LDR Lite district heating reactor benchmark with MELCOR

Tuomo Sevón, VTT Technical Research Centre of Finland

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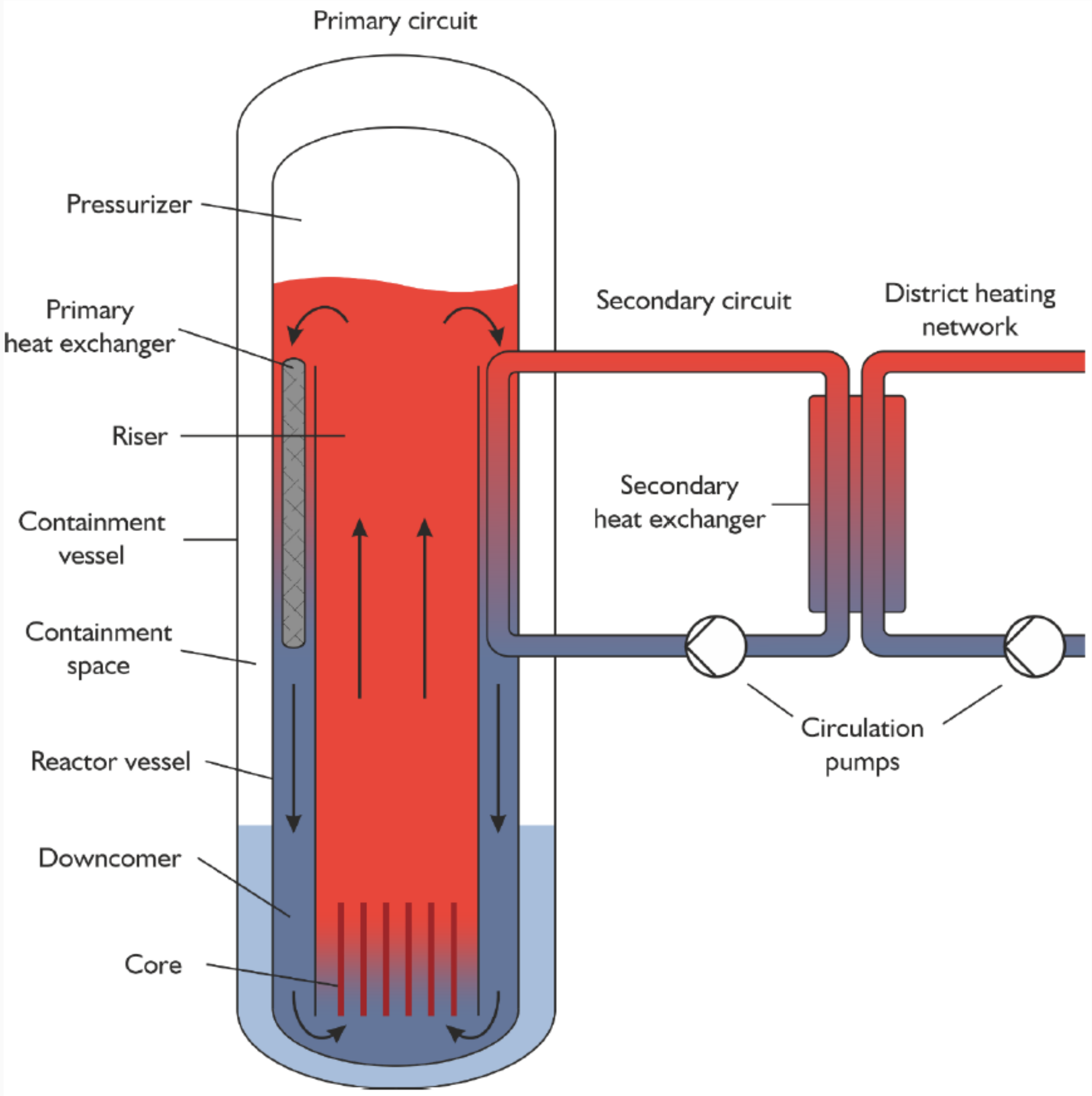
What is LDR Lite?

- **LDR-50** (Low temperature District heating Reactor):
  - 50 MW_{th} integral light water reactor design
  - Developed at VTT since 2020
  - Being commercialized by Steady Energy
- **LDR Lite**:
  - "Academic" version of LDR-50
  - Simplified
  - Public
  - Specifications available at https://www.ldr-reactor.fi/en/ldr-lite-benchmark/
  - Used in a benchmark in EU SANE project (Safety Assessment of Non-Electric uses of nuclear energy)

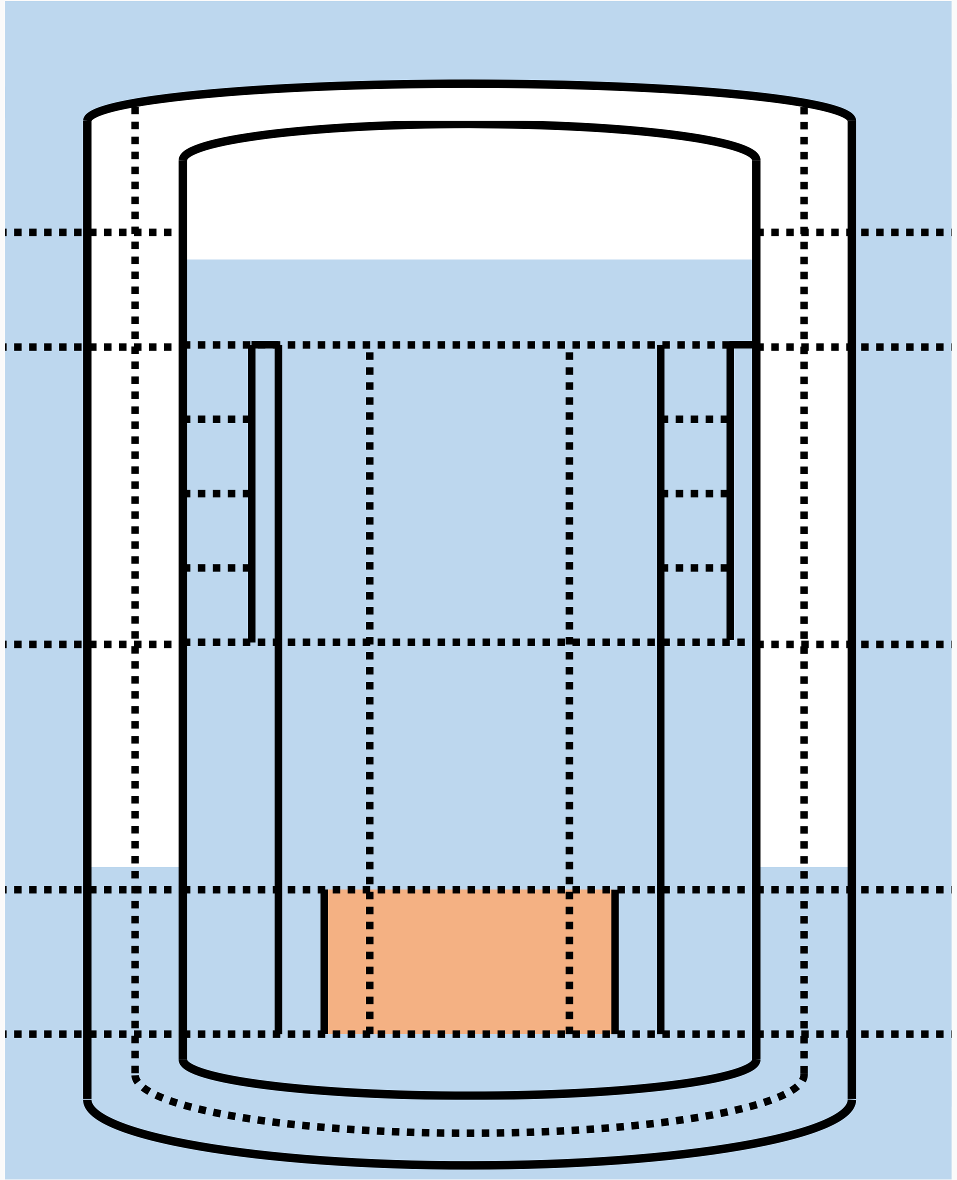
Features of LDR Lite

- PWR fuel, but shorter (1 m)
- Natural convection of primary coolant
- Pressurizer contains nitrogen
- Pressure follows core outlet temperature
- Heat transferred to district heating network via secondary circuit and two heat exchangers
- Reactor vessel enclosed in containment vessel
- Containment partially filled with water, inerted with nitrogen
- Containment submerged in a pool



Nodalization

- **Core**:
  - 4 radial rings (3 in active core)
  - 9 axial levels (5 in active core)
- **Reactor CVH**:
  - Lower plenum
  - 2 rings + bypass in core
  - 2 rings and 2 levels in riser
  - Pressurizer
  - 4 volumes in heat exchanger
  - 2 volumes in downcomer
- **Containment**: 2 rings, 6 levels
- **Pool**: 2 "rings", 6 levels



Major problems with lower head heat transfer

MELCOR calculated zero heat flux from lower head to water in containment during normal operation

COR Package Reference Manual

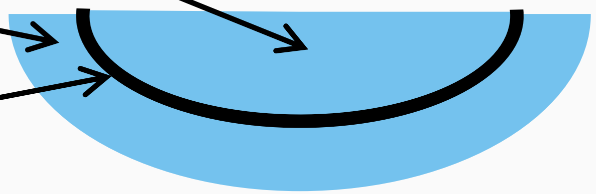
h_{ATM}, is implemented as sensitivity coefficient C1246(1), with a default value of 10 W/m^2-K. The unrelaxed heat transfer coefficient to the reactor cavity pool, h_{PL}, is calculated using a simple downward-facing saturated pool boiling model. Relaxation of h_{PL} is implemented exactly as discussed in Section 2.3. Heat transfer to the pool before boiling is currently ignored as is subcooling of the pool; it is calculated only when the temperature of the outer surface of the lower head exceeds the saturation temperature in the reactor cavity. Hence, the second term on the righthand side of Equation (6-8) cannot be negative.

Missing heat transfer mode modeled as a heat source and sink

- Set up two time-specified auxiliary control volumes
  - Upper volume follows pressure and temperature in the lower plenum
  - Lower volume follows pressure and temperature in the containment
- Heat Structure package evaluates convection heat flux q_{HS} between the auxiliary volumes
- Added a heat sink in lower plenum:

$$Q = (q_{HS} - q_{COR})A$$

- Equal heat source in containment
- Confirmed no anomalies with dT / dz model



q_{COR} = heat flux evaluated by Core package (zero if no boiling)

Possible solution to the lower head heat transfer

Model switch in COR_MS record, found in Users' Guide, undocumented in Reference Manual

(5) ILHHT

COR lower head convection heat transfer to pool switch.

(a) 0

Convective heat transfer between the lower head and external pool is inactive when submerged segment temperatures are below the saturation temperature of the pool.

(b) 1

Convective heat transfer between the lower head and external pool is active when submerged segment temperatures are below the saturation temperature of the pool.

(type = integer, default = 0, units = none)

Learned about this switch two weeks ago, seems to work, did not have time to rerun the simulations

Hot full power steady state

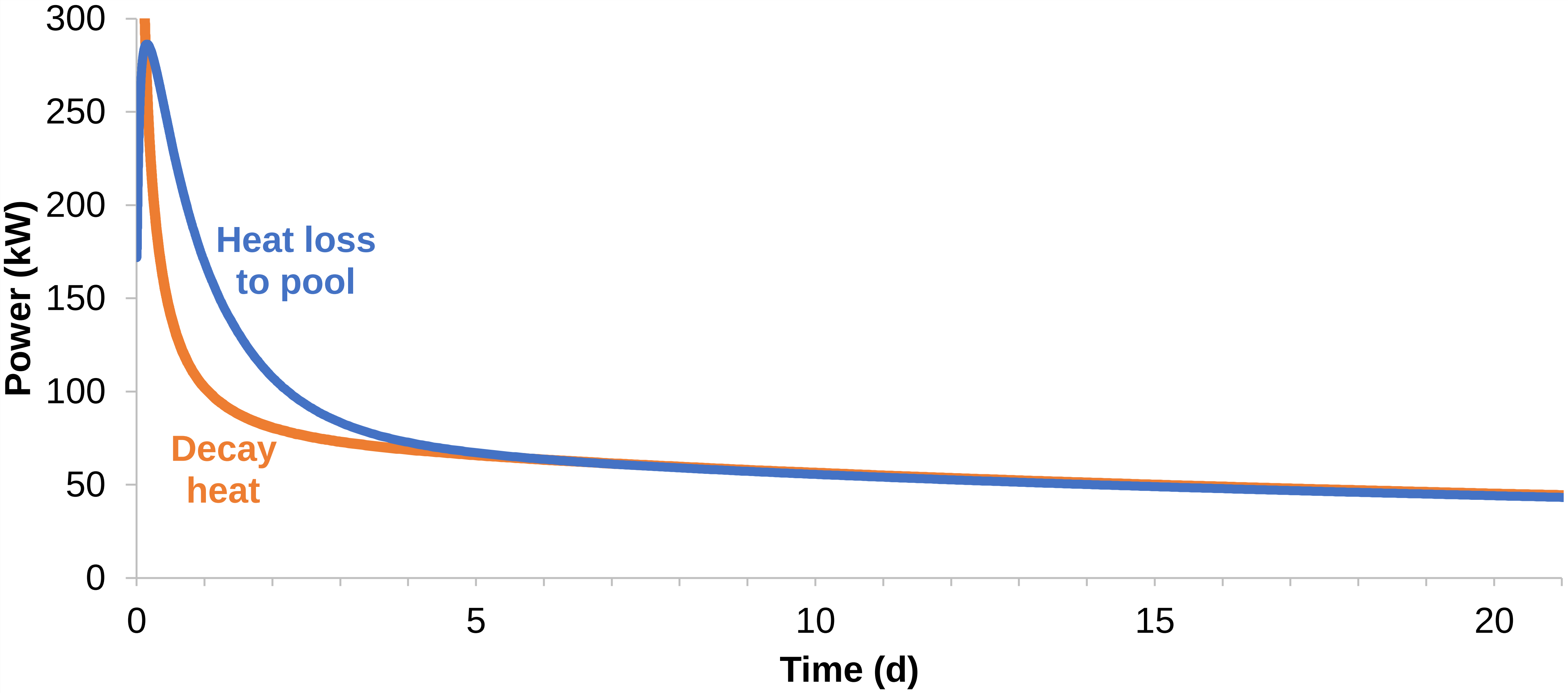
- Boundary conditions: reactor power 50 MW, secondary pressure 15 bar, secondary inlet temperature 77 °C
- Tuned secondary flow rate to get outlet temperature of 125 °C
- Results:
  - Pressurizer pressure 7.44 bar
  - Containment pressure 1.3 bar
  - Core inlet temperature 109.5 °C
  - Core outlet temperature 155 °C
  - Primary flow rate 255 kg/s
  - Heat loss to pool 172 kW (0.34 % of thermal power)
- These will be compared to other codes in the benchmark

Station blackout

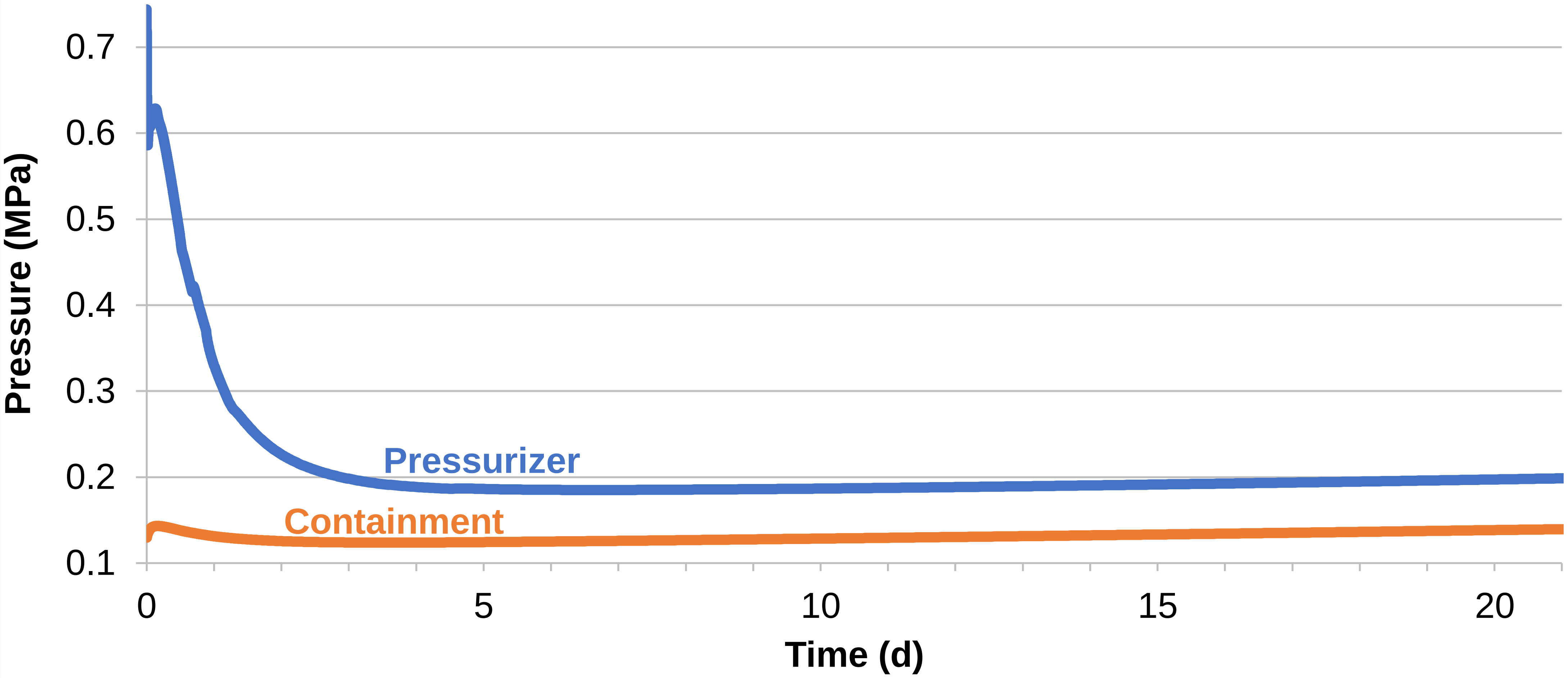
Test case for the passive decay heat removal

- Starts at hot full power steady state
- Time zero: feedwater lost, reactor scrammed
- No accident management systems or procedures

Station blackout: Heat loss to pool



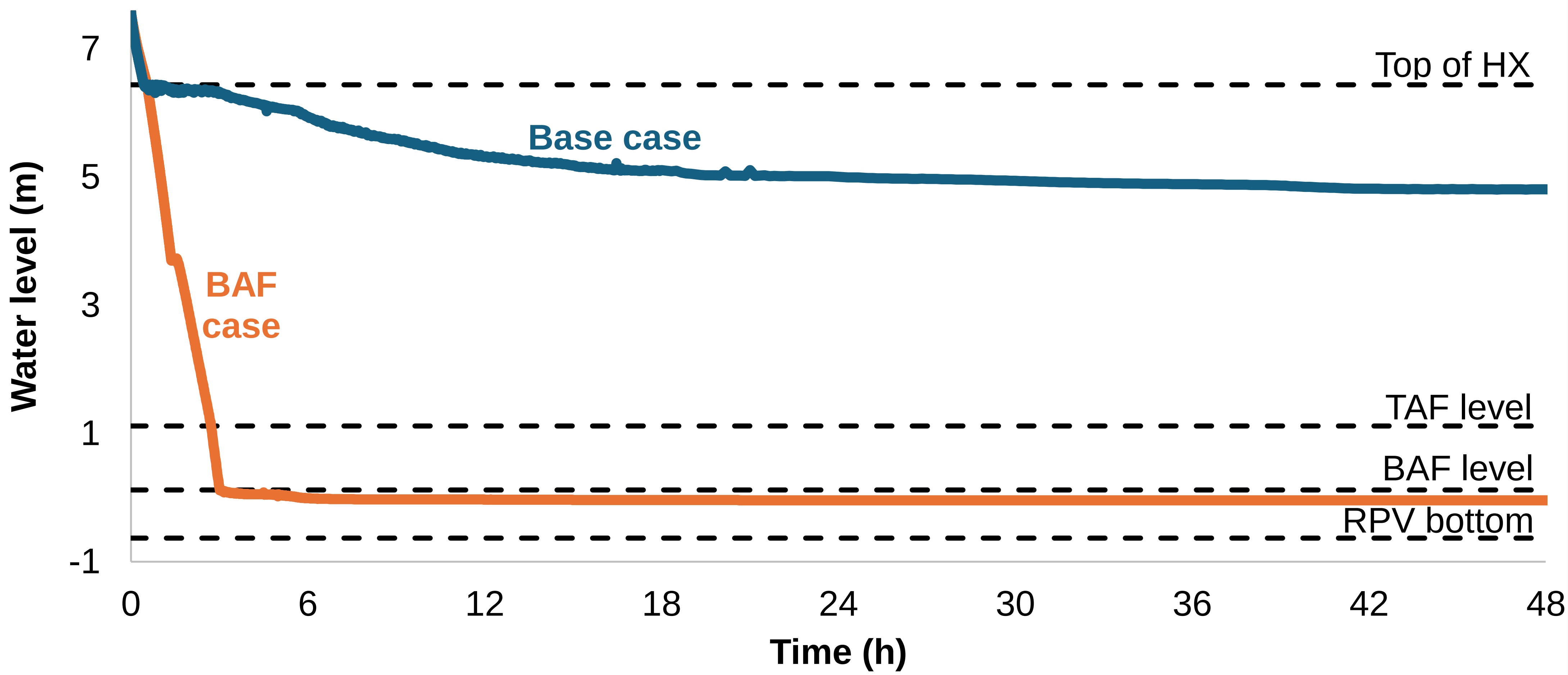
Station blackout: Pressure



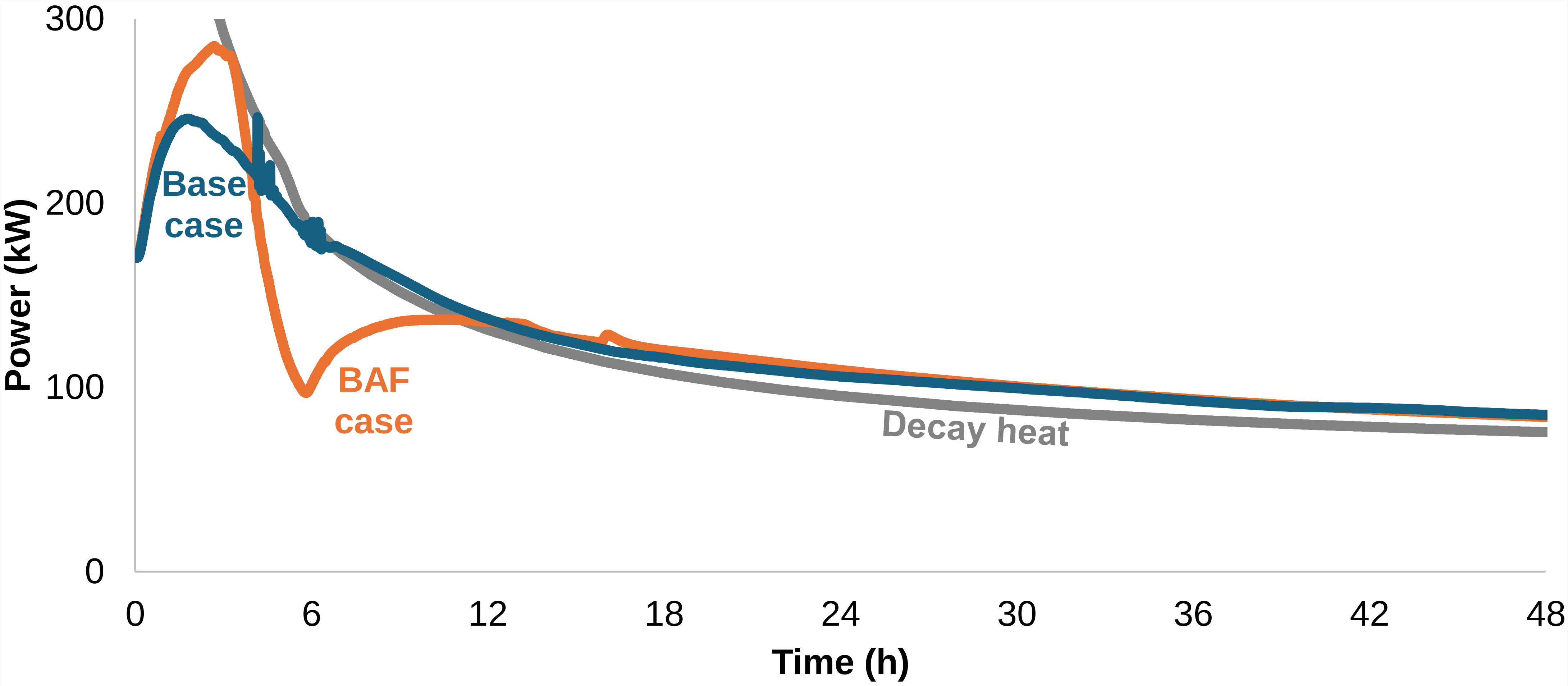
LOCA simulations

- Leak from reactor to containment cannot cause core uncovery because the coolant does not fit into the containment
  - Reactor coolant volume 34 m^3, containment gas volume 23 m^3,
- More interesting case: leak from reactor to outside of containment
- LDR Lite has the CVCS (Chemical and Volume Control System) line, penetrating the reactor vessel and containment vessel
- Assumed station blackout and CVCS line break outside the containment
- **Base case**: CVCS line located above the heat exchangers, as in LDR Lite specifications
  - Did not lead to core uncovery
- **BAF case**: moved CVCS line to bottom of active fuel elevation

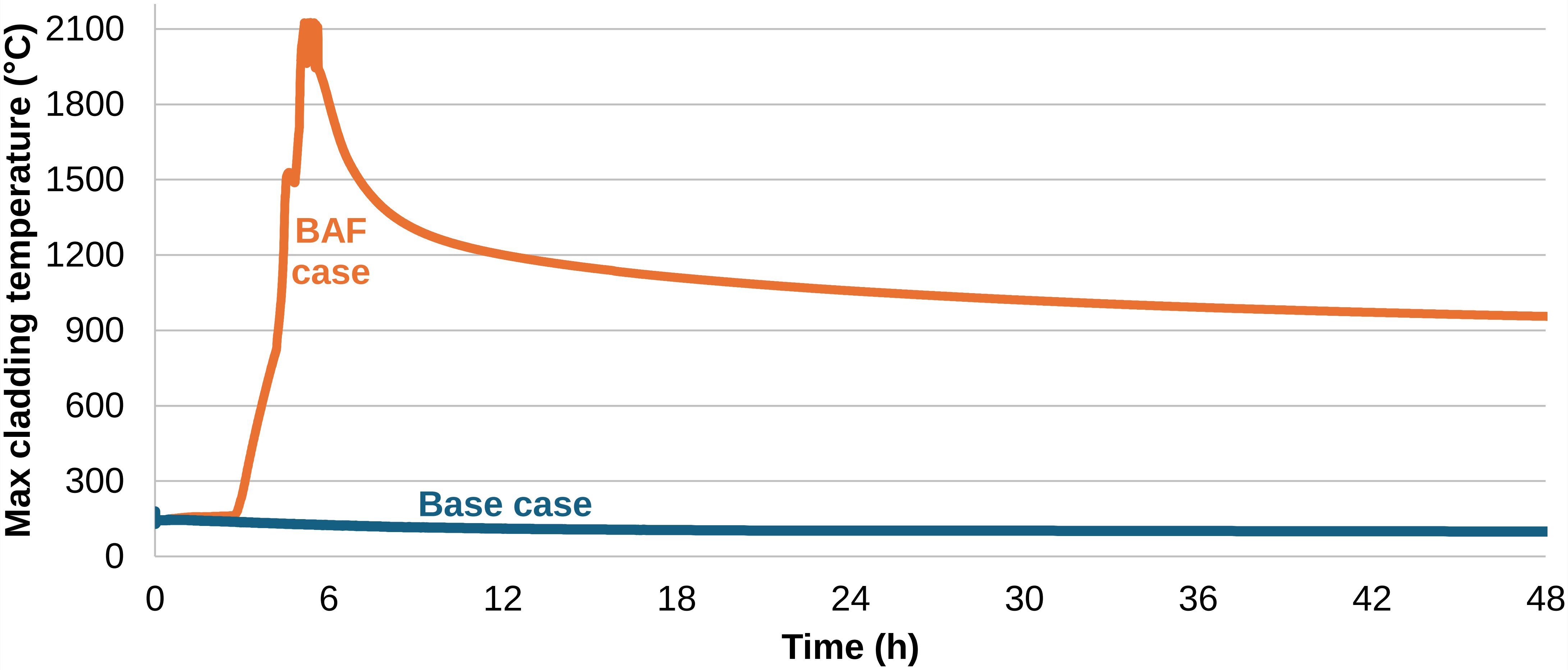
CVCS leak: Water level in reactor



CVCS leak: Heat loss to pool



CVCS leak: Max cladding temperature



Summary

- MELCOR ignored convection heat transfer from reactor lower head to water in containment
  - Had to simulate the missing heat transfer mode with a heat source and sink
  - (Possible fix with COR_MS input record)
- Successfully simulated steady state, station blackout, LOCA and containment bypass, with passive decay heat removal
  - Results will be compared to other benchmark participants
- Core uncovery achieved in containment bypass scenario, assuming that the leak is located at bottom of active fuel
  - Cladding temperatures close to, but below, the rod collapsing limit
  - Oxidized 27 % of Zr, generated 19 kg of hydrogen
  - Released 34 % of Cs inventory from fuel

SANE

tuomo.sevon@vtt.fi

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