Business from technology

VESPA2012/SAFIR2014

SAFIR2014 Interim Seminar
21-22.03.2013 Hanasaari, Espoo

Niina Könönen
(Mikko Patalainen, Kari Ikonen, Ilona Lindholm)

VESPA and the main objectives

- Started in January 2012

- Structural integrity
- Steam explosions
- Spent fuel pool accidents

- The applicability of a commercial code Abaqus for modelling reactor pressure vessel lower head failures was investigated.
- Evaluating steam explosion loads for BWR cavities with TEXAS-V code.
- Developing an analysis tool for studies of loss of coolant accidents in spent fuel pools. PANAMA and MELCOR 1.8.6 codes were used in this task.

Task 1.1: Benchmarking Abaqus against PASULA

Task 1.1: Benchmarking of Abaqus

- Experimental studies have been performed for example at the SANDIA Laboratories in the USA.
- The applicability of a commercial finite element code Abaqus for modelling large deformations of a reactor pressure vessel at high temperature was studied.
- Comparing the results of a commercial code with the results obtained with a field-specific code, PASULA, developed at VTT
- Knowledge transfer and training a new code user

Task 1.1: Benchmarking of Abaqus (2)

- Sandia OLHF-1 experiment was selected for studies.
- Axisymmetric geometry
- The PASULA code was used in this benchmark as well.

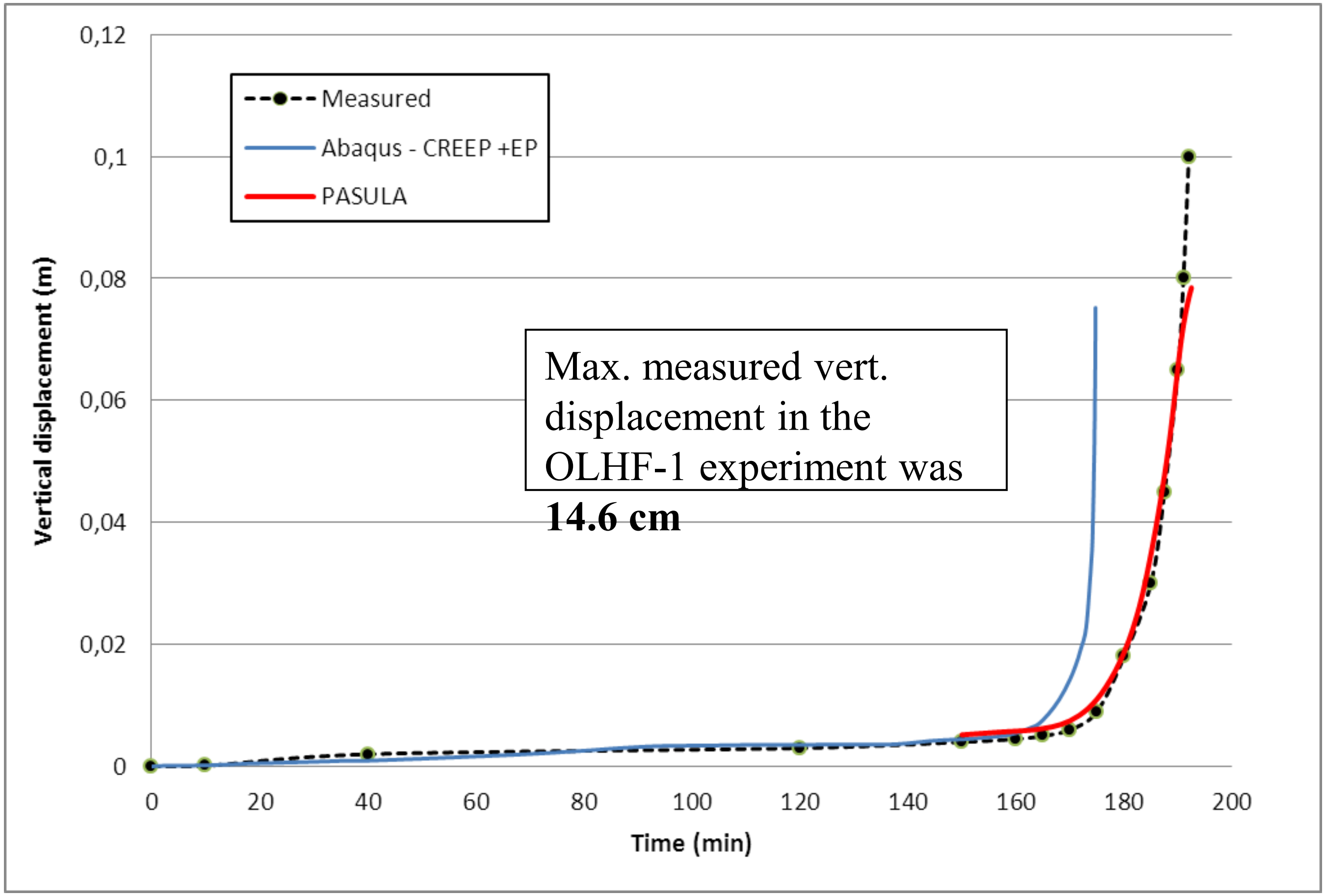
- A FE-model was generated according to the geometrical details and temperature dependent material properties provided by the OLHF-1 experiment.
- The thermal loading was modelled using measured temperature data which was interpolated to the nodes using a specific Fortran subroutine.

Task 1.2: Results

- High thermal stresses
- Integrity of the vessel was maintained until 150 minutes
- Non-reversible deformations were detected prior to the rupture
- Rupture of the vessel occurred at 174 minutes
- In the experiment the rupture occurred at 192 minutes

Task 1.1: Vertical displacement as a function of time from the bottom of the vessel at θ=90°

- The vertical displacement of the lower head bottom was computed relatively well by Abaqus prior to the rupture



Task 1.1: Conclusions

- The commercial finite element code Abaqus is suitable for modelling large deformation at high temperatures in a core melt scenario

- The vertical displacement result obtained in this work fits well in the variety of calculated and measured results of the OLHF-1 benchmark as well as the results from the PASULA simulation.

- The results are highly dependent on the utilised material parameters that need to be verified by experimental test data

Task 1.2: Steam explosions

Subtask 1.2: Steam explosions

- Steam explosions have been studied widely with both simulations and with experiments. The most recent experiments were made at OECD/SERENA2 project.
- Preserving of knowledge of steam explosions is important still today, since the risk of steam explosions during a severe nuclear accident cannot be excluded in our current nuclear power plants.

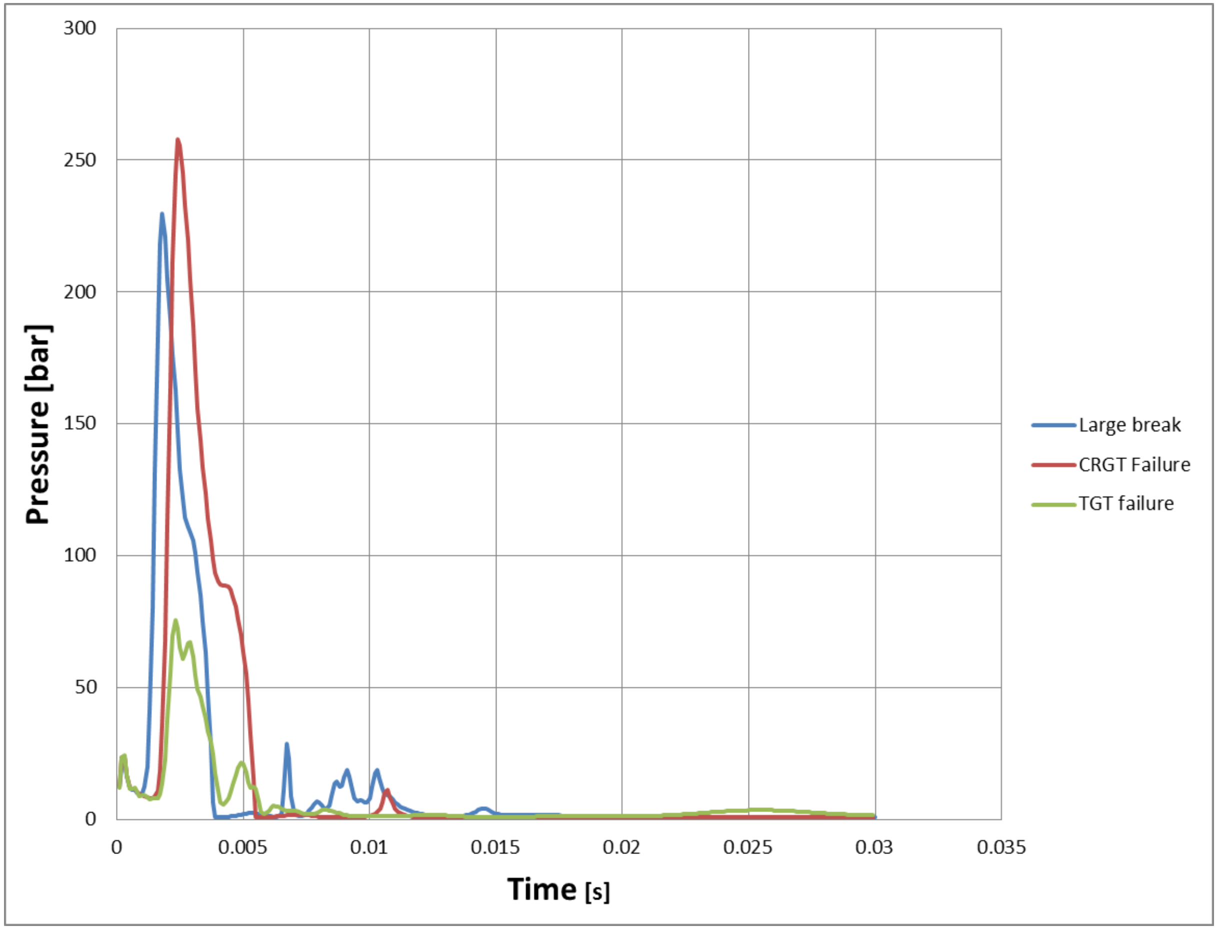
- In this task of VESPA2012 a new expert learnt the use of TEXAS-V code for simulating steam explosions.
- Steam explosion loads in Nordic BWR geometry were assessed as collaborative effort with KTH.
- Task is involved in many international projects (EU/SARNET2, OECD/SERENA2, NKS/DECOSE)

Subtask 1.2: Steam explosions (2)

- During the visit at KTH in November 2012 three reference cases were determined for TEXAS-V calculations
    - IGT Failure, 0.035 m
    - CRGT Failure, 0.07 m
    - Large break, 0.2 m
- Melt mass, base area and trigger time are adjusted according to the reference case.

Property	Variable	IGT Failure	CRGT Failure	Large break
Melt composition	-	70 % UO_2 – 30 % ZrO_2		
Initial melt temperature	TPIN	2950 K (range: 2950 K – 3270 K)		
Melt jet diameter	RPARN	0.035 m	0.07 m	0.1
Melt mass	TTLMSS	645 kg	1200 kg	2630 kg
Initial pressure difference between RPV and cavity	-			
Containment				
Base area	ARIY	1.25 m^2	17.0 m^2	
Initial pressure	PO(I)	0.3 MPa (range: 0.1-0.5 MPa)		
Initial gas temperature	TGO(I)	363 K		
Initial water pool temperature	TLO(I)	333 K (range: 333 K – 363 K)		
Water pool depth	THO, NTH	7.2 m (THO(1)=0.0, NTH(1)=48		
Free fall height of jet in atmosphere	THO, NTH, XPMAX	9 m (THO(2)=1.0, NTH=18, XPMAX=16.2)		
Triggering (bottom)	TMAX	8.5	8.5	9.0
Material Properties				
Density of liquid	RHOP	8000 kg/m^3		
Thermal conductivity	KFUEL	2.88 W/m/K		
Cp of liquid	CP	510 J/(kg*K)		
Latent heat	PHEAT	320 000 J/kg		
$T_{liquidus}$	TMEL	2870 K		
Surface tension	C(32)	0.45 N/m		
Emissivity	C(18)	0.79		
Dynamic viscosity	Not available in Texas-V			
Cp solid				
$T_{solidus}$				

Subtask 1.2: Maximum pressures



- Figure shows the pressure curves in the cell at height 0.225 m for the three scenarios. Biggest pressures are detected at this height.
- Maximum pressure (257 bar) is obtained in the CRGT Failure scenario.

Subtask 1.2: Conclusions

- Steam explosions can occur with the reference case parameters defined on the basis of SERENA2 BWR reactor application.
- CRGT Failure lead to the most energetic explosion
- The maximum detected pressure was 257 bar and the maximum impulse was 51.5 kPas.
- The evaluation of loads on cavity wall still requires extrapolation with TNT method or something similar.

- The work done with TEXAS-V has been extremely useful and educational. Many of the problems that occurred were solved during this work.
- The post-processing script received as gratuity from KTH is extremely important and helpful.

Task 1.3: Spent fuel pool analyses

Sub-task 1.3.1: PANAMA

- During the Fukushima accident in the spring 2011 also the spent fuel pools in the power plant area suffered some damage. Due to this accident the risks of core meltdowns in the spent fuel pools became an important field of investigation.

- The objective of the PANAMA sub-task was to develop calculational methods to evaluate the heat-up of the spent fuel and surrounding structures in a hypothetical accident of loss of water coolant in water cooled interim storages.
- The code development was focused on improving the existing multidimensional fluid flow and convection heat transfer models.

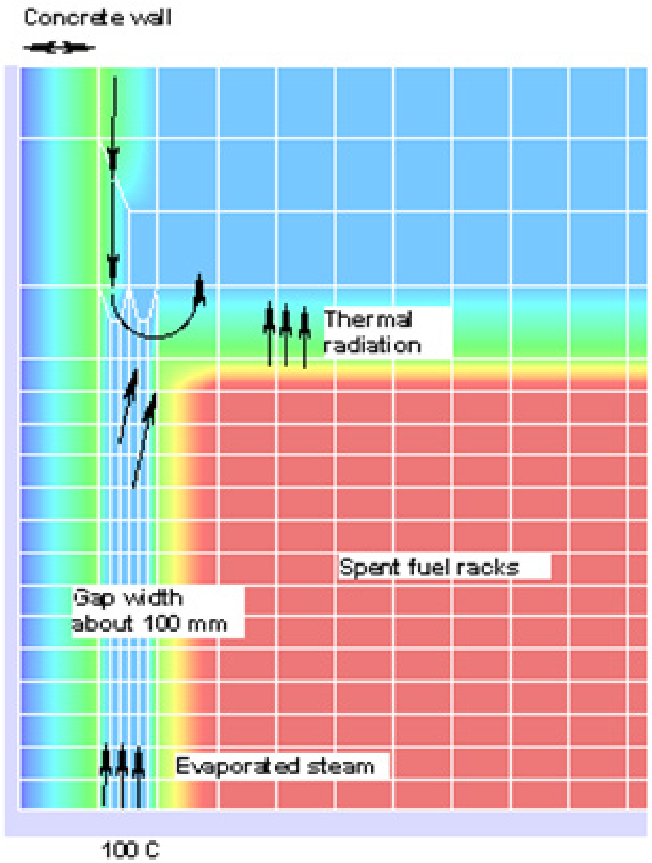
Subtask 1.3.1: PANAMA (2)

- Problems that need solving:
- How well is the gas mixed between the storage pit and the hall?
- How efficient is the cooling effect of the steam flowing downwards to the pool along the concrete wall?

- During the project many different ways to improve the computation efficiency were studied.
- Validation at high temperatures was an essential subtask
- A special mesh generator was developed to model the gap area and other parts of the racks and walls

Subtask 1.3.1: Demonstration

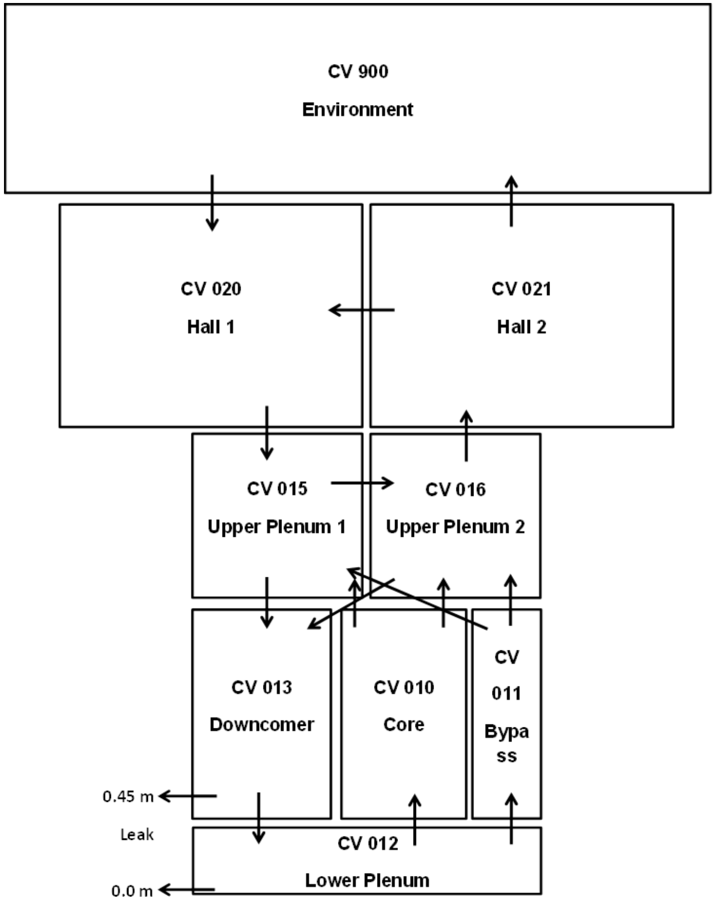
- Example on the right shows the steam flows in the gap between the rack and the concrete wall and in the volume above the rack.
- The initial velocity of the steam at the bottom of the gap is 10 mm/s.
- Part of the steam coming down the wall turns towards the open volume and does not enter the gap.



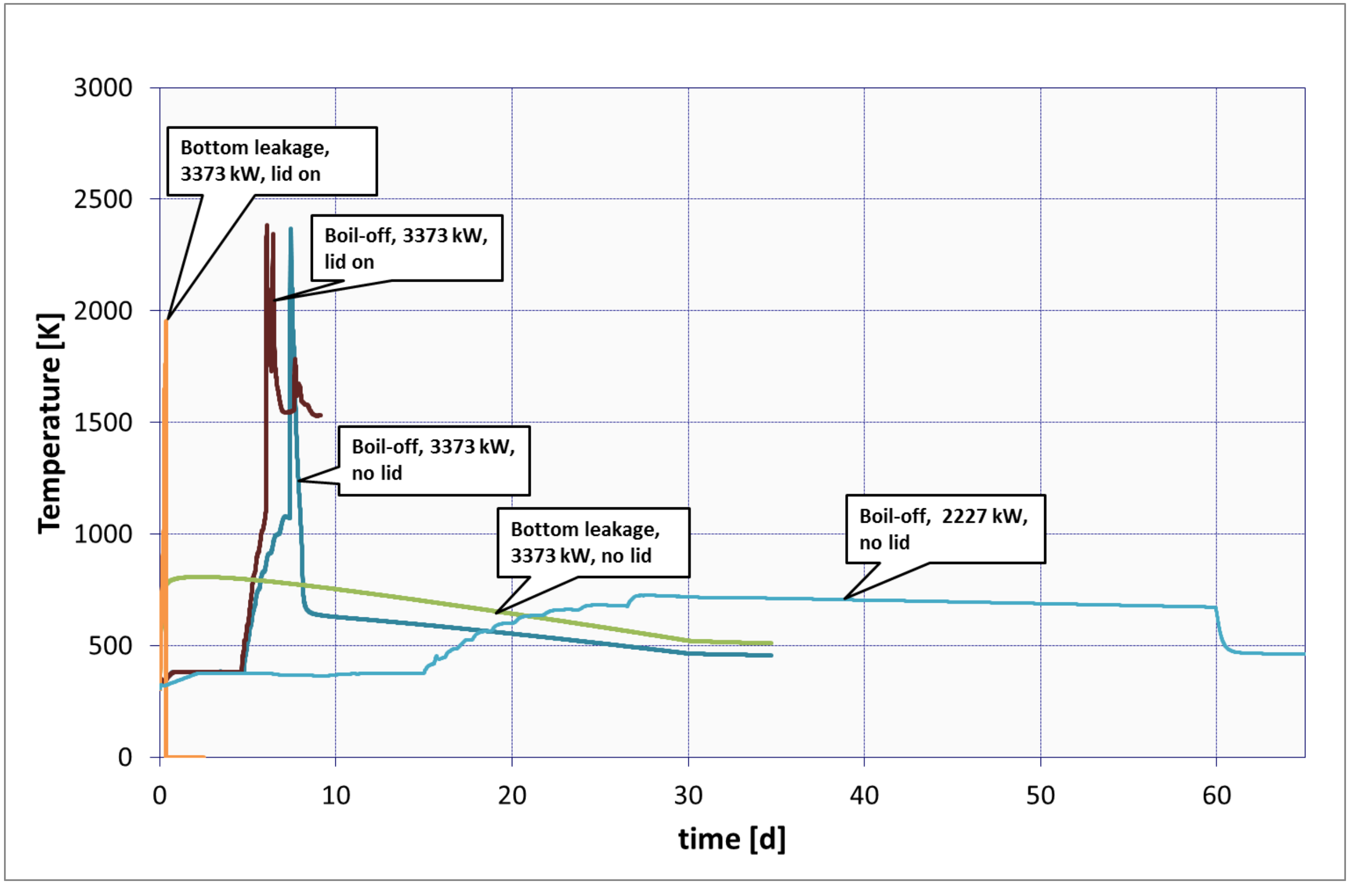
Sub-task 1.3.2: MELCOR

- MELCOR version 1.8.6 was used for modelling several different spent fuel pool accident scenarios for a Nordic BWR.

- The investigated variables were
  - nodalization
  - the total decay heat power of fuel assemblies
  - the initiator of the accident: loss of pool cooling (boil-off) or loss of coolant from the pool (leakage)
  - the LOCA leak elevation
  - the alignment of the re-flooding injection
  - the use of a lid on top of the pool

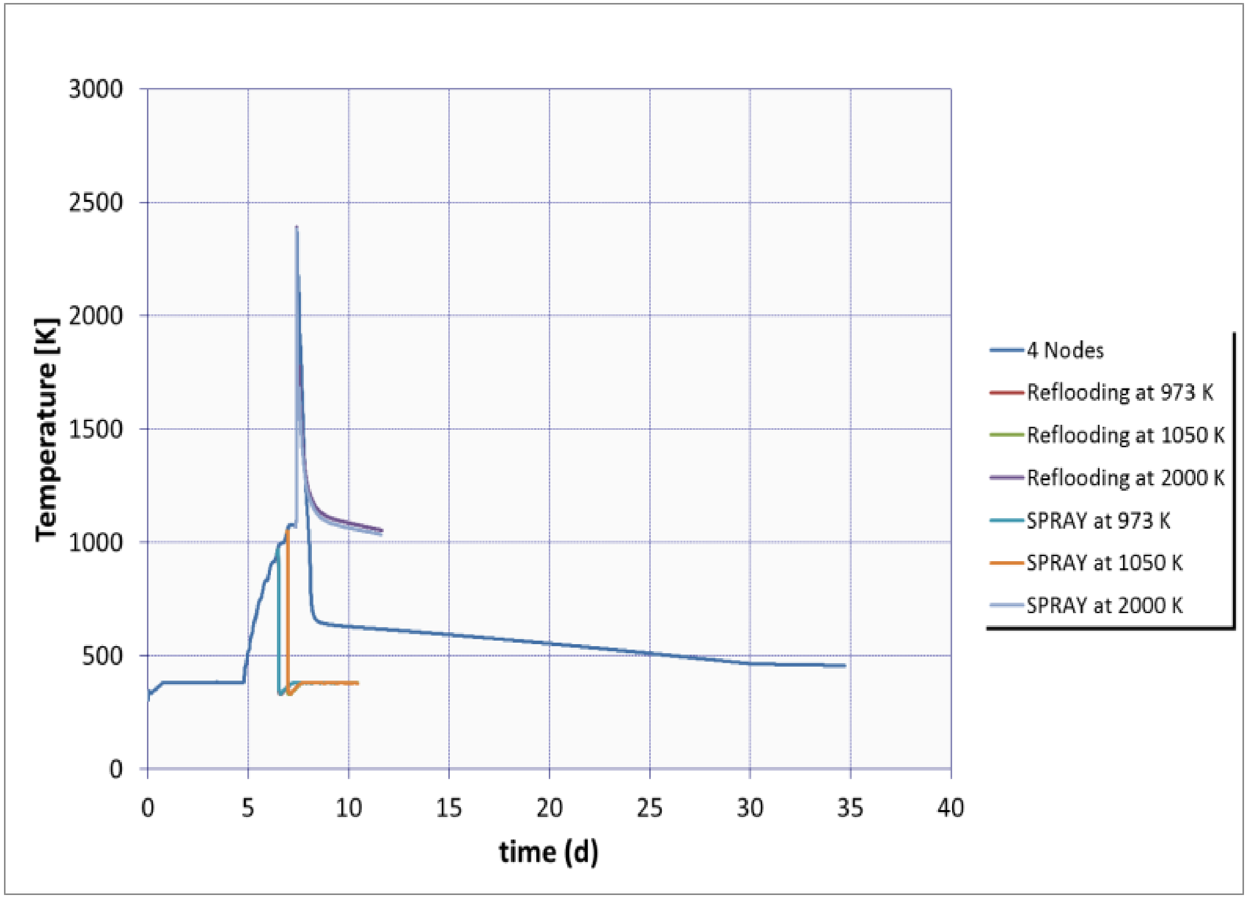


Subtask 1.3.2: Maximum fuel temperatures in boil-off and bottom leakage scenarios, with and without a lid.



- Ensuring natural circulation of air in the fuel is essential in preventing fuel damages
- With a power of 2227 kW the fuel remains intact

Subtask 1.3.2: Effect of re-flooding



- If water injection to the SFP is started before the fuel temperature reaches the cladding failure criterion (1173 K), the rewetting of fuel assemblies is successful and the fuel temperatures will quickly drop and the assemblies will remain intact

Subtask 1.3.2: Conclusions

- The time scales are long which leaves plenty of time for accident management measures
- Ensuring natural circulation of air in the fuel is essential in preventing fuel damages.
- In most cases the fuel will damage, but the temperatures start to drop.
- The fuel remains intact if the highest decay heat power is 2227 kW.
- If re-flooding is started before the fuel temperature reaches the cladding failure criterion, the fuel temperatures will quickly drop and the assemblies will remain intact.
- Re-flooding of already damaged fuel assemblies will also cool the fuel rods and reduce the radioactive releases to the environment. However, it may result in greater hydrogen releases.

VTT - 70 years of

technology for business and society