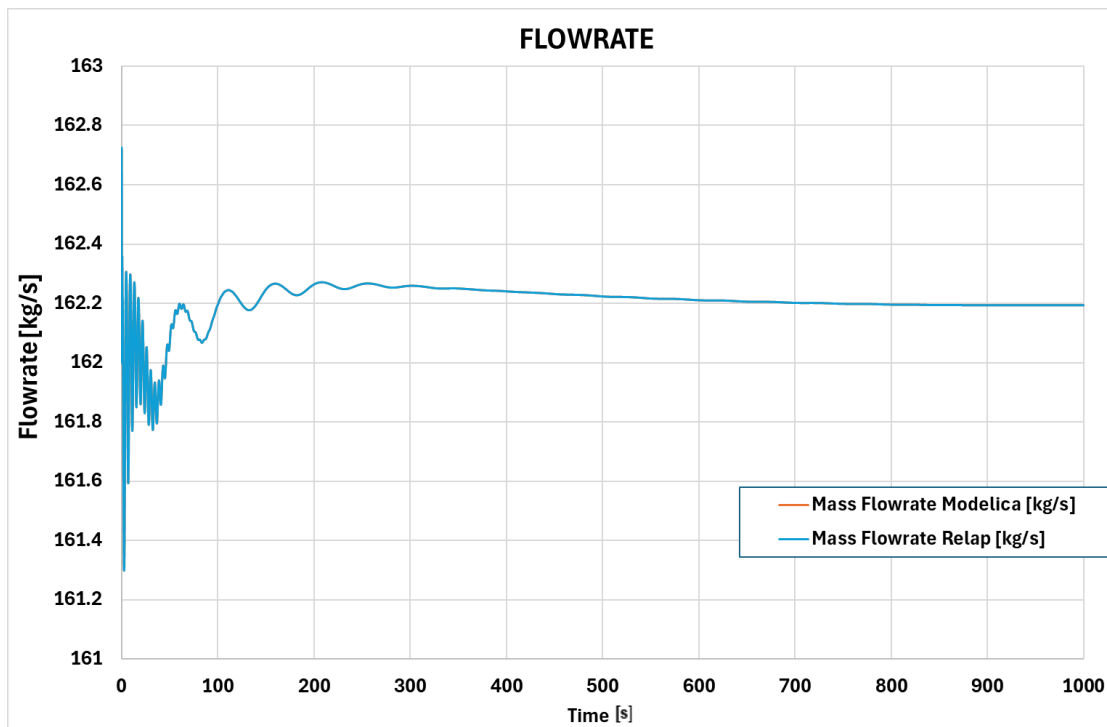
VALIDATION CASE – RESULTS – 1/3

The graph shows that the hot loop approaches the temperature level of the cooler fluid circulating in the exchanger which has a constant temperature (isothermal heat exchanger).



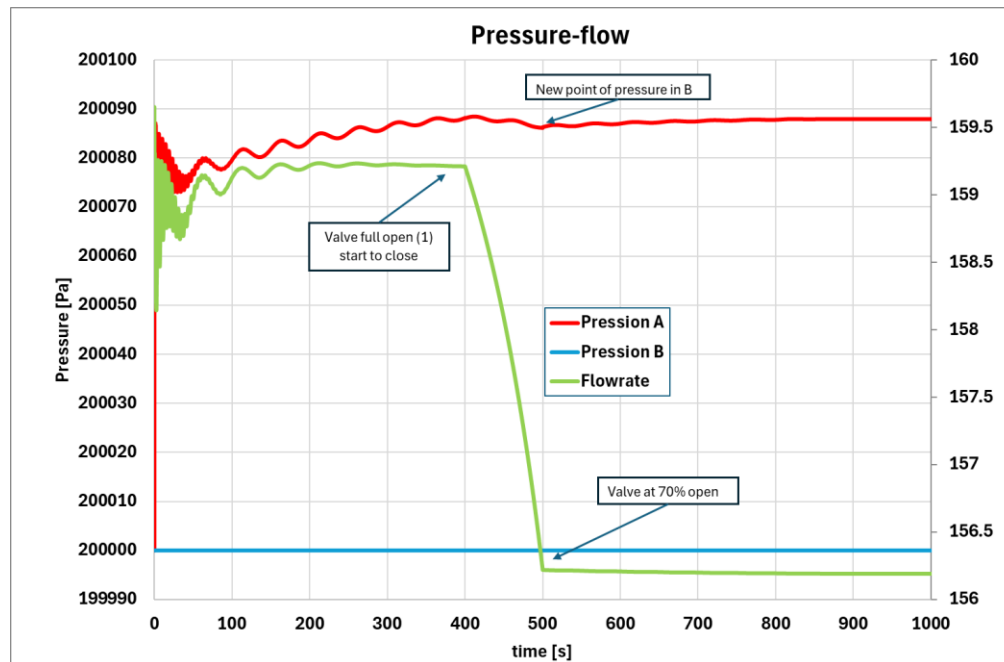
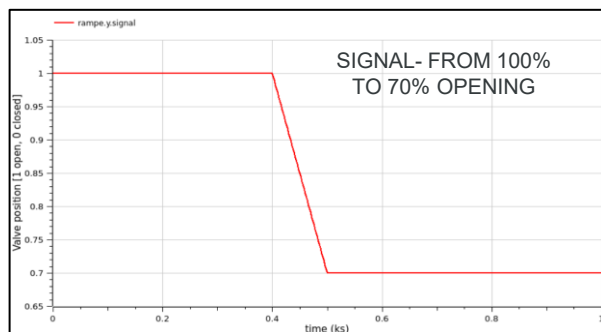
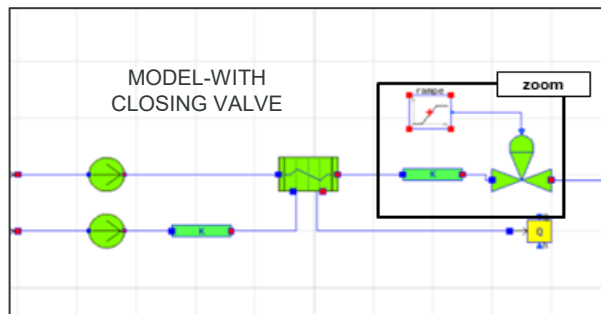
VALIDATION CASE – RESULTS – 2/3

The fluid flow rate is determined by the pump curve and the circuit characteristics (pressure losses). The flowrate is well exchanged in the coupling Modelica-Relap.



VALIDATION CASE – RESULTS – 3/3

The model was tested in a transient condition where a fully open valve, having reached steady state, begins to close, and the new operating point was calculated



3. DEC A: SLBOUT combined with SGTR and loss of CVCS

3.1 SCENARIO

3.2 MODELS/NOVEL APPROACH

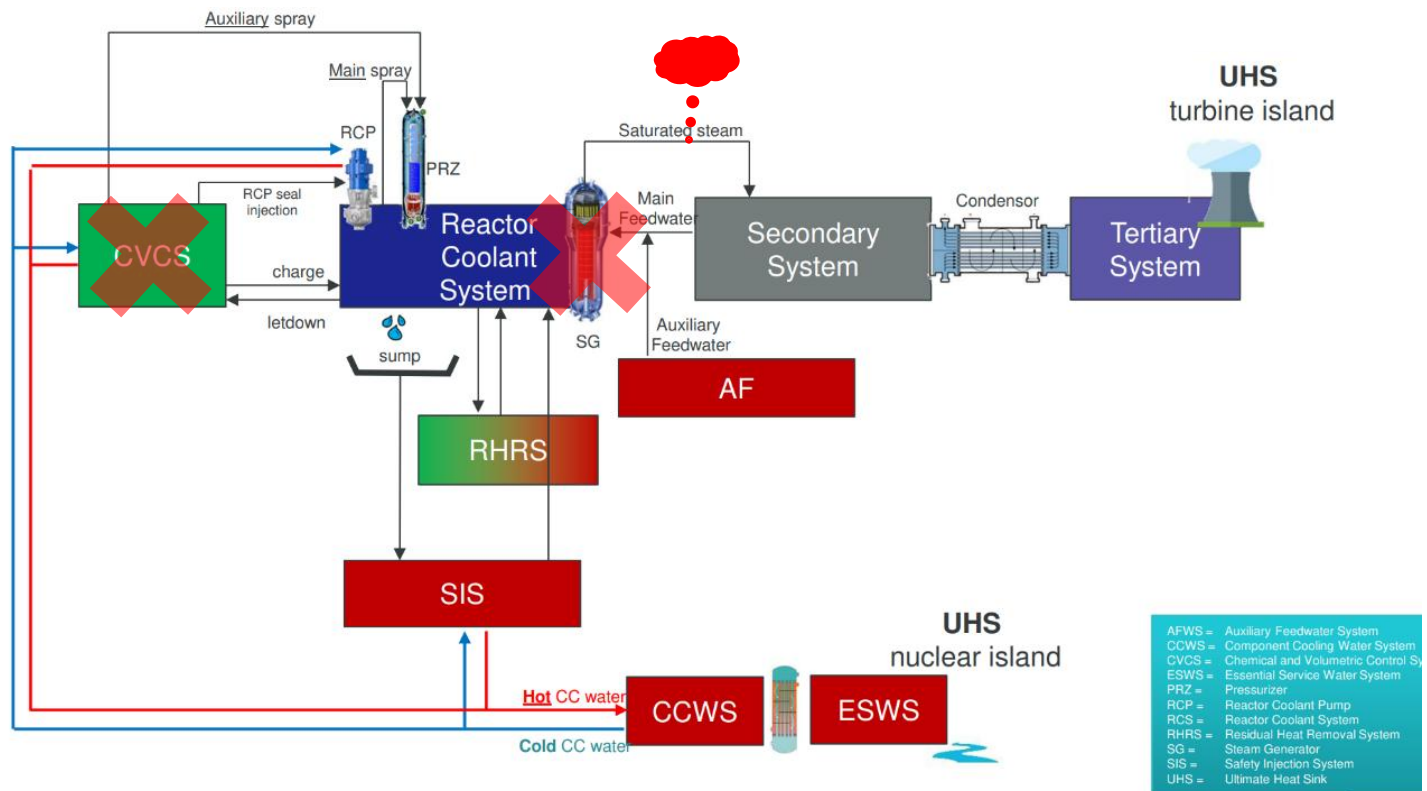
3.3 RESULTS

3.3.1 HEAT WAVE RESULTS

3.3.2 LIMIT TEMPERATURE

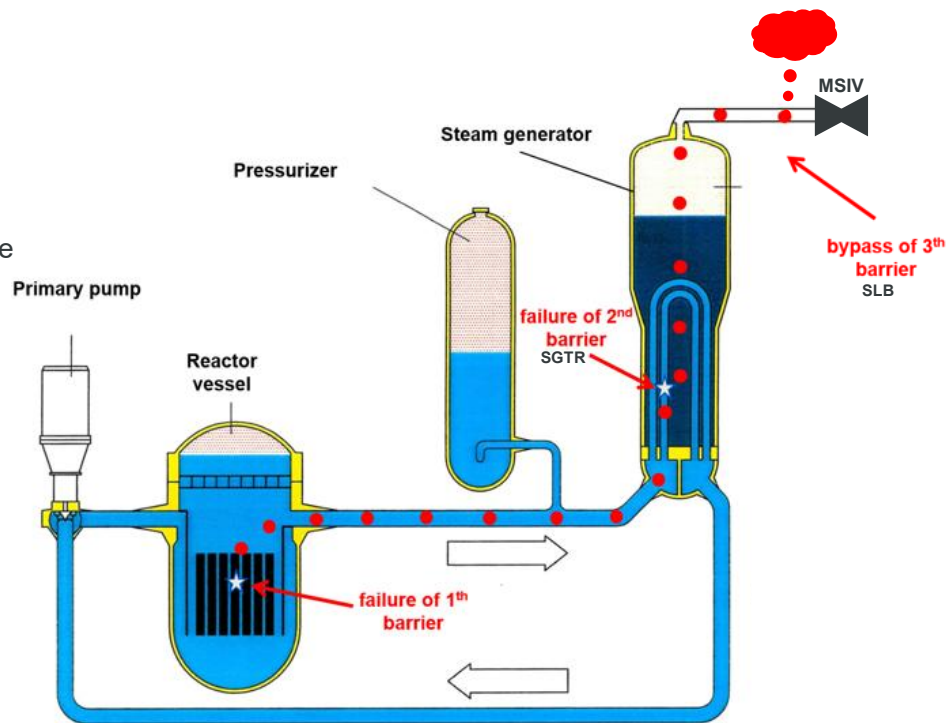
3.4 CONCLUSIONS

CONFIGURATION - SCENARIO



SCENARIO

- The accident scenario of concern consists of two events: a non-isolable SLBOUT (before MSIV) and the rupture of 1 to 3 tubes in the same SG. The CVCS is postulated lost at initiator. Since the SLB occurs outside the containment and cannot be isolated, this transient is equivalent to an SBLOCA without possibility to recirculate

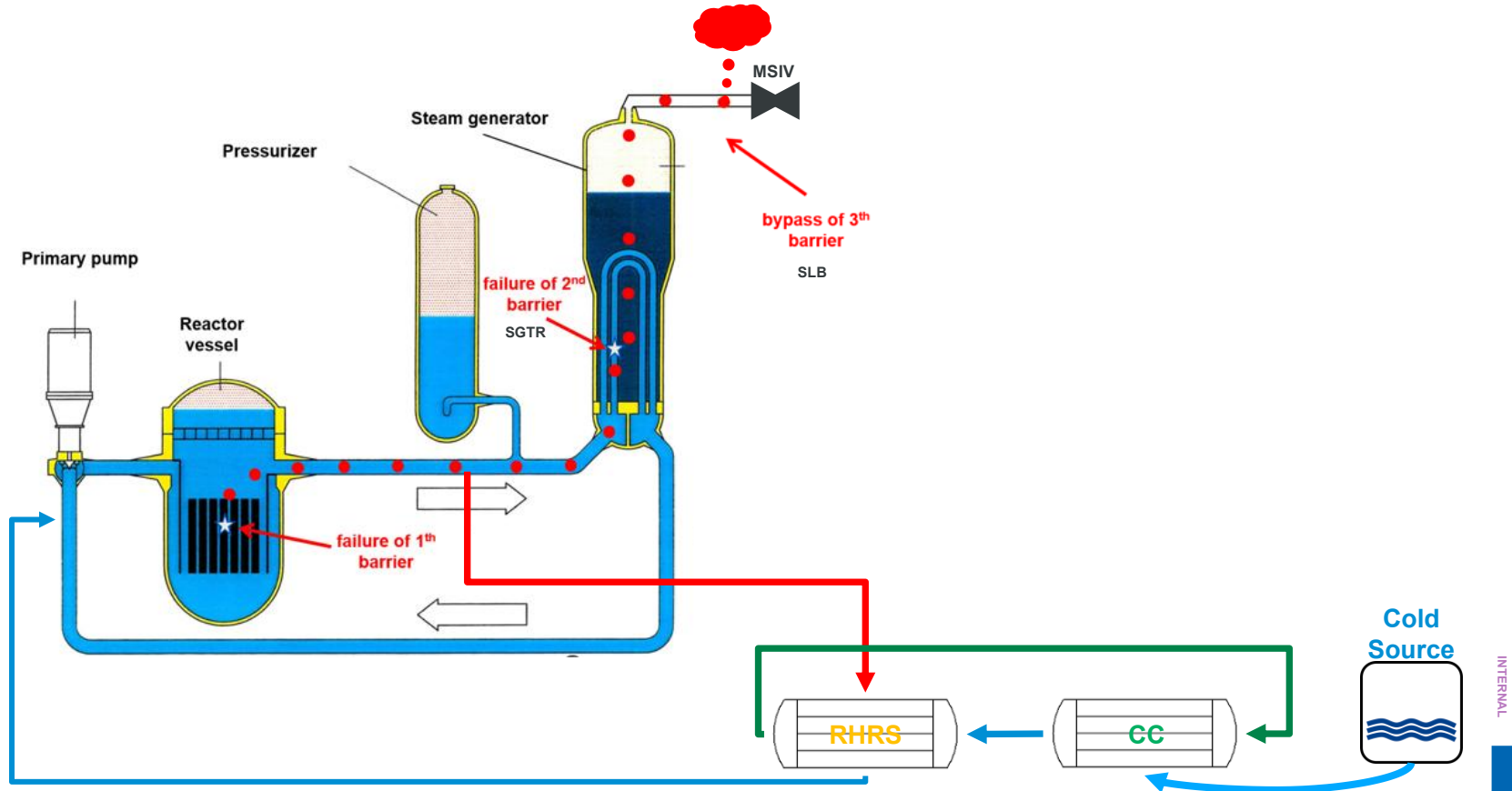


-
- Primary pump
- Reactor vessel
- Pressurizer
- Steam generator
- MSIV
- bypass of 3rd barrier SLB
- failure of 1st barrier
- failure of 2nd barrier SGTR
- Hp: 28 °C/h = Max cooling rate (mechanical stress)
- It should be noted that the real cooling rate is to be as low as possible as required by the criteria used for the assessment of the mechanical stress response of the damaged components.

- INTERNAL

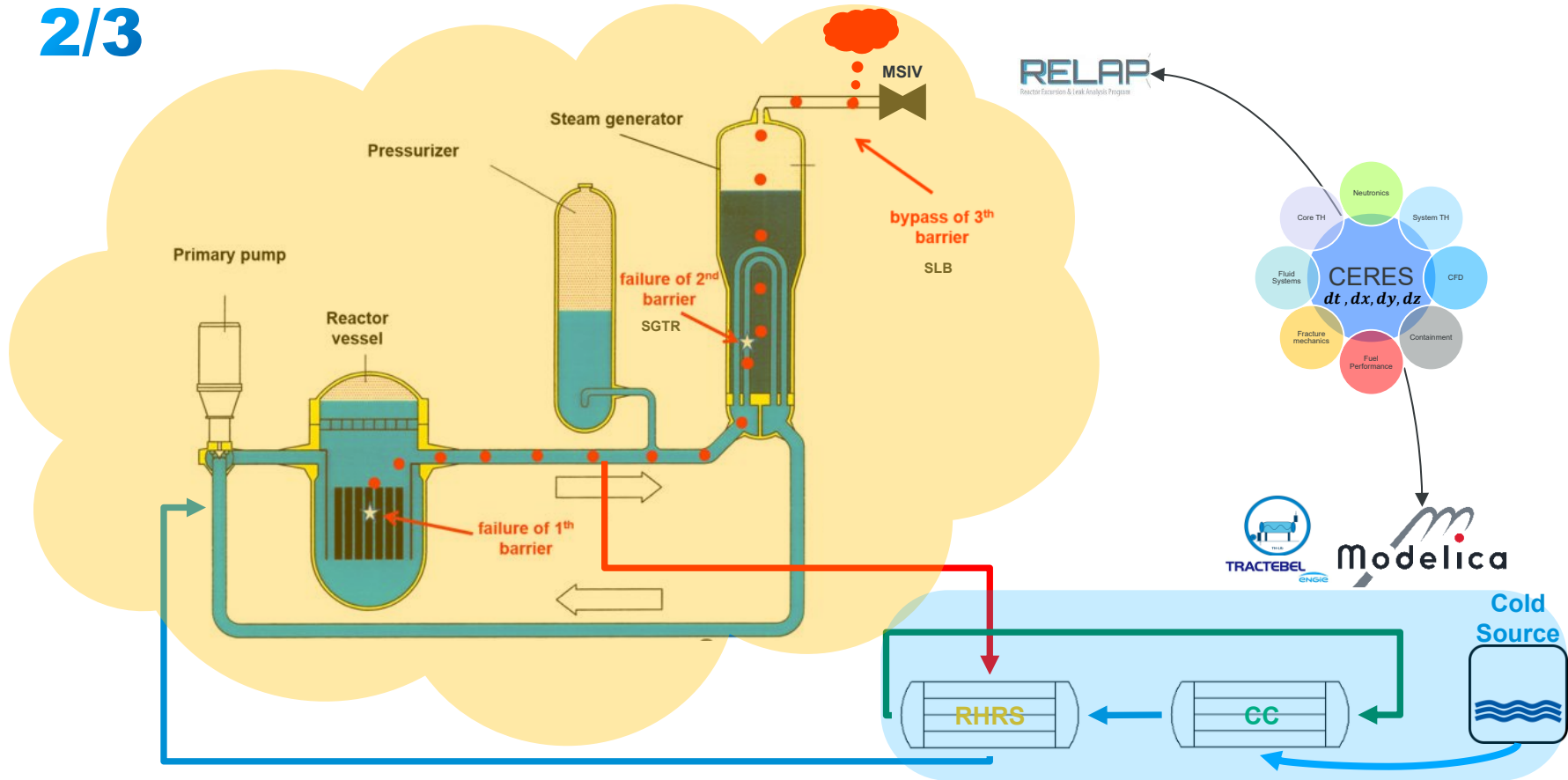
NOVEL APPROACH – MODEL RHRS

1/3



NOVEL APPROACH – MODEL RHRS

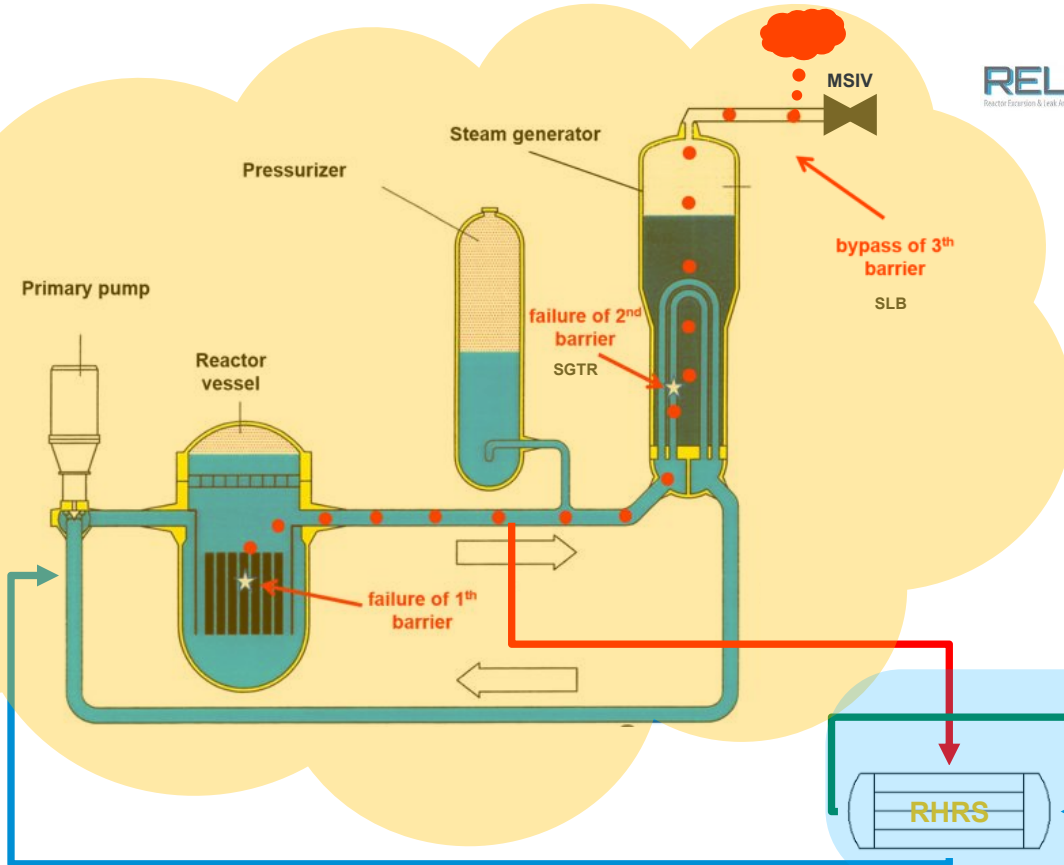
2/3



NOVEL APPROACH – MODEL RHRS

3/3

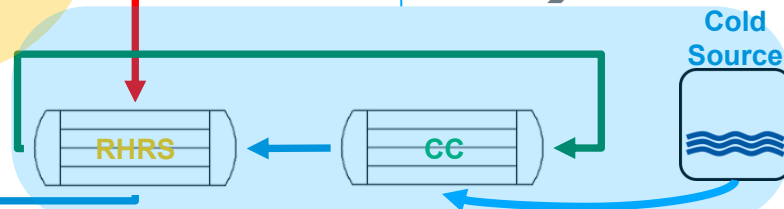
RELAP
Reactor Excursion & Leak Analysis Program



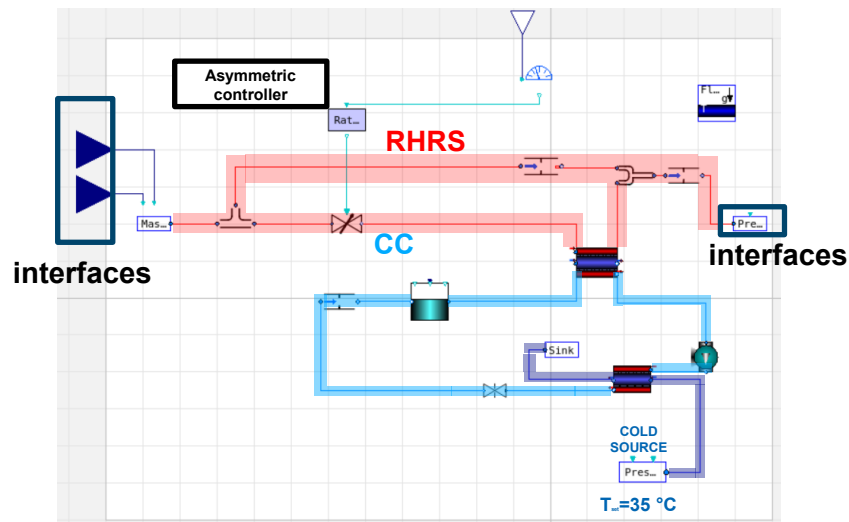
CLIMATE CHANGE - STUDY

How could the cold source temperature impact the radiological release ??

Modelica
TRACTEBEL
ENGIE



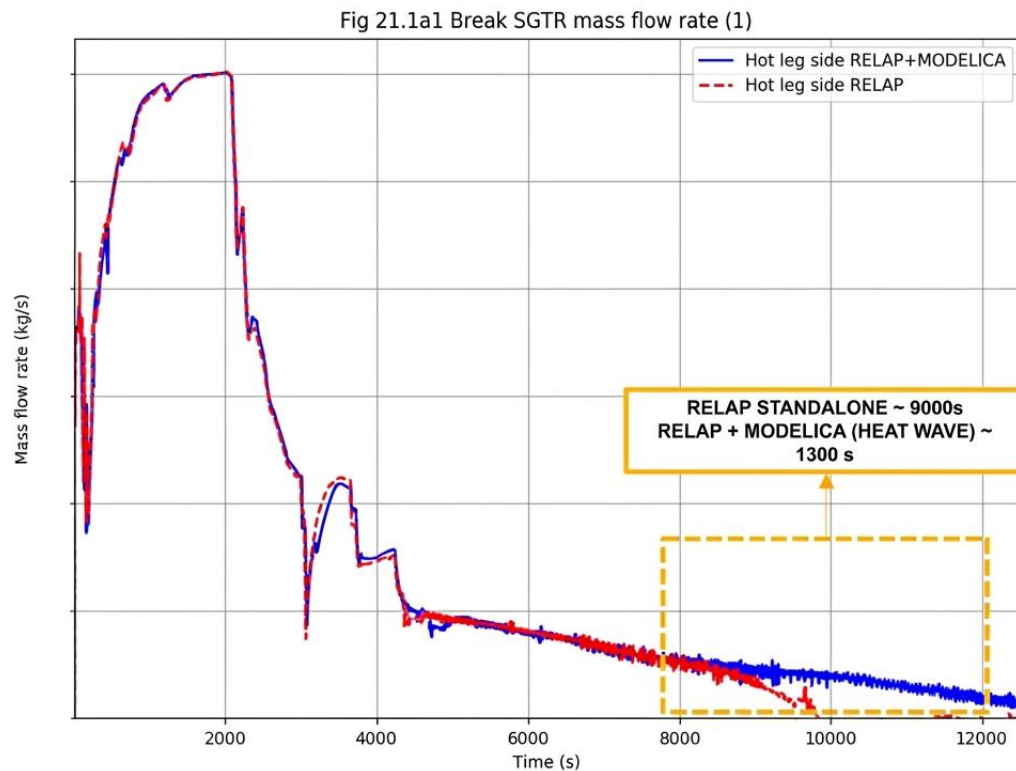
MODELS



Confidential !

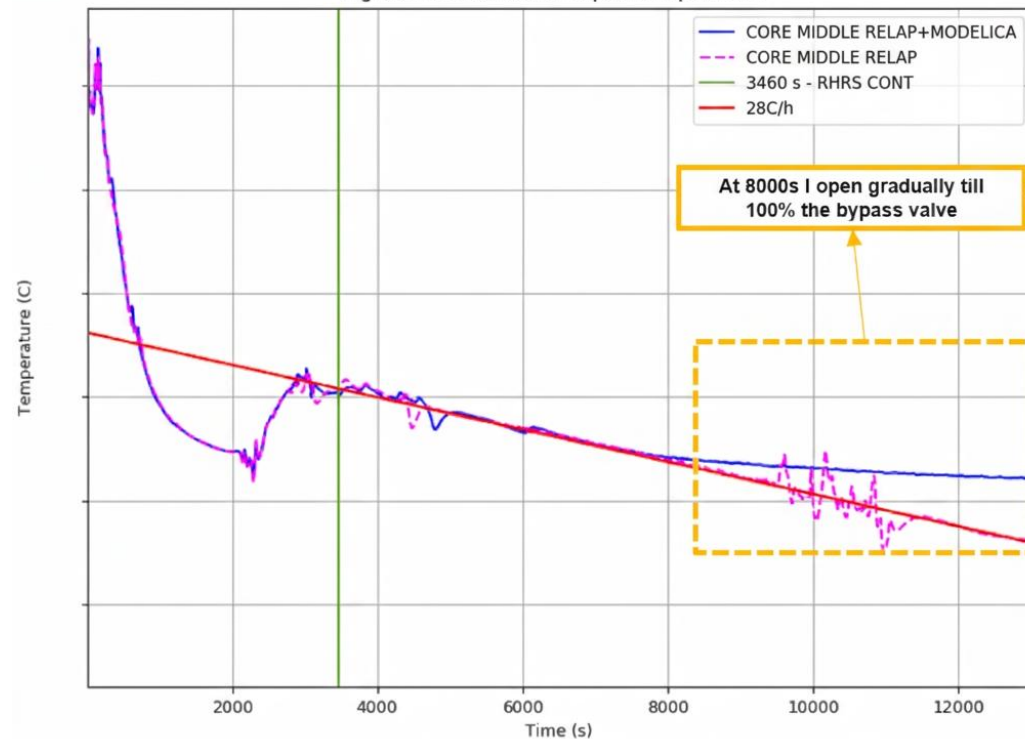


RESULTS – 1/4



RESULTS – 2/4

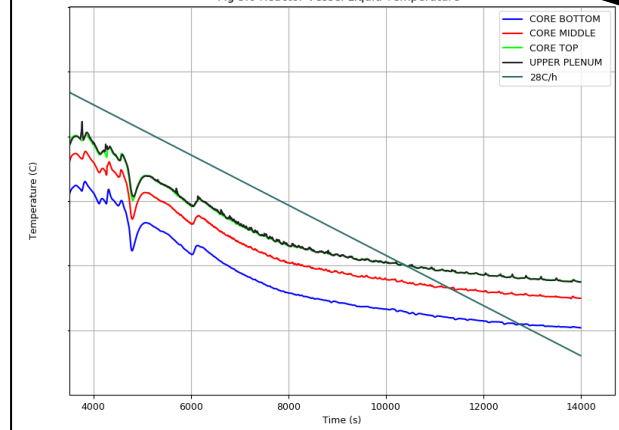
Fig 5.6 Reactor Vessel Liquid Temperature



RELAP+MODELICA

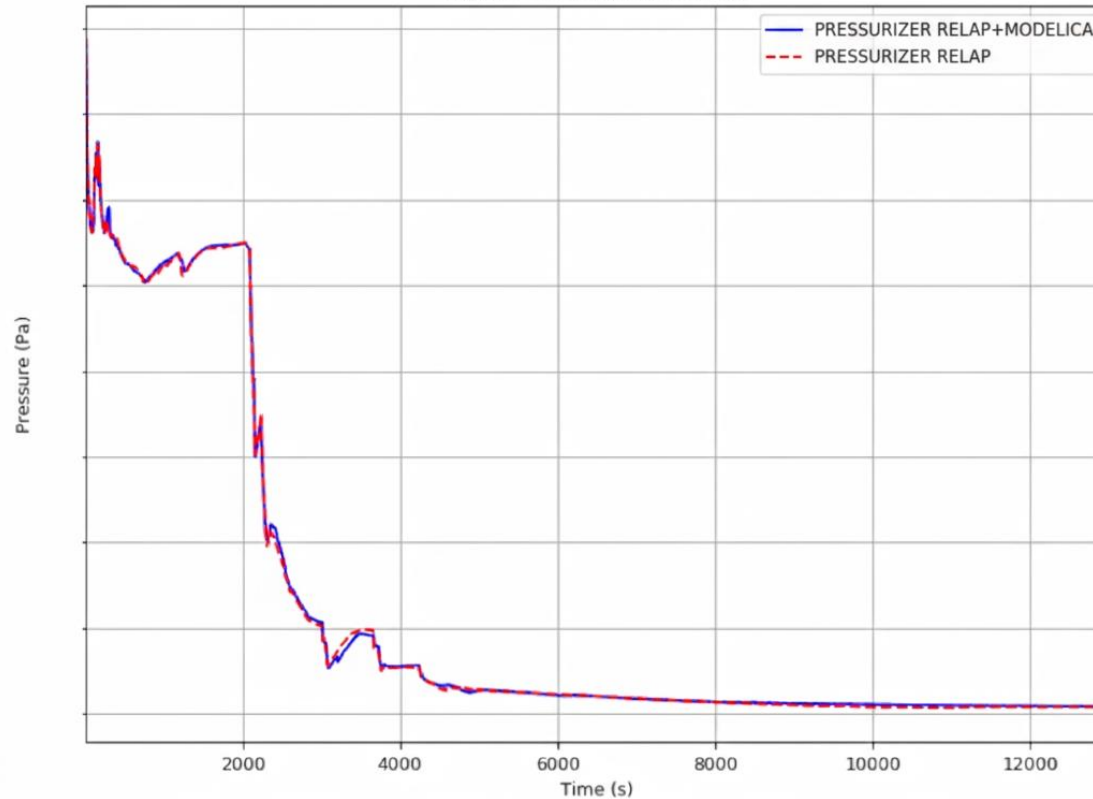
ZOOM

Fig 5.6 Reactor Vessel Liquid Temperature

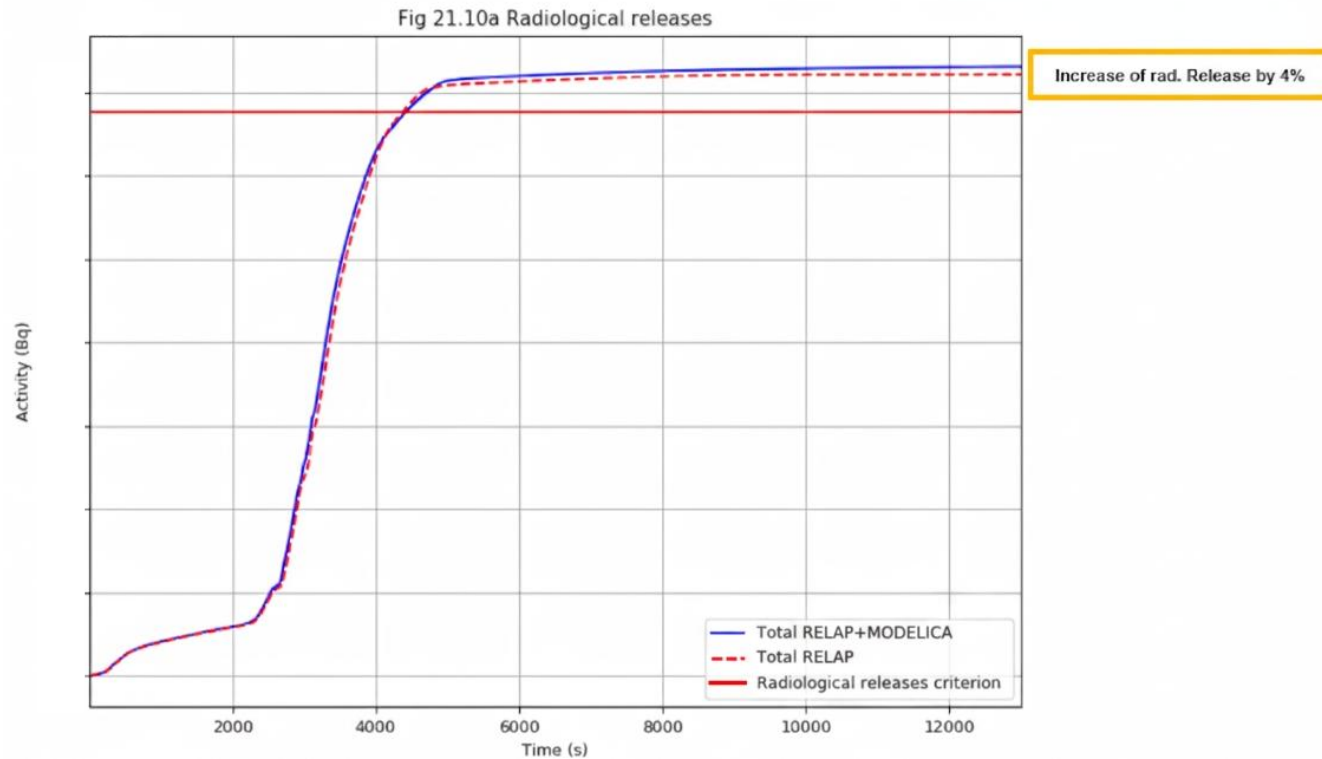


RESULTS – 3/4

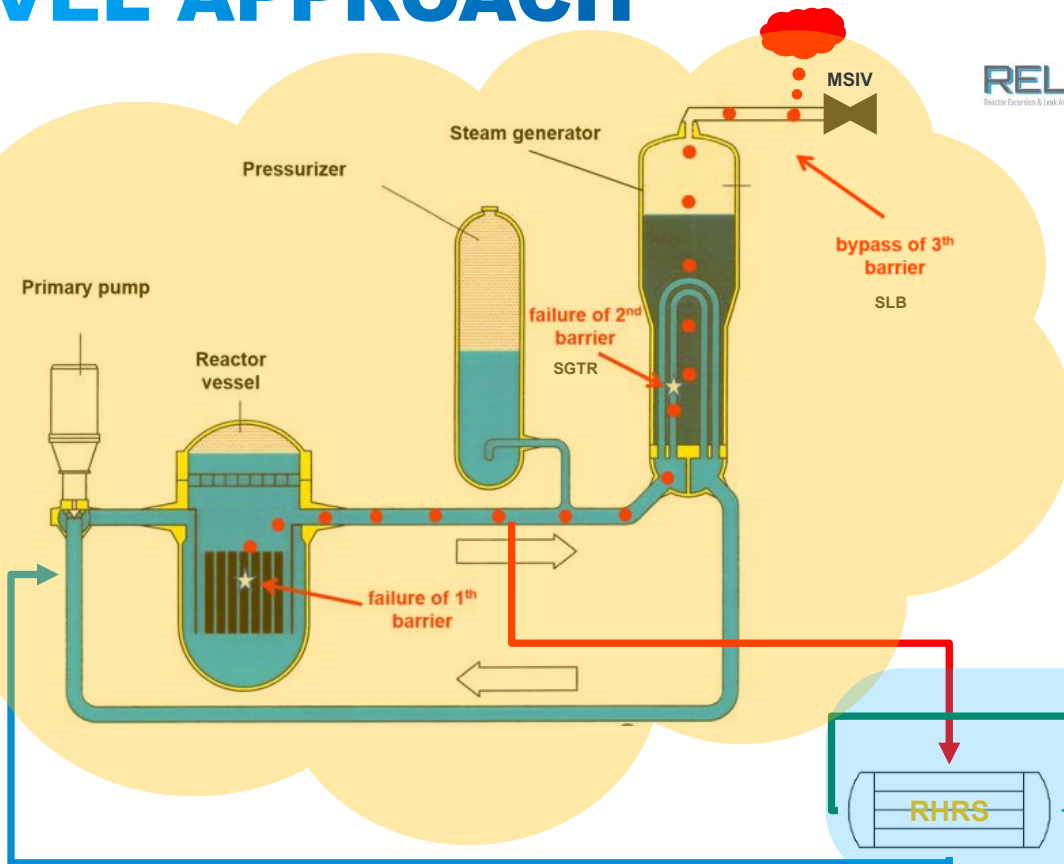
Fig 2.1 Pressurizer Pressure



RESULTS – 4/4



NOVEL APPROACH



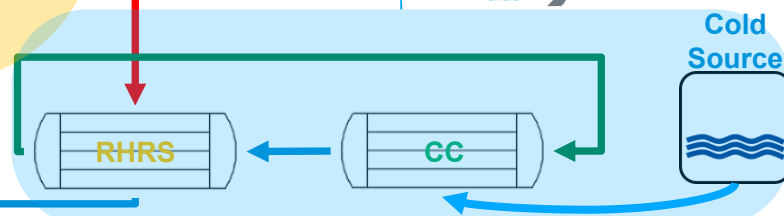
RELAP
Reactor Excursion & Leak Analysis Program



"What is the temperature threshold beyond which the hypothesis is no longer valid?"



Modelica



RESULTS – 1/2

T cold source = 5 °C

Fig 21.2 Break SGTR mass flow rates

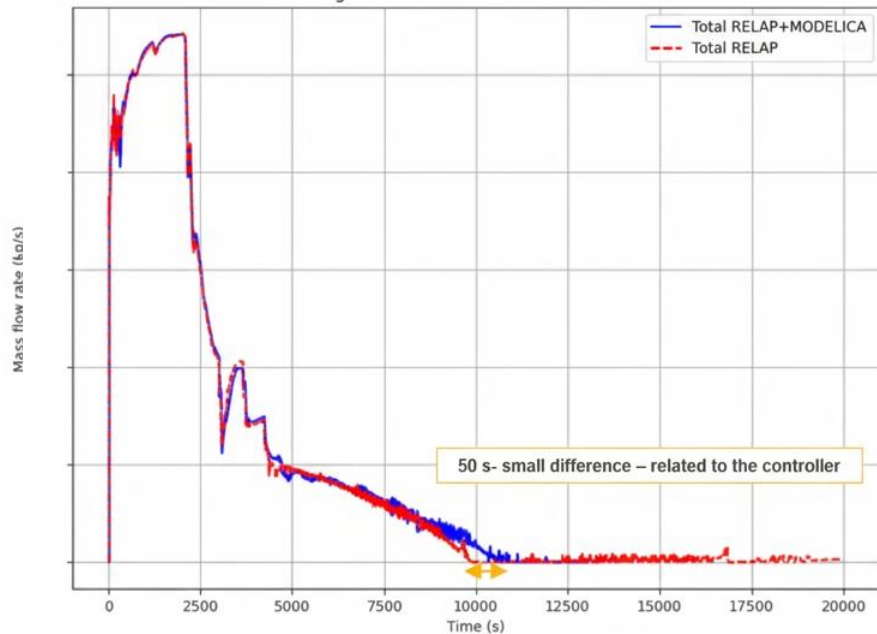
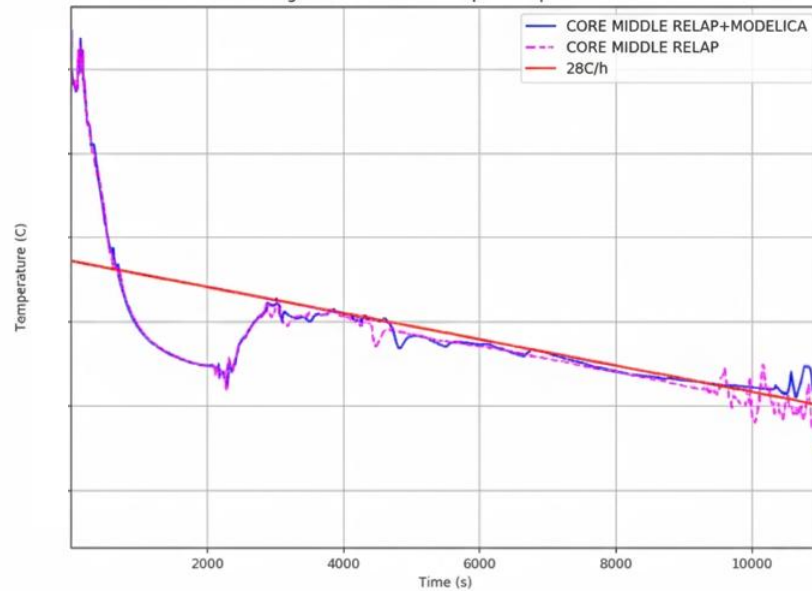


Fig 5.6 Reactor Vessel Liquid Temperature



CNT3 SLBOUT SGTR HFP_P0

Radiological release is the same as the RELAP simulation

RESULTS – 2/2

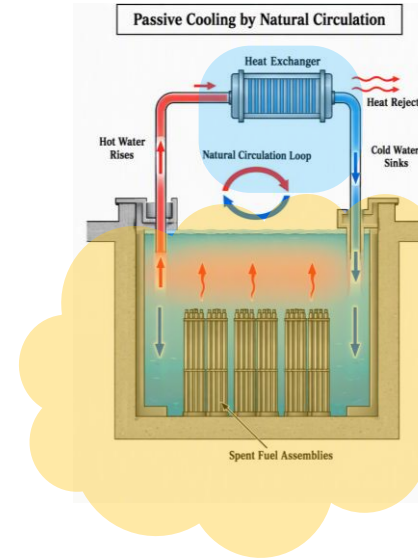
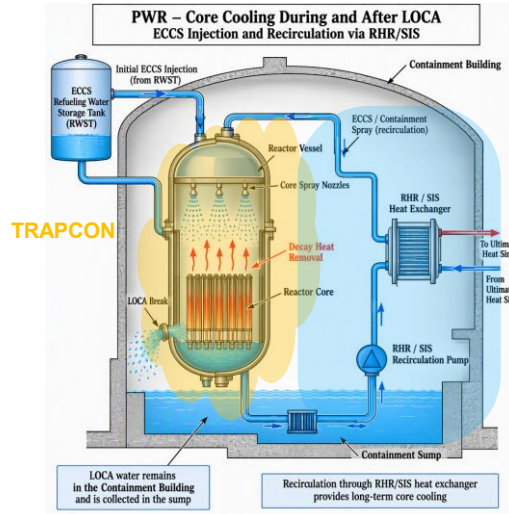
Cold source temperature [degC]	Radiological release difference [%]
5	-
15	-
15	-
25	~1%
35	~4%

CONCLUSIONS

The following considerations can be made:

- Considering the accidental base scenario (SGTR + SLB+ loss CVCS) + Heatwave, lead to an increase equal to ~4% of the radiological release
- The break release from the PRI to the SEC time window increase (~40 %)
- Around 100 °C the 28 °C/h cannot be sustained anymore through the cold chain (reasonable since the Decay heat = 29 MW + cold source = 35 °C)
- For cold source temperatures below 25°C, the hypothesis of a 28°C/h cool down rate is considered applicable.

FUTURE DEVELOPMENTS



RELAP
Reactor Excursion & Leak Analysis Program

THANK YOU !



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QUESTIONS

