
Wir schaffen Wissen – heute für morgen

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Spent Fuel Pool boil down calculations with MELCOR 1.8.6

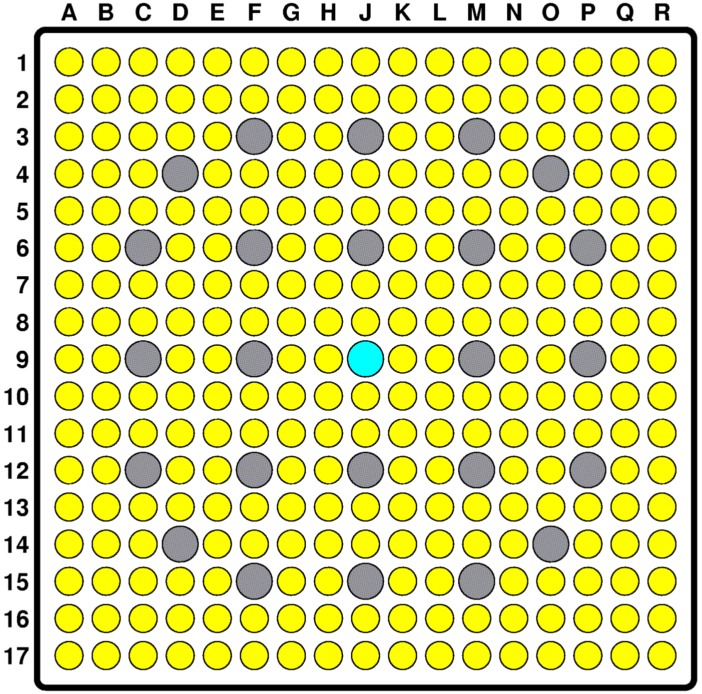
Content

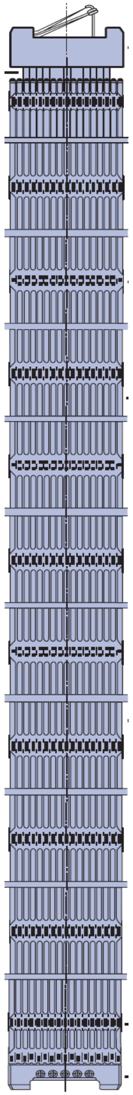
Definition of Accident Scenario

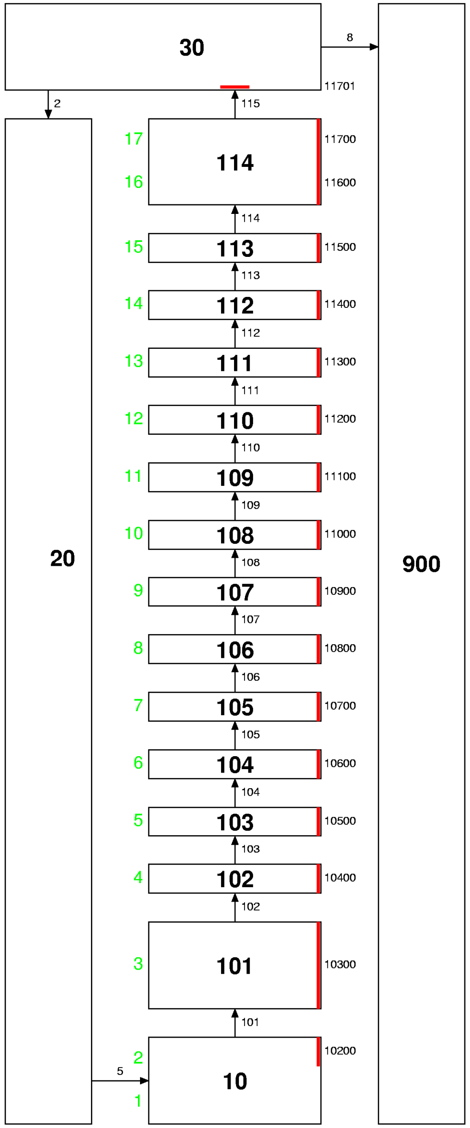
- Spent fuel with different heat load stored in an SFP
- 17 x 17 rods standard PWR fuel elements
- Spent fuel pool racks without cross flow
- Heat up and boil down from completely covered fuel
- Ambient pressure, ambient temperature
- Zircaloy oxidation under steam environment

Nodalization

Spent fuel rack with fuel rods, guide tubes and 1 instrumentation tube







Boil Down and Heat Up Calculations

Shortly after placing a fuel element from the reactor into the spent fuel pool the heat load is proportional to the power of the reactor, because the short living radio nuclides are responsible for the decay heat.

In case of a longer storage time in the SFP the heat load becomes more proportional to the burn up of the fuel element, because now the longer living fission products become responsible for the heat load.

Therefore it is important to know the burn up and the storage time in the spent fuel pool for the calculation of the heat load.

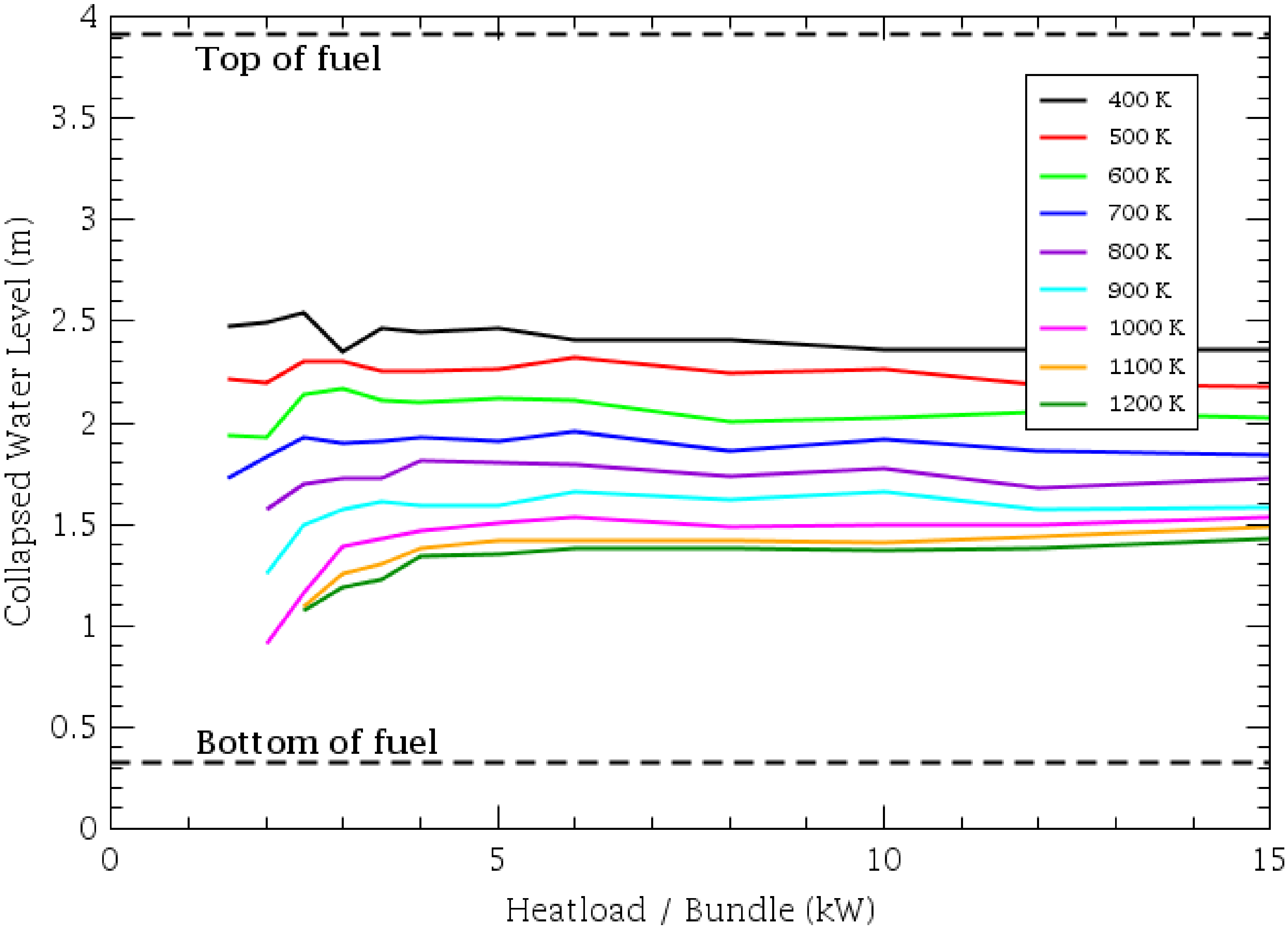
Boil Down and Heat Up Calculations

The heat load of different fuel elements may show huge differences. About 3 days after end of cycle the heat load of one FE is about 50 kW, after 3 months it is about 15 kW and after 3 years it is about 5 kW. In some cases much older spent fuel is stored in an SFP, so that some fuel elements may have only 1 kW.

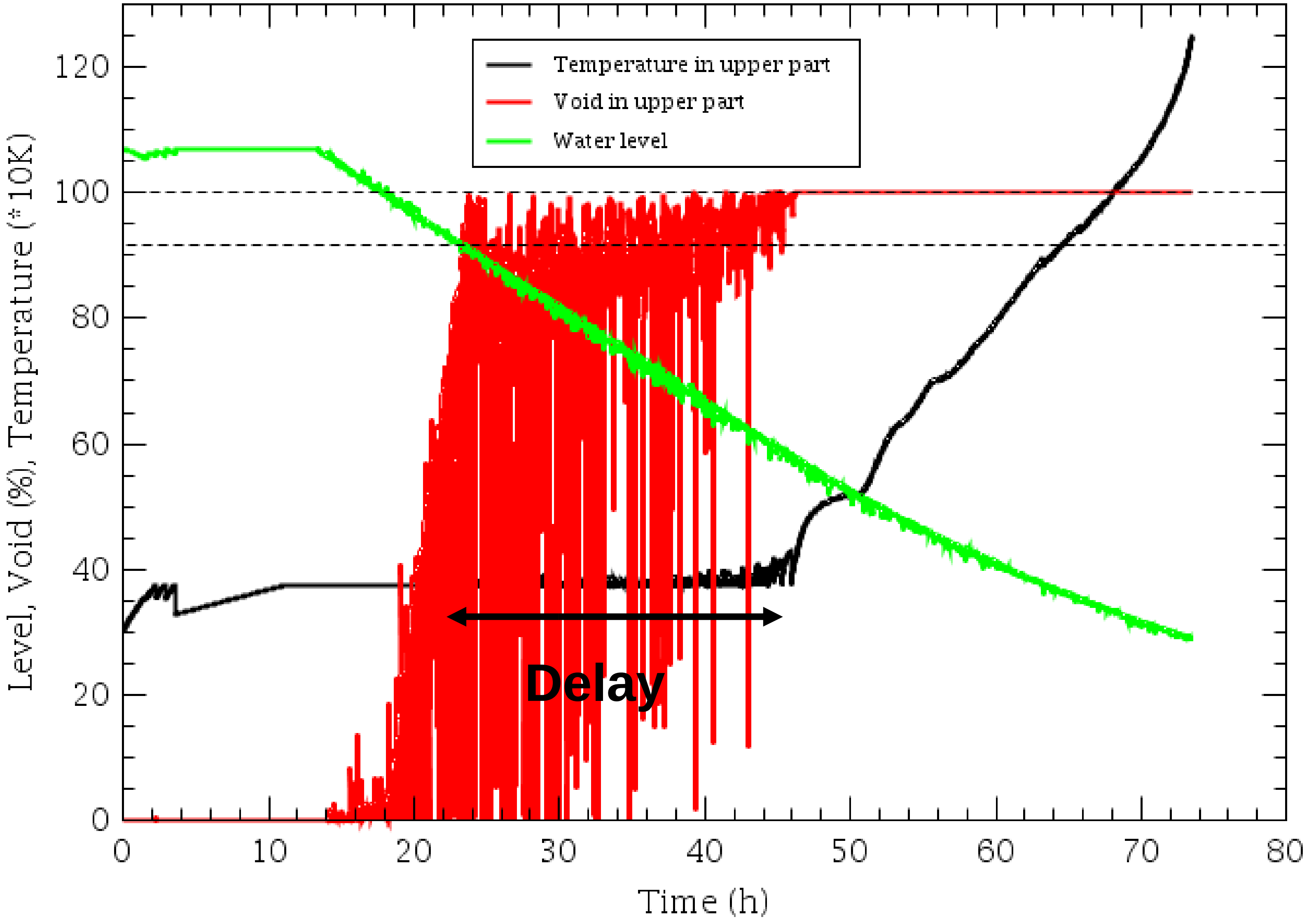
This huge range of heat loads implies a huge range in swell levels of the boiling water during a postulated severe accident inside the different spent fuel racks. A set of calculations was executed to compare heat up with water level. The onset of oxidation calculation was set to 600K.

Remember: Spent fuel racks does not allow cross flow between different fuel elements.

Maximum Cladding Temperature at different water levels



Void, Level and Temperature at 6 kW heat load



uppermost
heated
volume

Boil Down and Heat Up Calculations

Because of the increasing swell level with increasing heat load one would expect a decreasing collapsed water level for the onset of heat up at higher heat loads. The completely flat onset of heat up (400 K) after almost half of the active fuel is uncovered cannot be explained physically.

At lower heat loads the swell of the liquid level is expected to be much less compared with the high heat load during a reactor accident sequence. Therefore the onset of heat up of the fuel elements would be expected at higher level.

It seems that to much water is transported into the higher hydraulic nodes which delays heat up above the saturation temperature.

Sensitivity Calculations

For sensitivity studies several parameters which could influence the hydro dynamic behavior of the boil down sequences were identified.

- Maximum void parameter (preset: 0.4)
- Bubble rise velocity (preset: 0.3 m/s)
- Momentum exchange length between pool and gas phase (preset: full flow path length)

The void parameter was set to 0.1, the bubble rise velocity was set to 1 m/s or the momentum exchange length was set to 0 m.

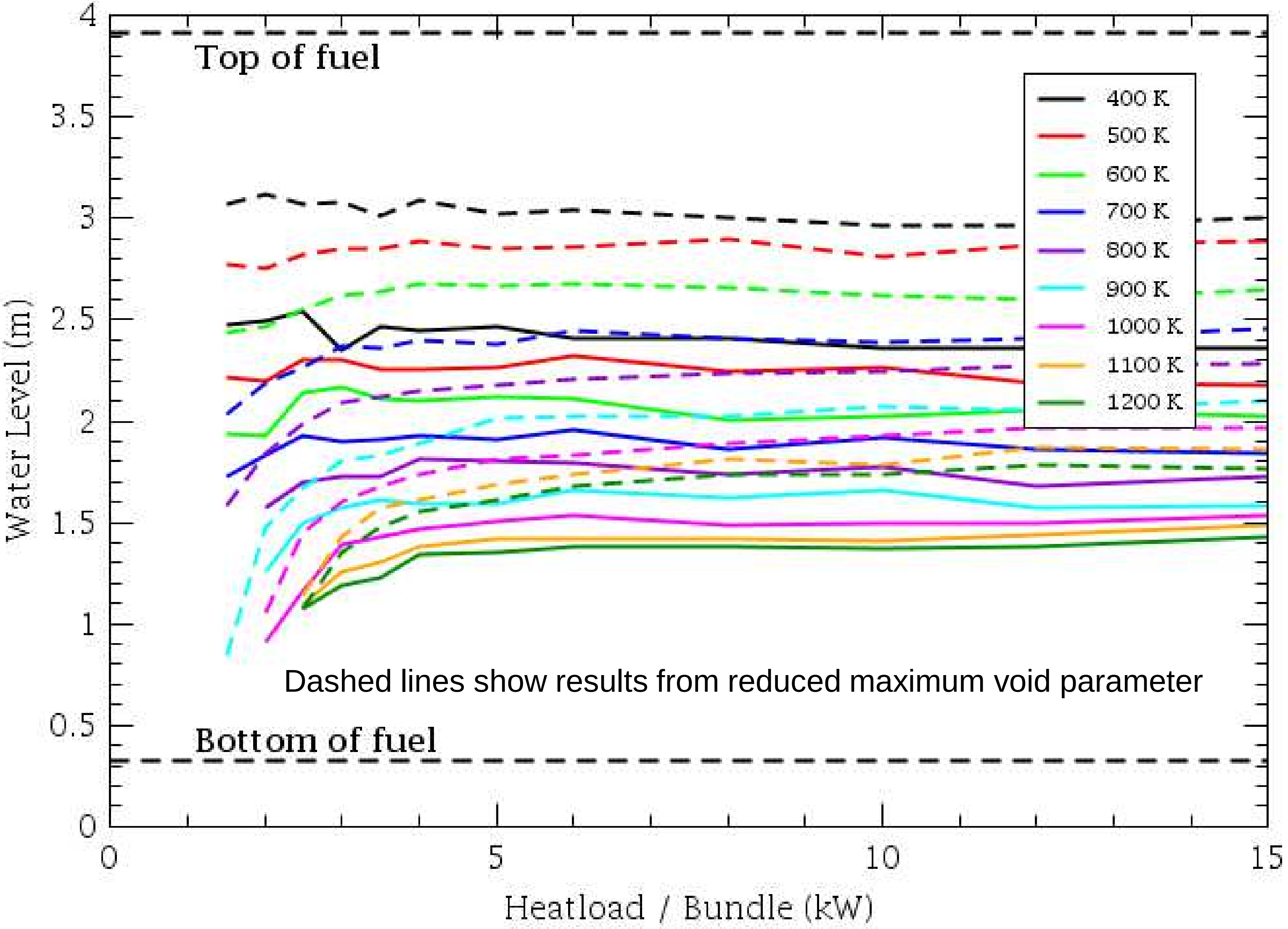
Matrix of Sensitivity Calculations

Heat load	1 kW	1.5 kW	2 kW	2.5 kW	3 kW	3.5 kW	4 kW	5 kW	6 kW	8 kW
Standard	X	X	X	X	X	X	X	X	X	X
Max. Void 0.1	X	X	X	X	X	X	X	X	X	X
Bubble velocity 1.0 m/s	X	X	X	X	X	X	X	X	X	X
Pool-Gas decoupling	X	X	X	X	X	X	X	X	X	X
PSI Break away	X	X	X	X	X	X	X	X	X	X

Matrix of Sensitivity Calculations

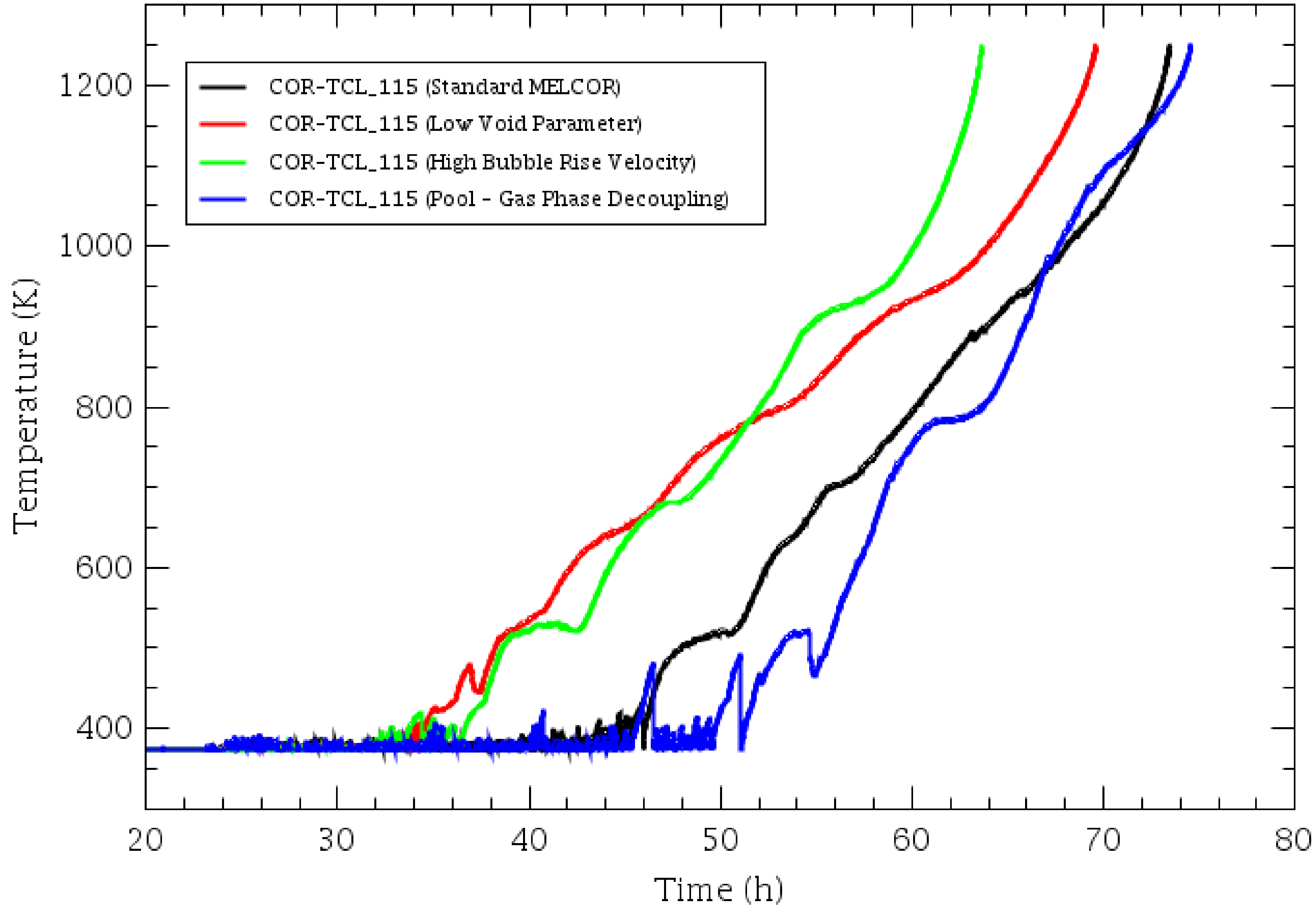
Heat load	10 kW	12 kW	15 kW	40 kW	70 kW	100 kW	200 kW	400 kW
Standard	X	X	X	X	X	X	X	X
Max. Void 0.1	X	X	X	X	X	X	X	X
Bubble velocity 1.0	X	X	X	X	X	X	X	X
Pool-Gas decoupling	X	X	X	X	X	X	X	X
PSI Break away	X	X	X					

Effect of Reduced Maximum Void Parameter



Dashed lines show results from reduced maximum void parameter

Sensitivity calculations at 6 kW heat load



Changing the Geometry of the Spent Fuel Element

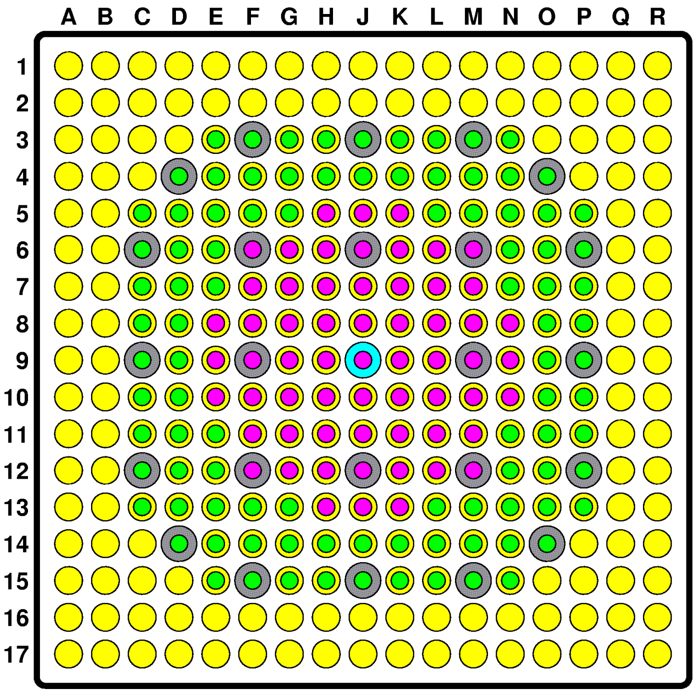
Reducing the maximum void or increasing the bubble rise velocity leads to earlier dry out of the materials in the upper part of the spent fuel. But the modelling itself is arbitrary and not based on physical processes.

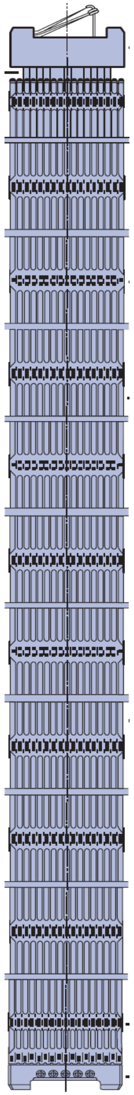
Would obvious cross flow alleviate this problem?

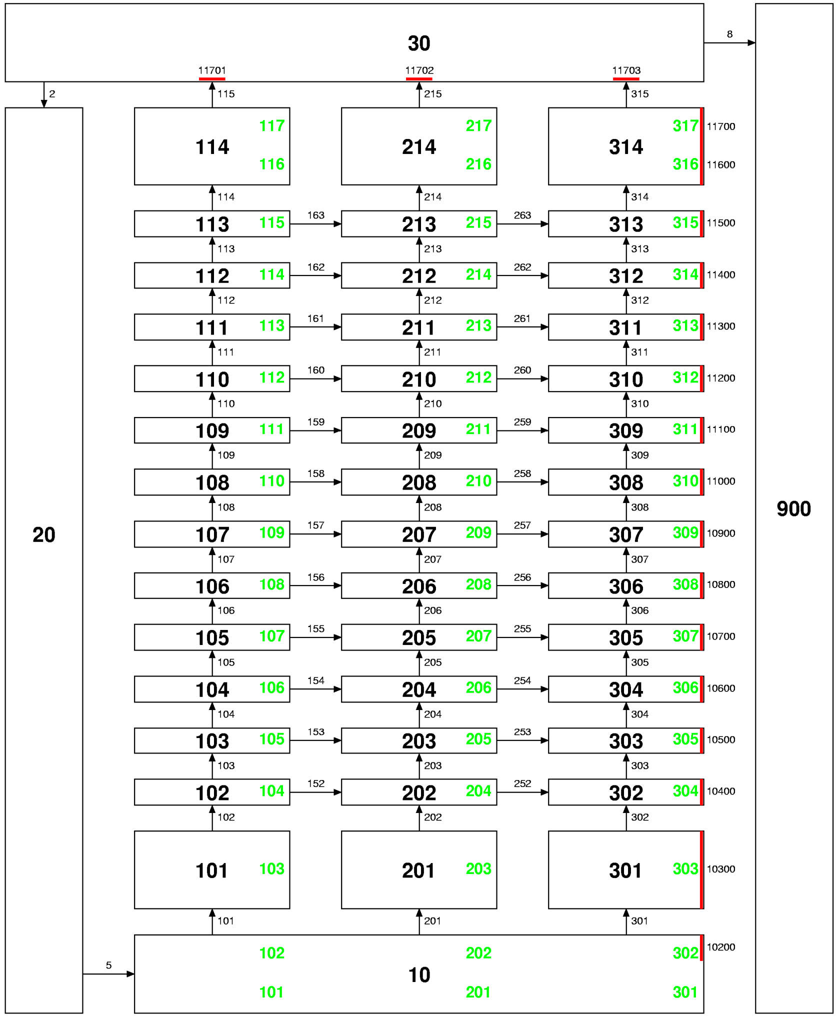
A three ring model was used for one spent fuel element to calculate the boildown behavior. For the calculation of a whole spent fuel pool this would not be feasible because of the limited number of rings available in MELCOR.

Nodalization II

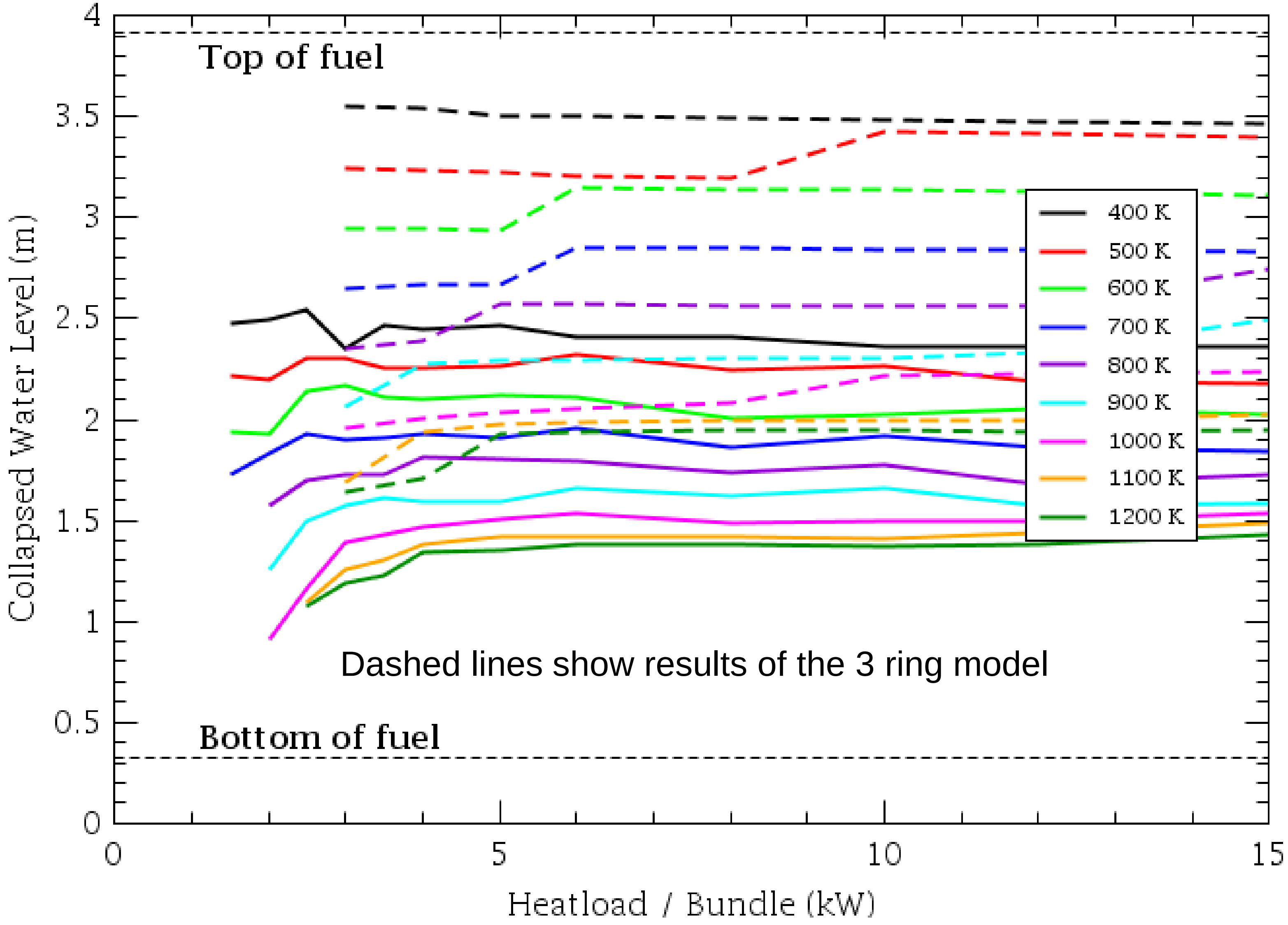
Spent fuel rack with fuel rods, guide tubes and 1 instrumentation tube





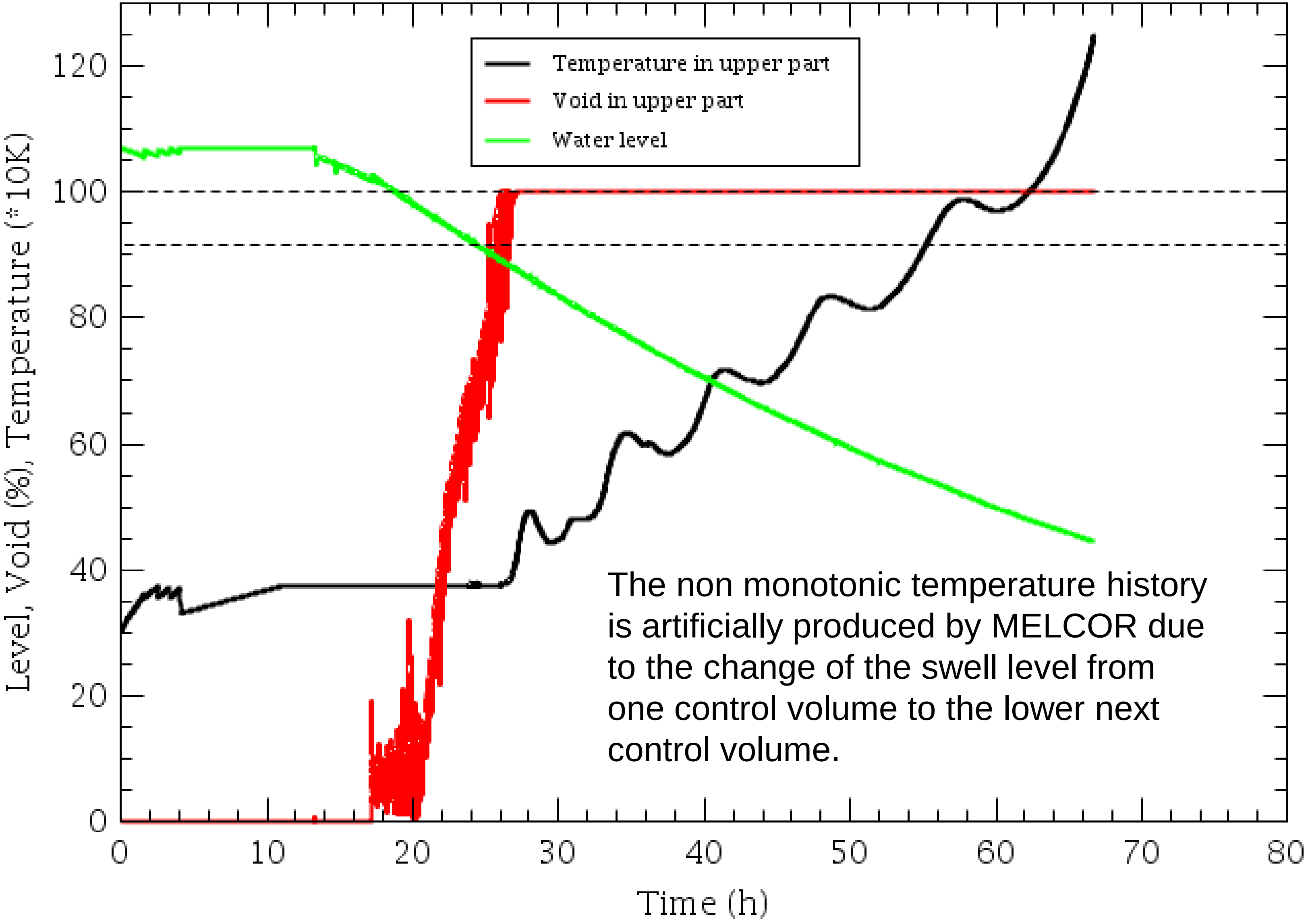


Effect of 3 ring model



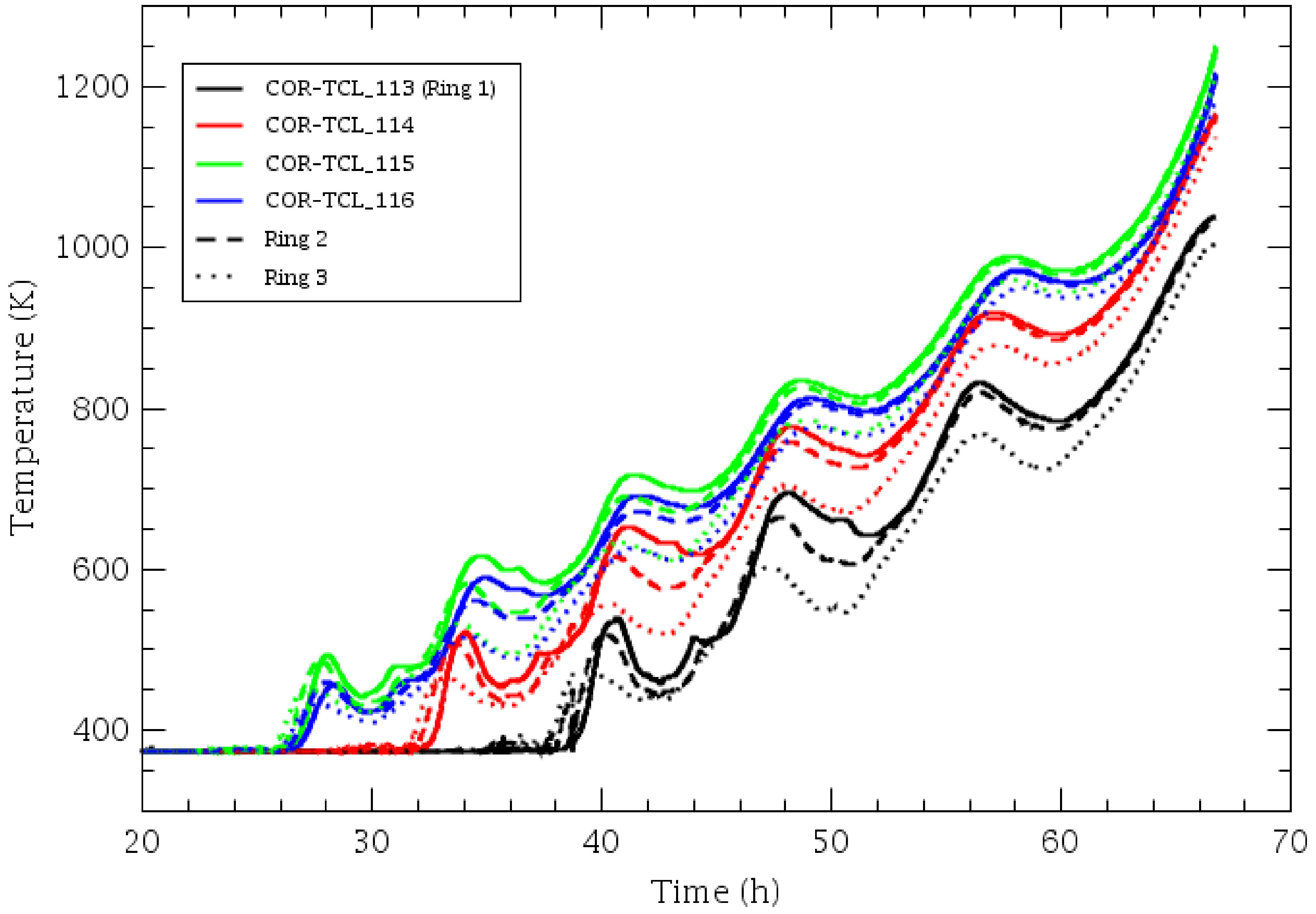
Dashed lines show results of the 3 ring model

Effect of 3 ring model

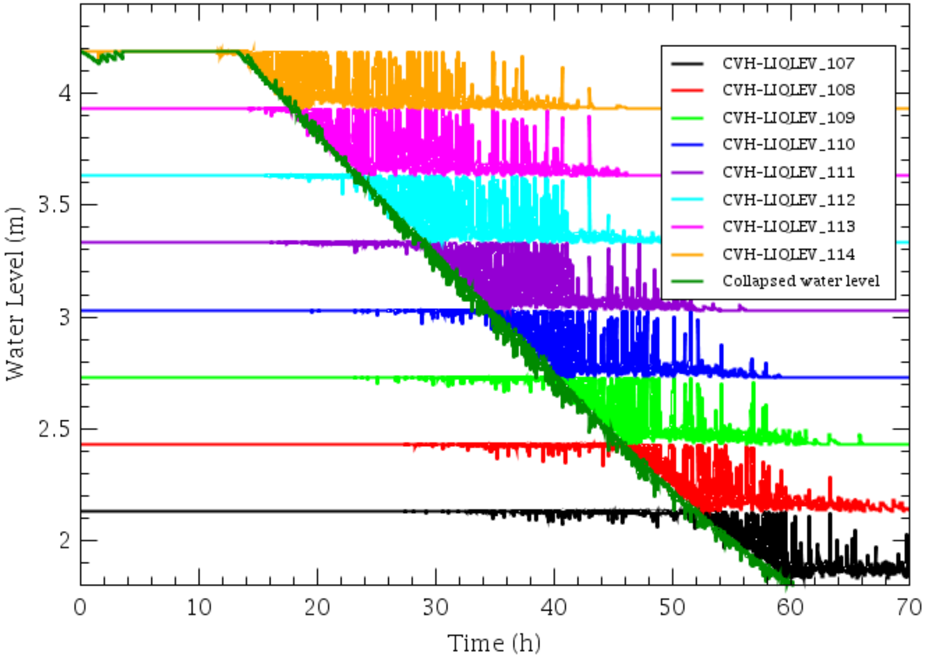


The non monotonic temperature history is artificially produced by MELCOR due to the change of the swell level from one control volume to the lower next control volume.

Temperature history of 3 ring model

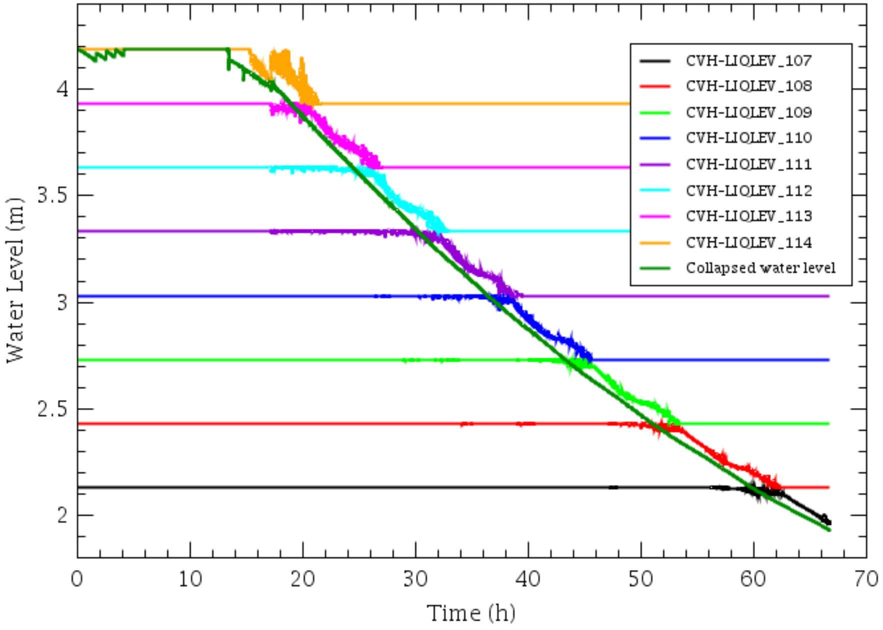


Comparison of 1-ring and 3-ring model



The 1-ring model shows a faster boil down because more heat is used for the production of steam and therefore the heat up is strongly delayed.

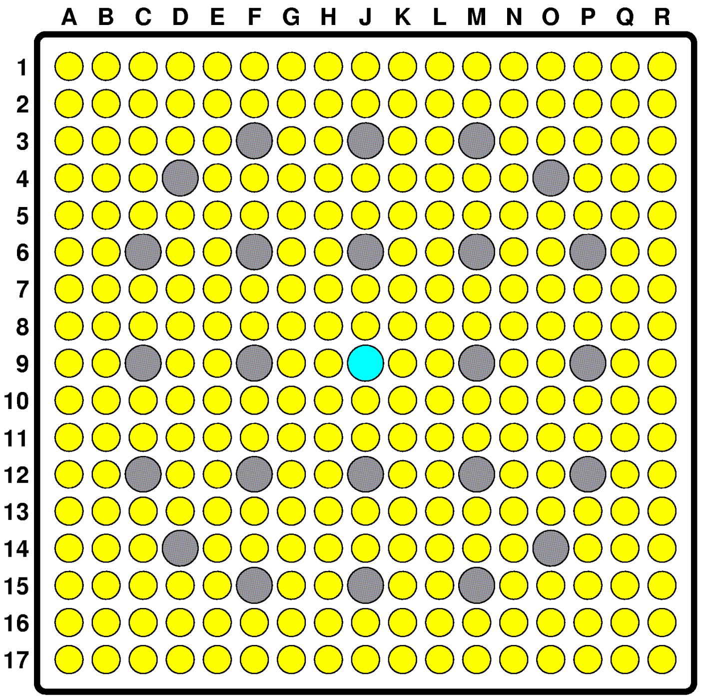
The cyclic behavior of the liquid level when changing from one control volume into the next lower one results in an unphysical behavior of the temperature rise during the boil down phase.

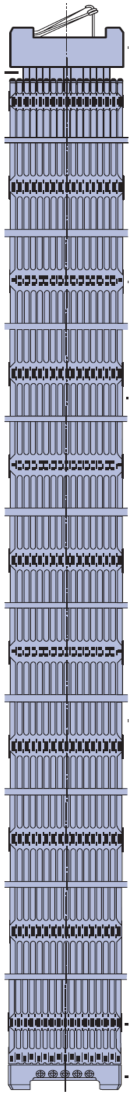


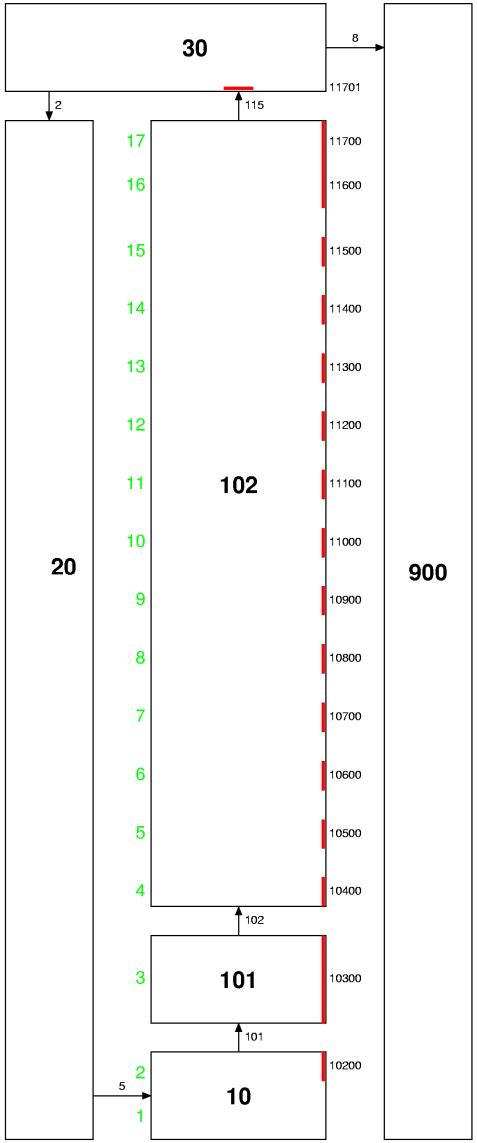
Nodalization III

Spent fuel rack with fuel rods, guide tubes and 1 instrumentation tube

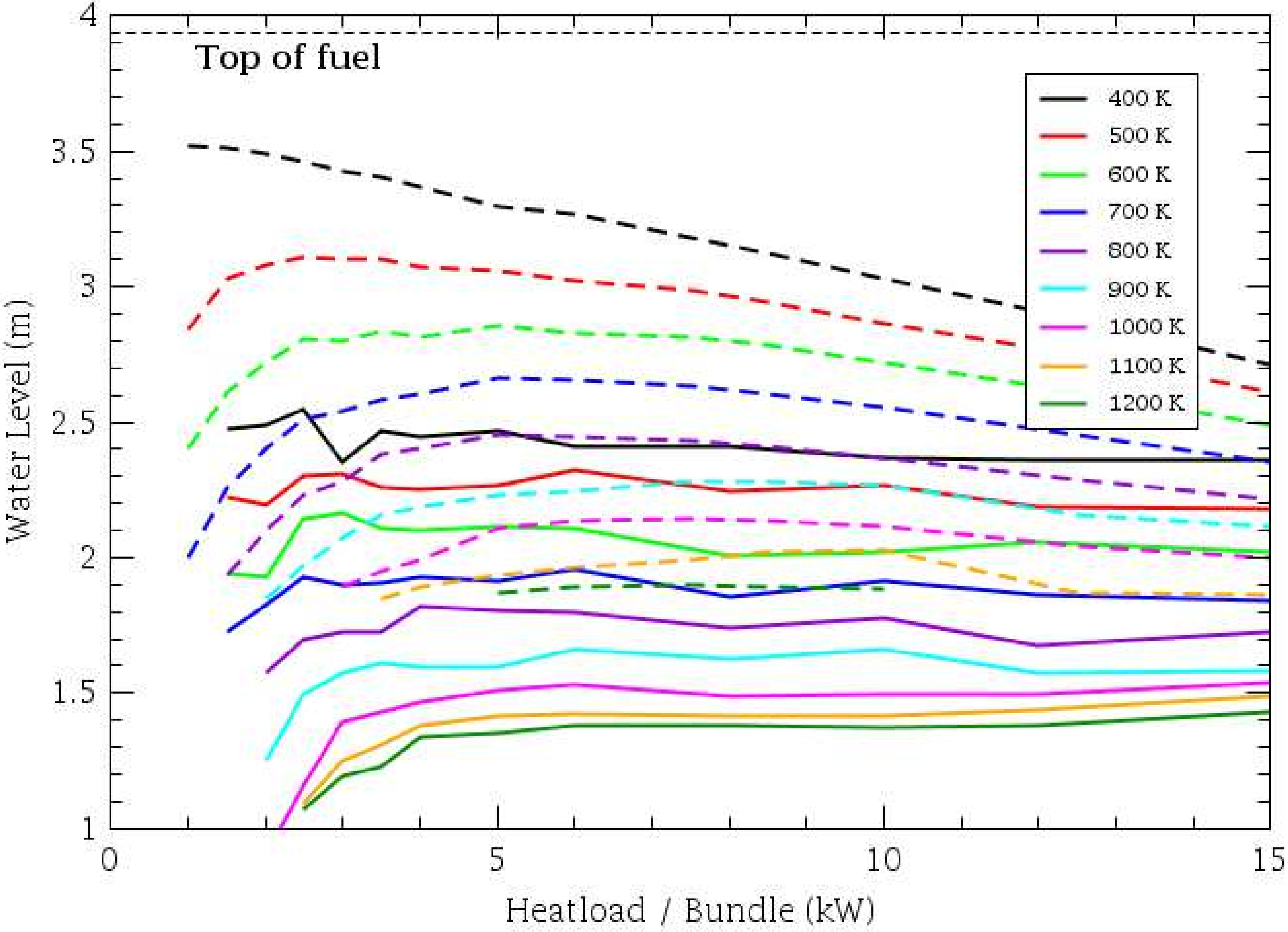
bubble rise velocity = 0.6 m/s



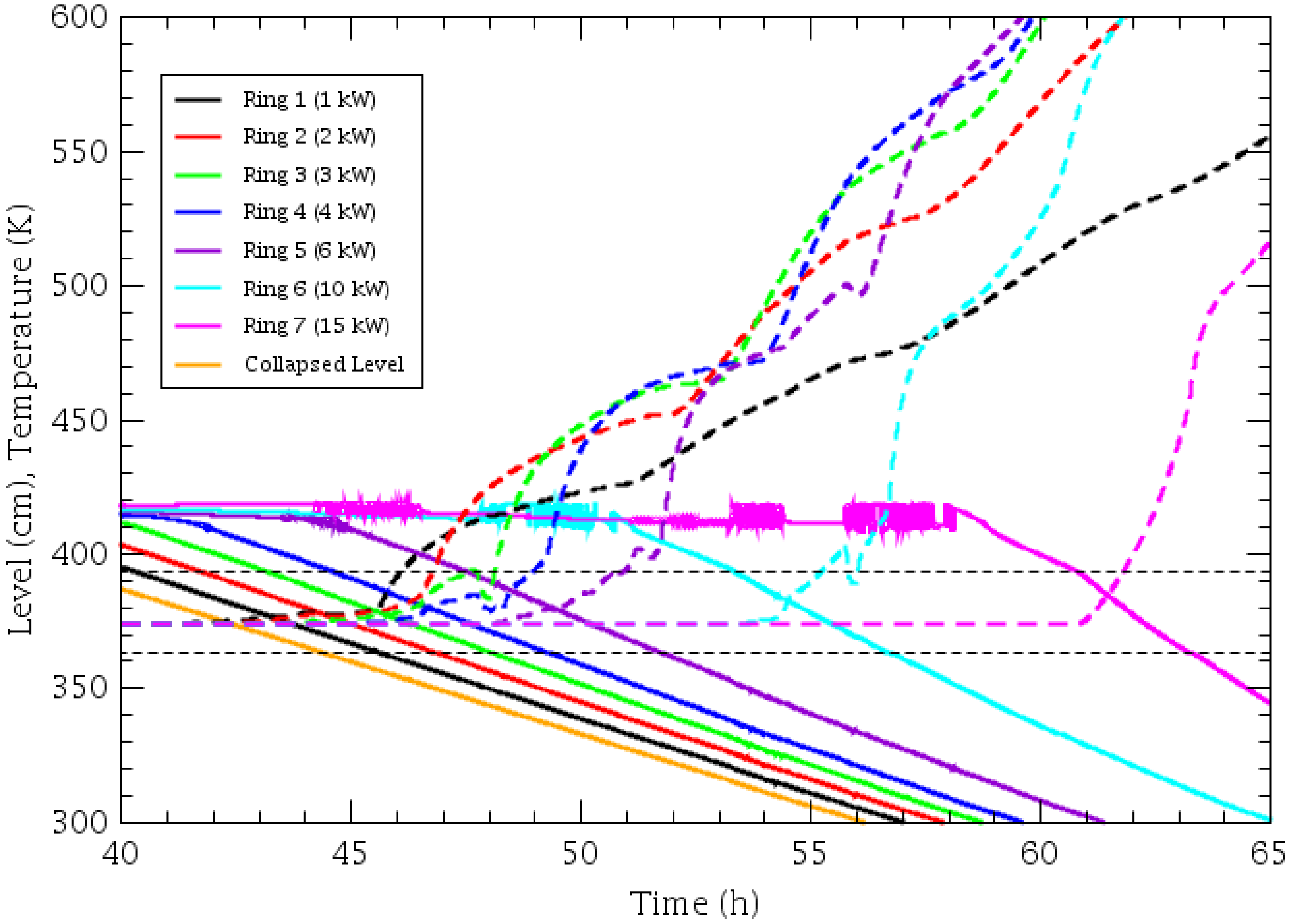




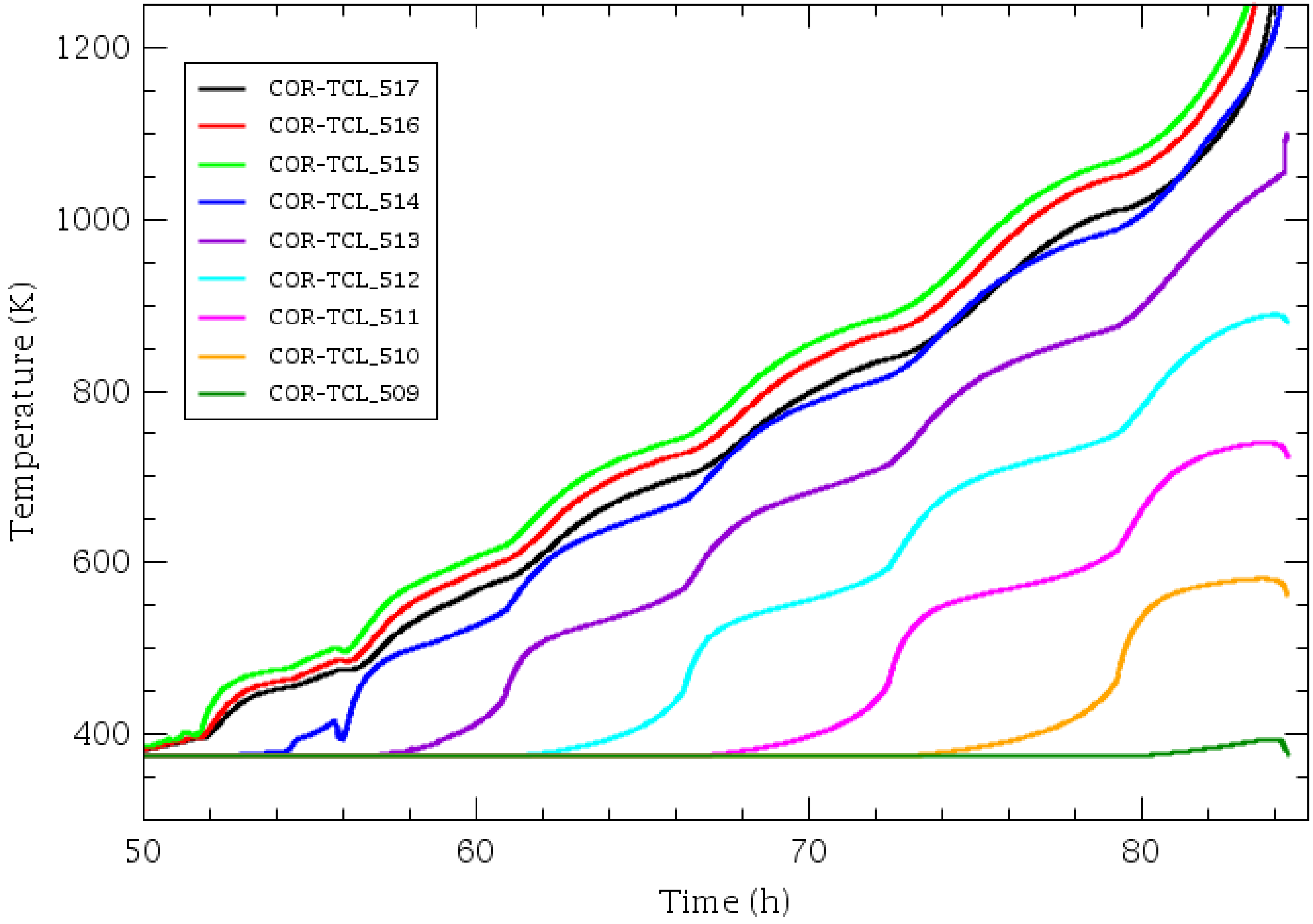
Calculation with one control volume



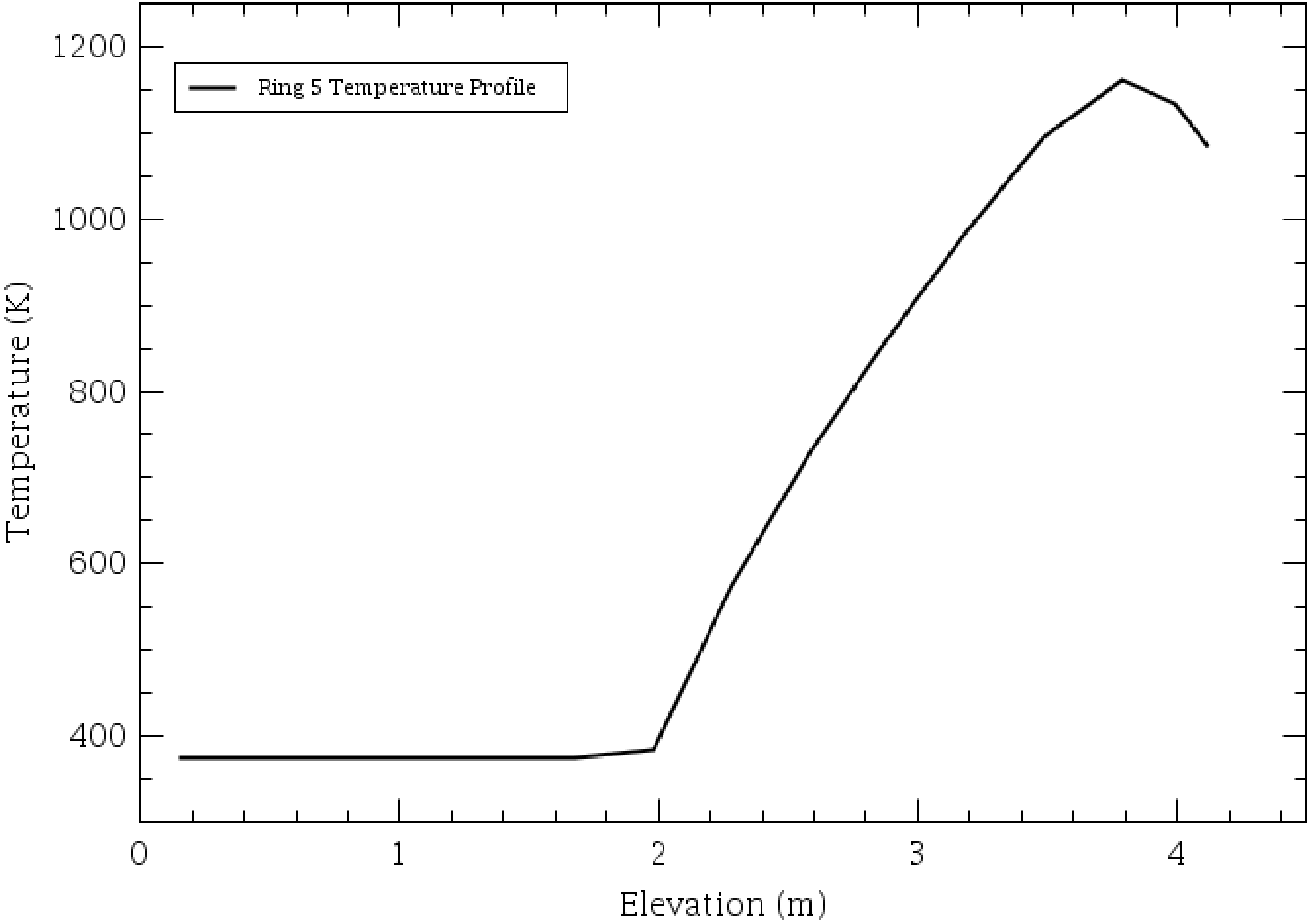
Calculation with one control volume



Calculation with one control volume



Calculation with one control volume



Calculation with one control volume

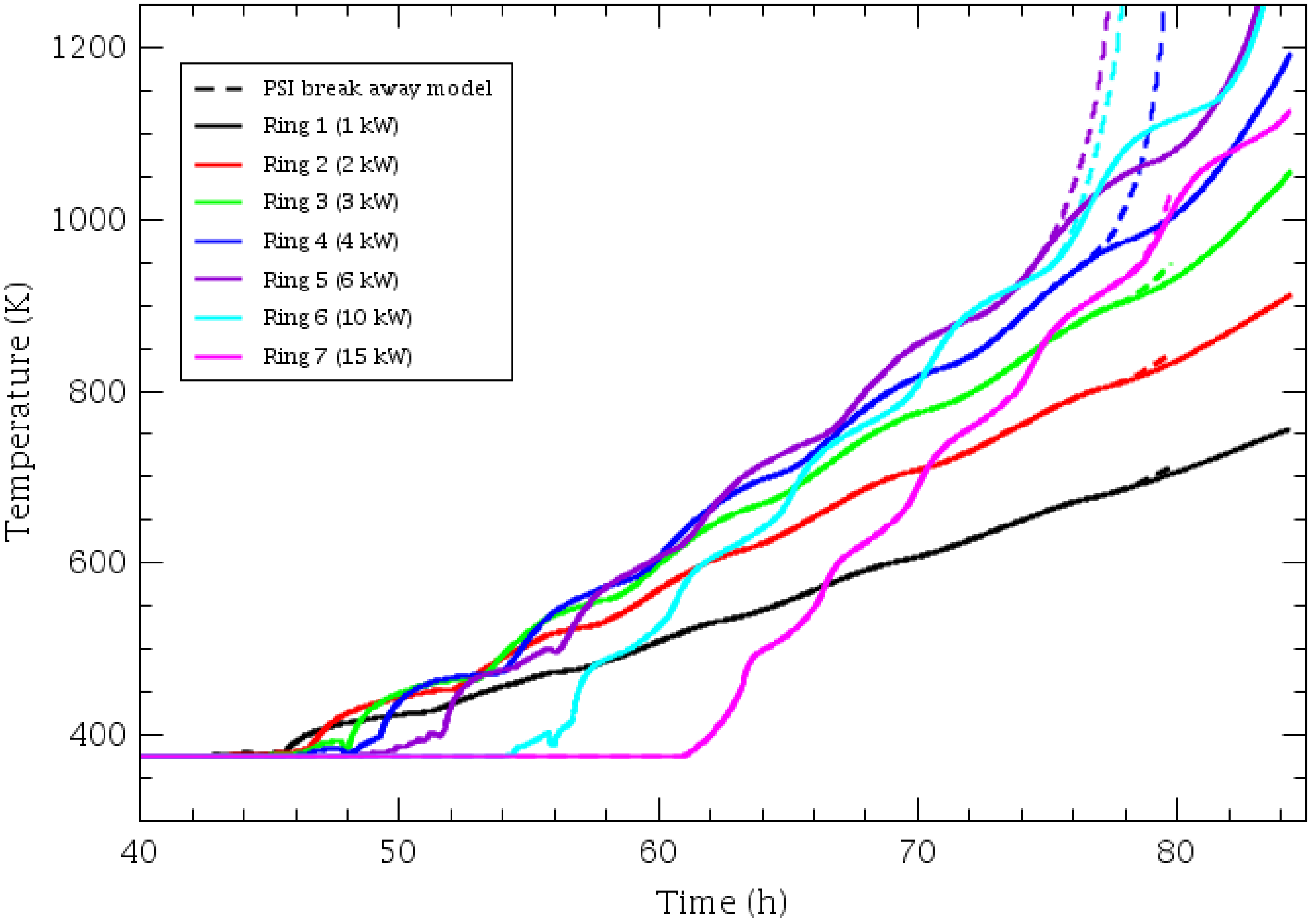
The model with only one control volume for each ring resulted in physically interpretable data.

The onset of temperature increase could be observed first in the ring with lowest heat load as expected.

The calculation of the swell level has to be validated, because it is important for the heat up of the spent fuel. The bubble rise velocity is the parameter to influence the swell level in MELCOR.

The temperature profile along the uncovered fuel pins has also to be validated.

Influence of PSI Break Away Model



PSI Break Away Model

The PSI break away model for the oxidation under steam is based on experimental data from seperate effect tests.

It shows that in case of a slow accident progression in the spent fuel pool the temperature escalation can occur several hours earlier than predicted without break away taking into consideration.

Highest importance for the break away model was found for medium heat load SFA‘s because they are reaching ignition conditions first.

In case of a reactor accident with much higher heat loads in the fuel elements break away under steam environment does not play any role because temperature increase is very fast.

Conclusions

Important outcome of the sensitivity study are the following points:

- A validated model for the calculation of heat load dependent swell level is important
- The break away model is neccessary for slow oxidation processes to calculate break away under steam oxidation
- The nodalisation dependency observed from the 3-ring model and 1-ring model comparison is the result of unphysical modelling of the two phase flow
- There is a clear need for a modern 2 phase flow model, especially for spent fuel pool calculations
- SFP LOCA should not be calculated with a stack of CV‘s

Thank you for your attention