Station Blackout Transient Analyses for VTT's SMR Design LDR-50

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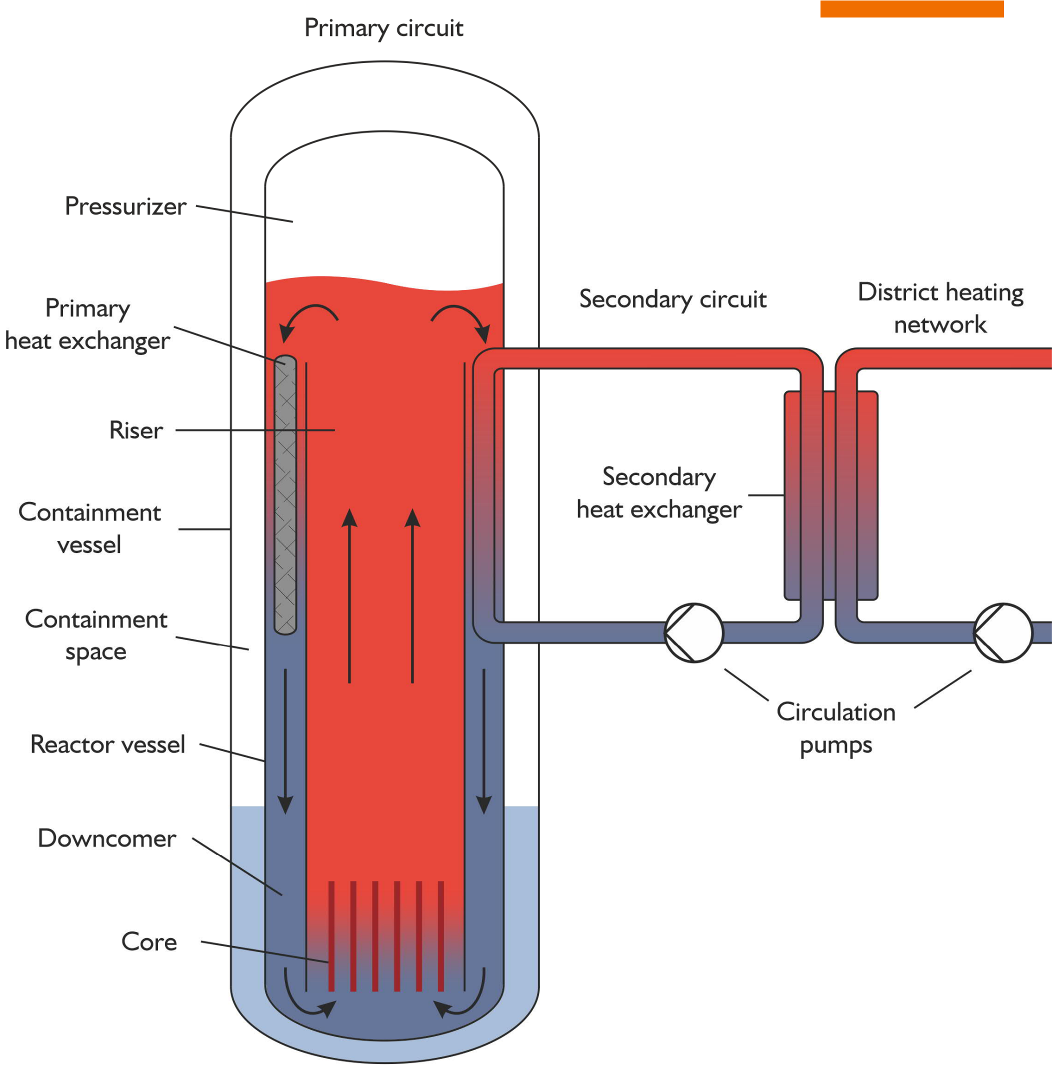
LDR-50

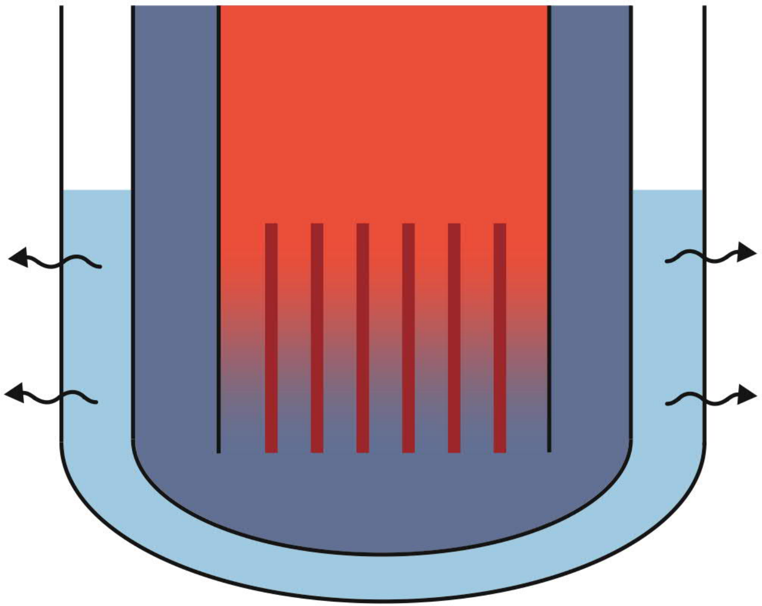
Low Temperature District Heating and Desalination Reactor

- Development started at VTT in 2020
- Integral PWR design with passive safety features
- Produces low temperature heat in low pressure
- Primary circulation driven by natural convection
- Connected to district heating network via secondary circuit



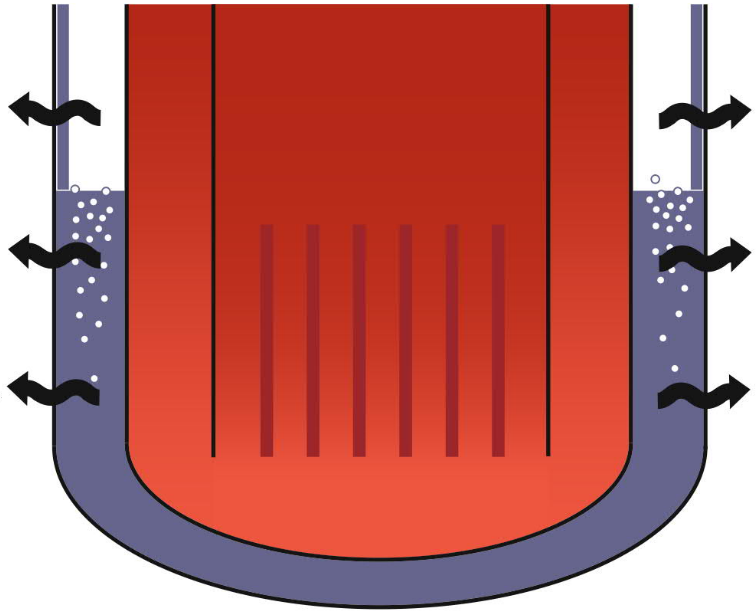
LDR-50 – passive heat removal function

- Innovative decay heat removal system without any mechanical moving parts
- Containment space partially filled with water
  - In normal operation below saturation temperature (heat losses to pool < 1 %)



LDR-50 – passive heat removal function

- Innovative decay heat removal system without any mechanical moving parts
- Containment space partially filled with water
  - In normal operation below saturation temperature (heat losses to pool < 1 %)
- Decay heat removal mode: boiling in the containment opens an effective heat transfer path to the pool
  - Capable of decay heat removal without any mechanical moving parts

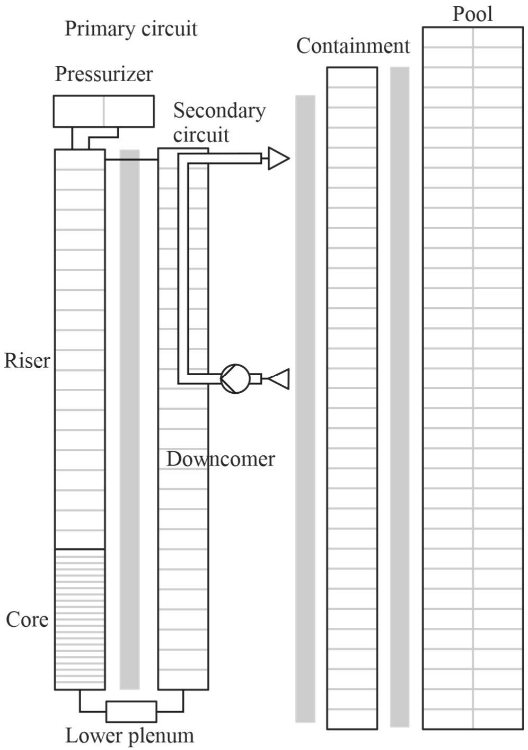


LDR-50 – main parameters

Thermal power	50 MW
Module height	11.5 m
Number of assemblies	37
Fuel	17x17 standard PWR
Active fuel length	100 cm
DH supply temperature	80-120 °C
Operating pressure	3-7 bar
Core outlet temperature	110-150 °C

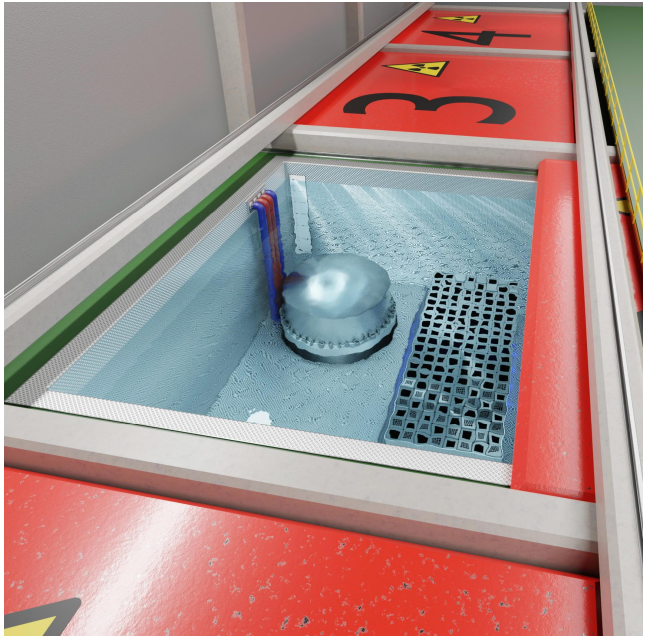
LDR-50 – Apros model

- Apros is a process simulation software developed by VTT and Fortum
  - Used widely for NPP safety analyses as well as other applications
- Apros has been used in the design process of LDR-50
- Apros model includes primary and secondary circuits, containment, pool, district heating network and shutdown cooling systems as boundary conditions
- Point kinetics parameters produced with VTT's Kraken reactor simulator



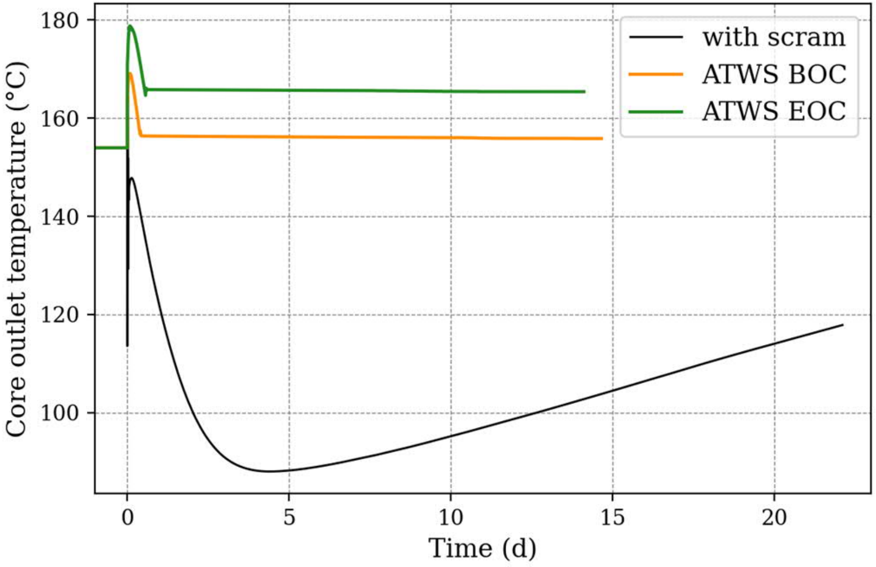
Station blackout variations

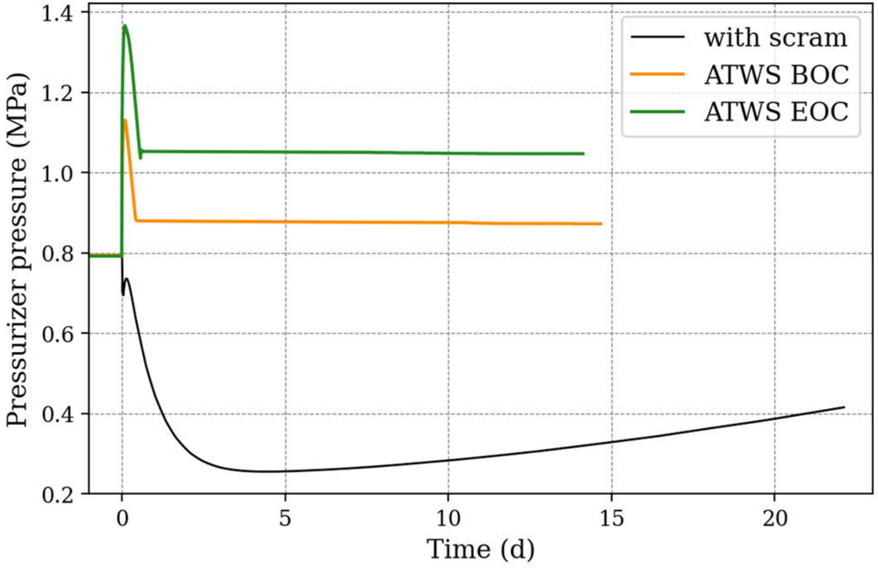
- All power is lost → secondary circulation stops, pool is not cooled
- Spent fuel in the pool
  - Constant 88 kW power was assumed (5 fuel cycles)
  - Pool volume 1000 m3
- Heat transfer out of the pool is not modelled
- Variations:
  - With scram
  - Anticipated transient without scram (ATWS)
    - Beginning of cycle (BOC)
    - End of cycle (EOC)
- Emergency boron injection not taken into account
- Initial state: hot state (DH supply 120 °C)
- When does the pool reach boiling point (~100 °C)?
- Primary pressure should not exceed 16 bar



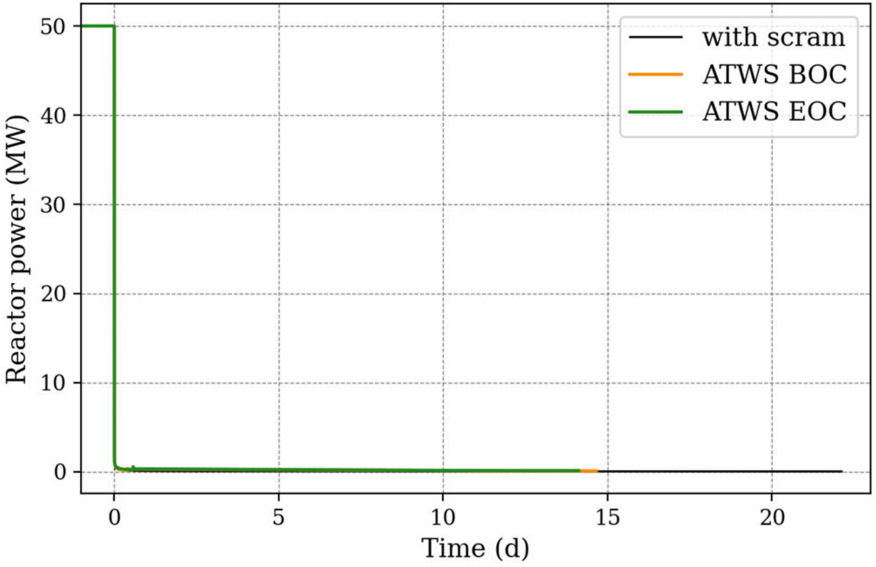
Results

Results

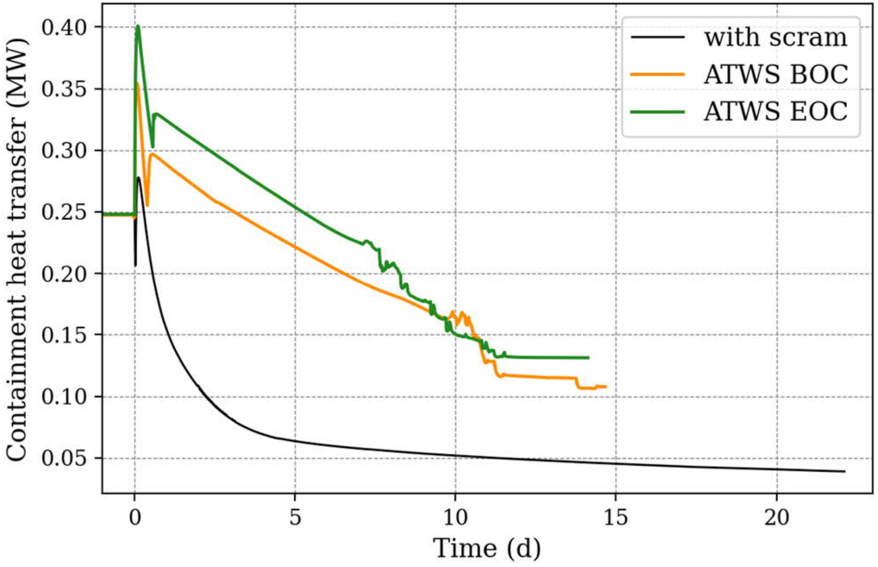

Core outlet temperature (°C)
180
160
140
120
100
0
5
10
15
20
Time (d)
with scram
ATWS BOC
ATWS EOC


Pressurizer pressure (MPa)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
5
10
15
20
Time (d)
with scram
ATWS BOC
ATWS EOC

Results

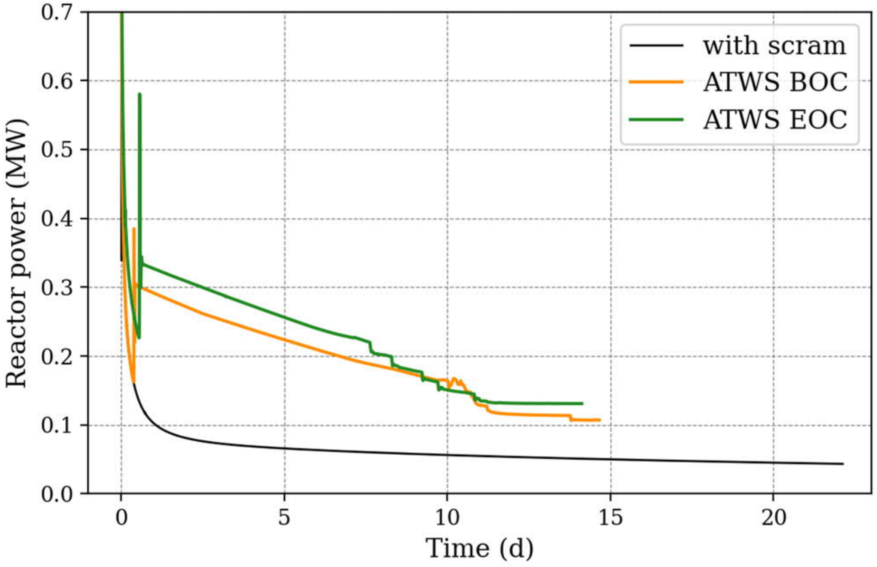


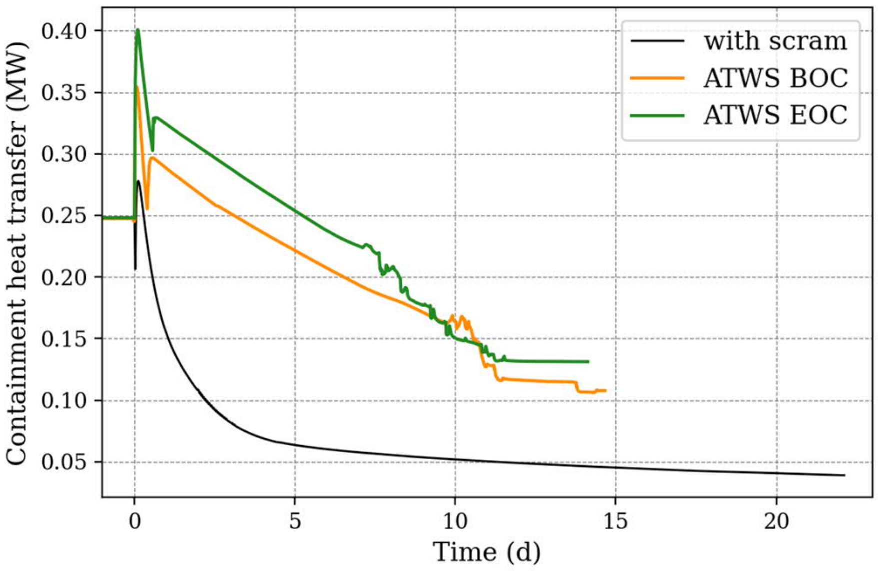
Reactor power (MW)
50
40
30
20
10
0
0
5
10
15
20
Time (d)
with scram
ATWS BOC
ATWS EOC



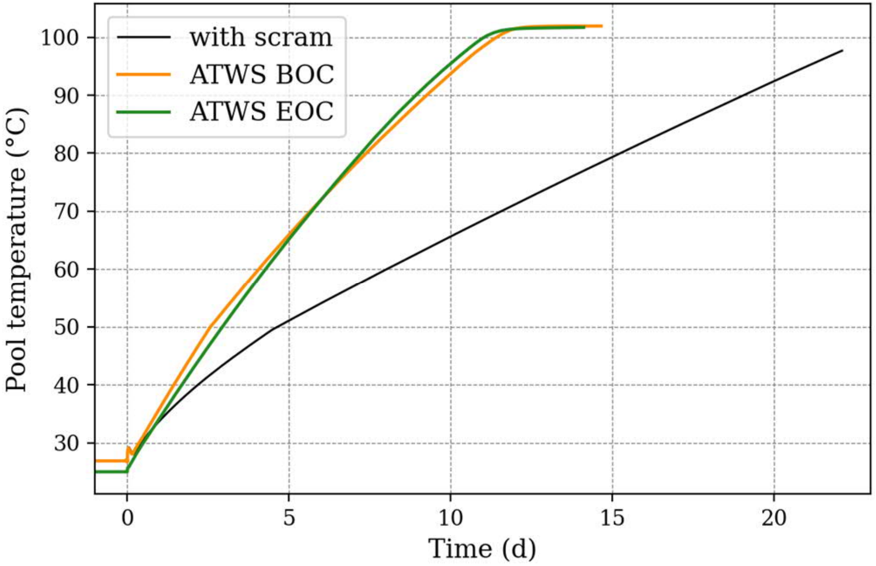
Containment heat transfer (MW)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
5
10
15
20
Time (d)
with scram
ATWS BOC
ATWS EOC

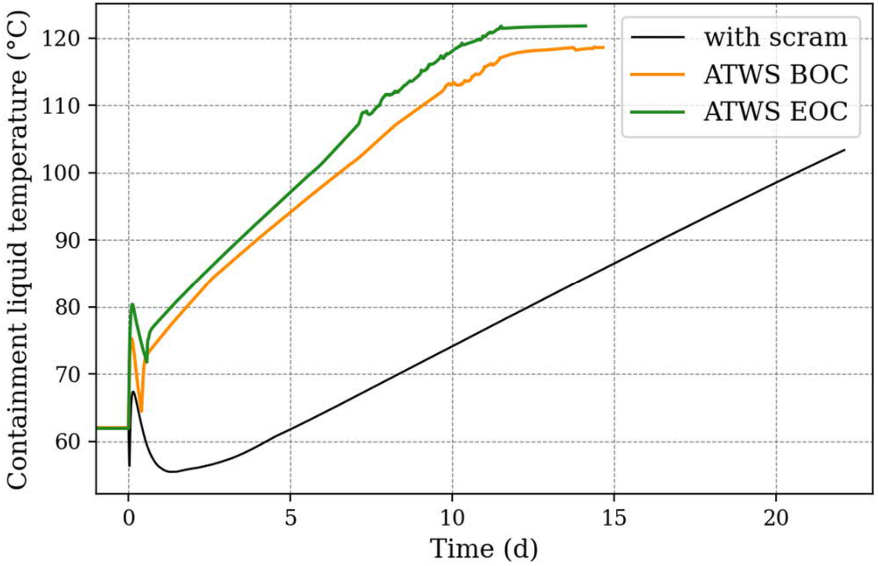
Results


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Reactor power (MW)
0
5
10
15
20
Time (d)
with scram
ATWS BOC
ATWS EOC

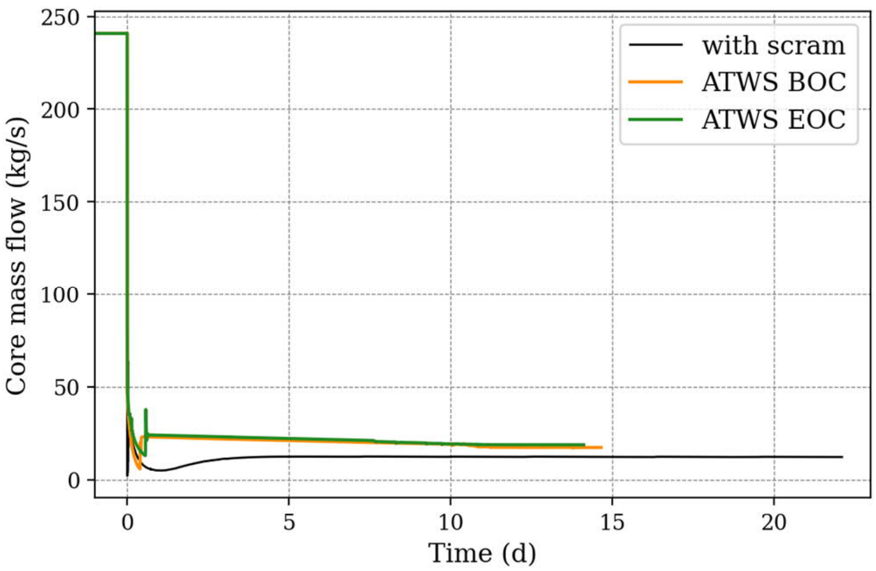

0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
Containment heat transfer (MW)
0
5
10
15
20
Time (d)
with scram
ATWS BOC
ATWS EOC

Results

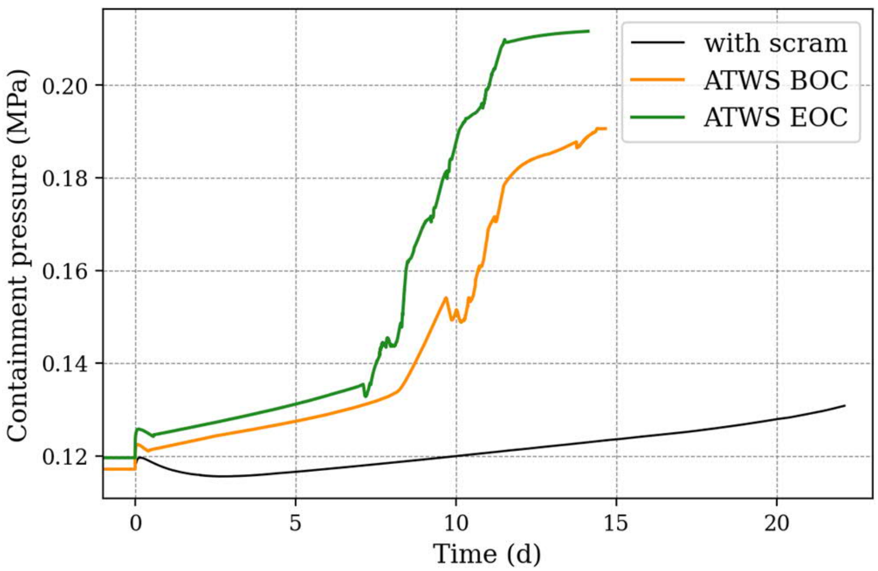

with scram
ATWS BOC
ATWS EOC
Pool temperature (°C)
Time (d)
0
5
10
15
20
30
40
50
60
70
80
90
100


with scram
ATWS BOC
ATWS EOC
Containment liquid temperature (°C)
Time (d)
0
5
10
15
20
60
70
80
90
100
110
120

Results



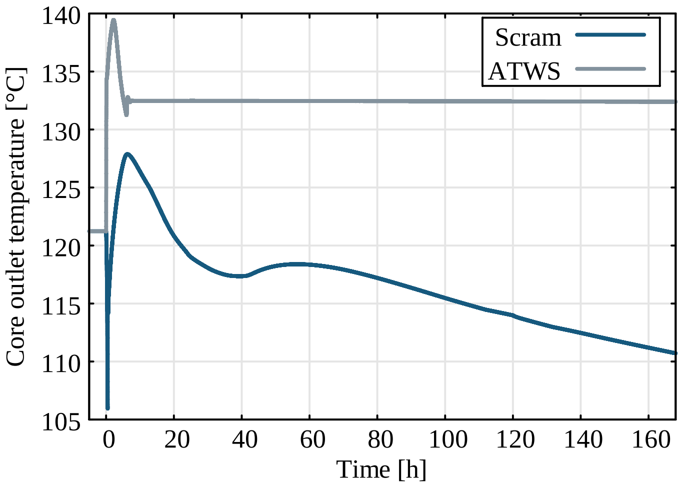
Core mass flow (kg/s)
250
200
150
100
50
0
0
5
10
15
20
Time (d)
with scram
ATWS BOC
ATWS EOC

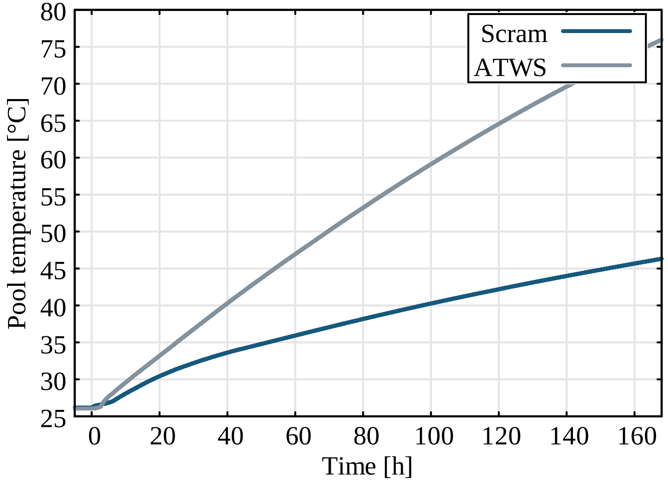


Containment pressure (MPa)
0.20
0.18
0.16
0.14
0.12
0
5
10
15
20
Time (d)
with scram
ATWS BOC
ATWS EOC

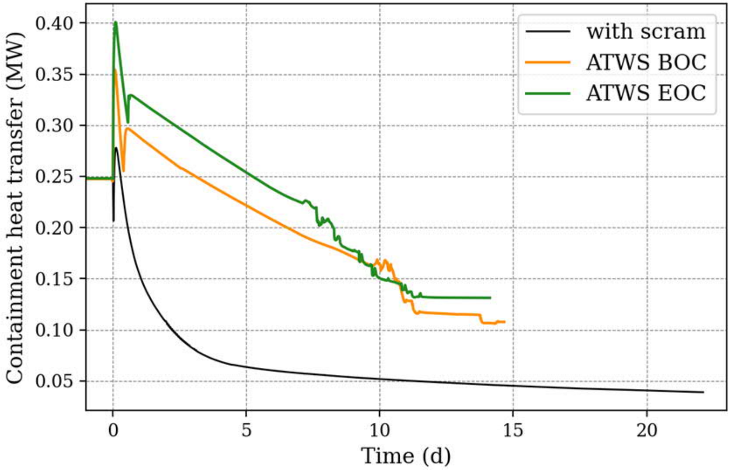
Results

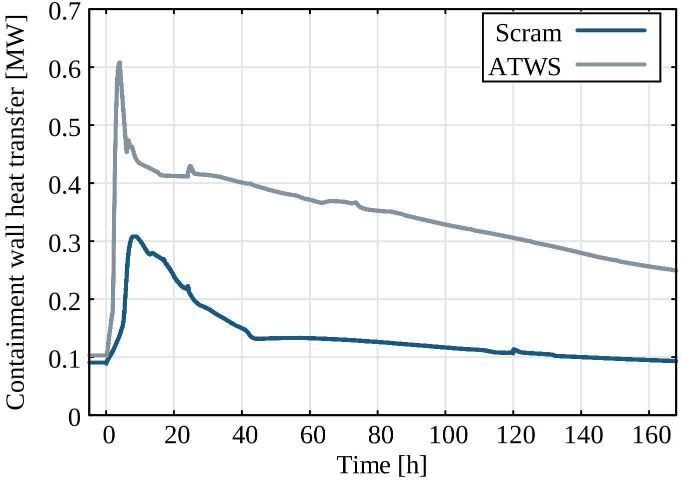
- Results are similar to previous simulations with the old design and no spent fuel in the pool
- Differences in containment modelling can be seen compared to previous calculations

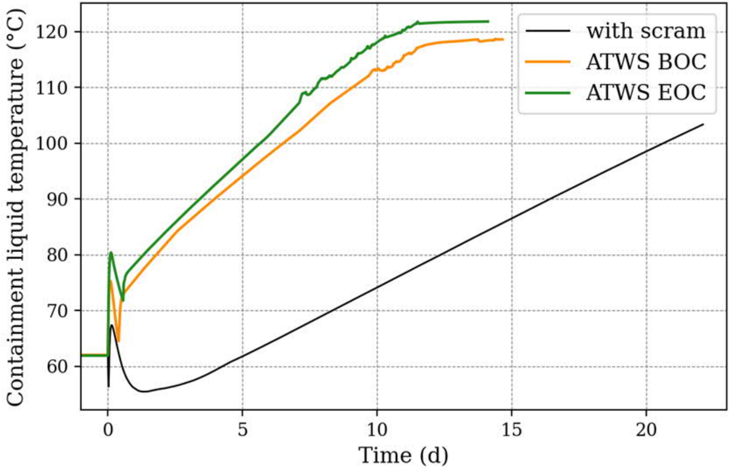


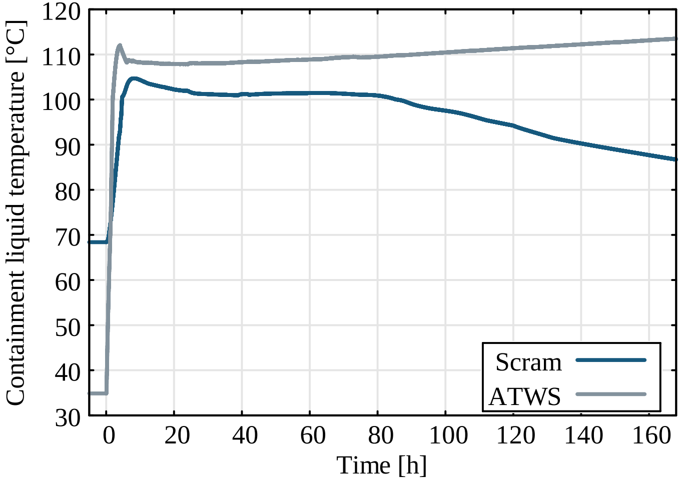


R. Komu, S. Hillberg, V. Hovi, J. Leppänen, J. Leskinen, "A Finnish District Heating Reactor: Thermal-Hydraulic Design and Transient Analyses," In proc. 28th International Conference on Nuclear Engineering (ICONE28), Virtual conference, online, August 4–6, 2021









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Discussion

- Difference in results likely due to spent fuel in the pool
  - Additional heat source in pool → increased circulation → enhanced heat transfer to pool
- Containment model needs to be refined
  - Current correlations not necessarily suited for large volumes with stationary liquid
  - CFD calculations and eventually experimental results are needed

Conclusion and next steps

- The passive decay heat removal system transfers heat efficiently to the pool
- Long grace-period before any actions are needed
  - With scram 22 day and without 12 days before the pool reaches boiling point (with spent fuel in the pool)
- Refining the containment model
- Design work continues to engineering phase
- More analyses, in future with coupled neutronics

beyond the obvious

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