Wir schaffen Wissen – heute für morgen

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Spent Fuel under Severe Accident Conditions

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Content

- Introduction
- Boundary conditions and modelling
- SFP boil down accidents
- Total loss of coolant
- Partial loss of coolant
- Conclusions

Spent Fuel under Severe Accident Conditions

After Fukushima the spent fuel behaviour comes into the focus of interest for the international research community.

Calculations of spent fuel behaviour were conducted in several countries and results were presented and discussed.

Experimental investigations of spent fuel behaviour under severe accident conditions has started earlier, initiated from the terrorist attack in USA (9/11). NRC started a national programme to investigate BWR spent fuel under total loss of coolant conditions. In 2009 an international OECD/NEA programme was started with 13 participating countries inclusive PSI for Switzerland to investigate PWR spent fuel under the same conditions. The project finished end of February 2013.

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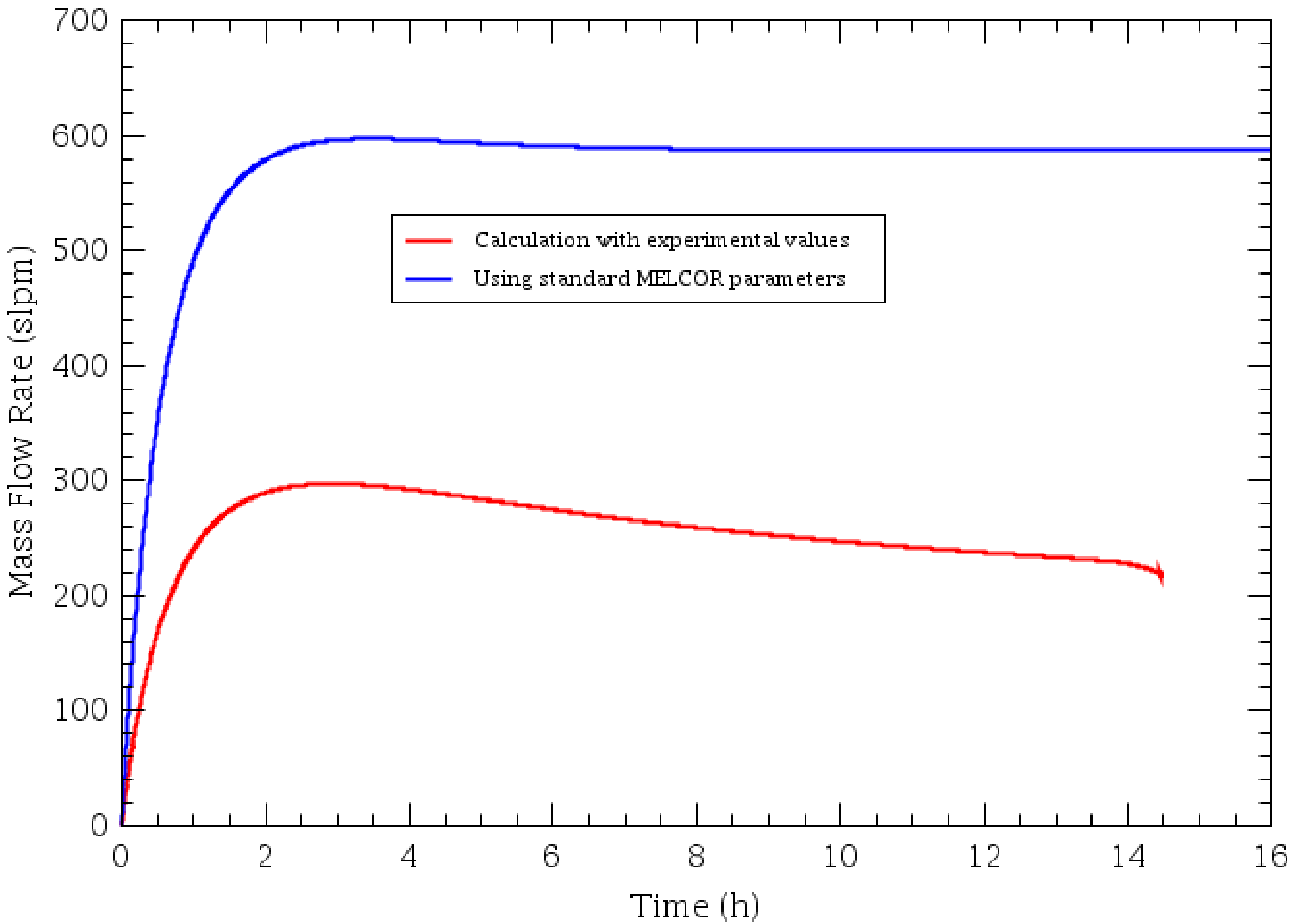
Special Spent Fuel Boundary Conditions

- Spent fuel racks (increasing flow resistance)
- Air availability (oxygen and nitrogen reactions)
- Additional phenomena arises due to low temperature processes
- Low heat load and slow accident progression
- Non cylindrical geometry (radial heat transfer)
- No additional barriers for FP release (only cladding)
- Chemical reactions influencing release of FP’s

Spent Fuel under Severe Accident Conditions



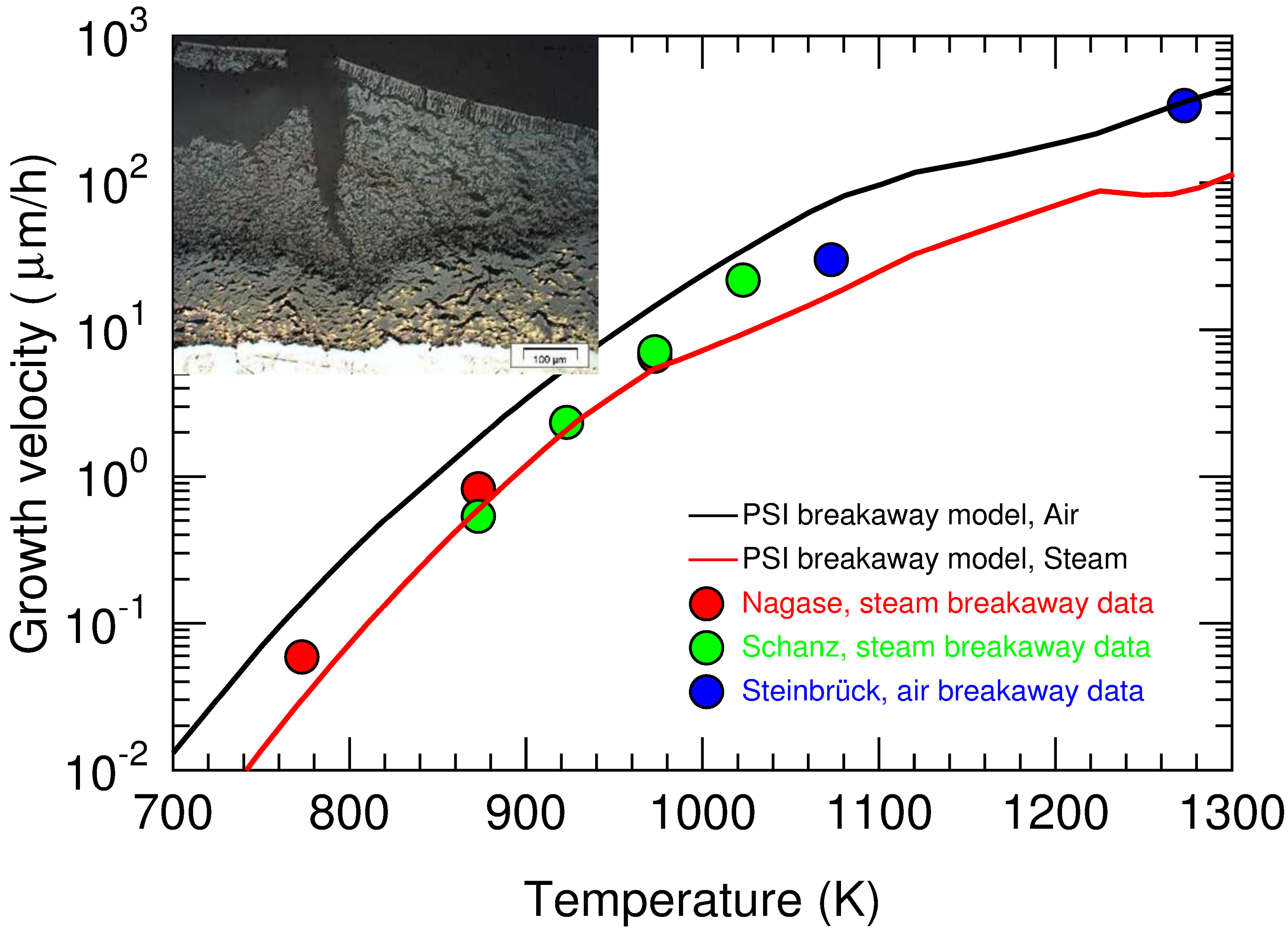
Spent Fuel under Severe Accident Conditions

The first surprising result was the strongly enlarged flow resistance due to the spent fuel rack, which is closed on the sides and only open at the inlet and the outlet of the fuel bundle.
The reduction of flow velocity leads to lower heat loss and therefore higher temperatures can be reached.

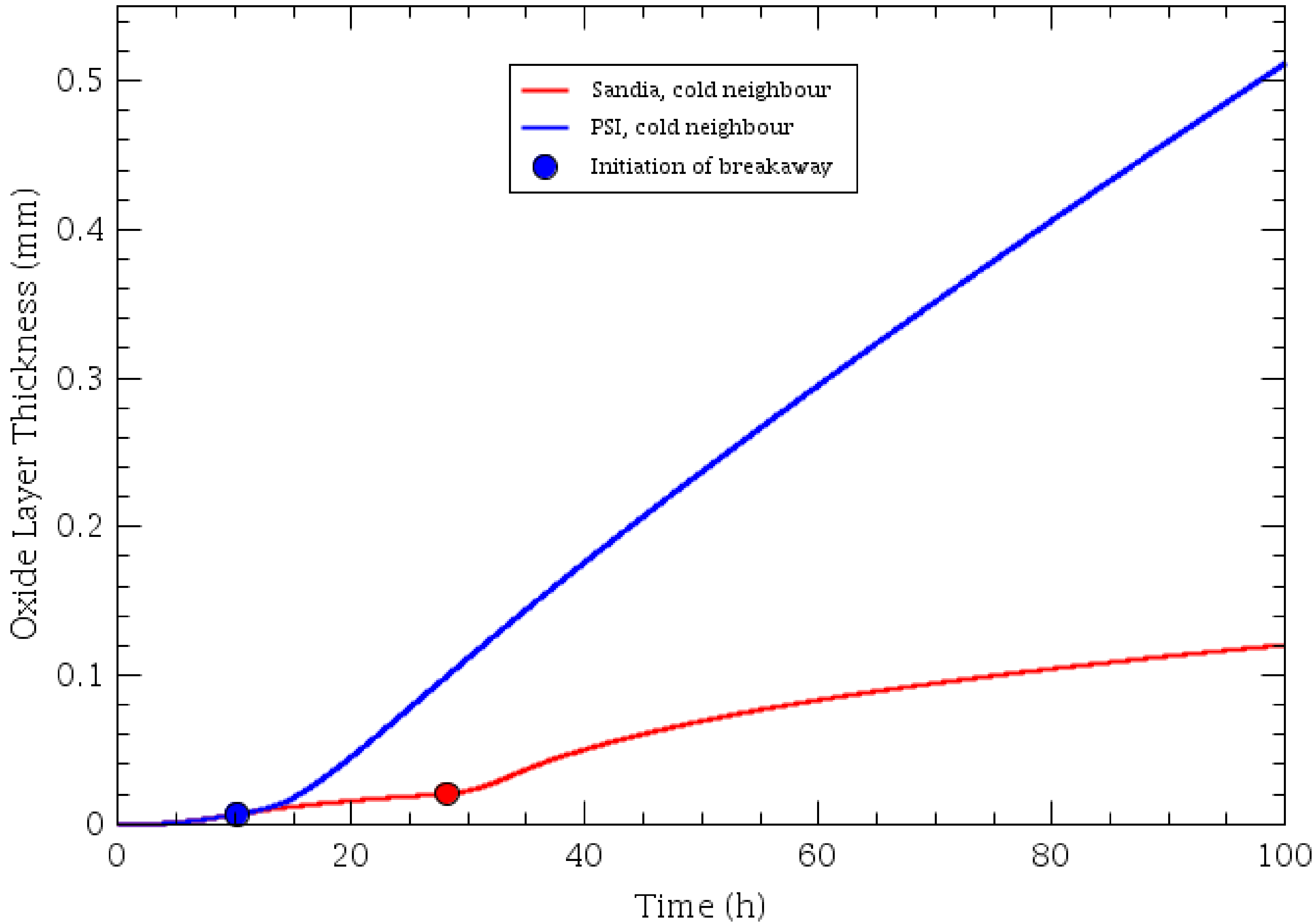
Separate effect tests at KIT in 2007 showed at temperatures below 1300 K a change of the oxidation behaviour due to the so called oxide crust breakaway. At about this time PSI started the development of a breakaway model which could be successfully implemented in the severe accident codes SCDAPSim and MELCOR in February 2013.

Some breakaway model still results in parabolic oxide layer growth.

Spent Fuel under Severe Accident Conditions



Spent Fuel under Severe Accident Conditions



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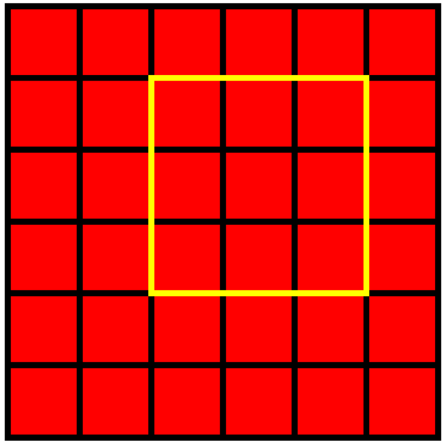
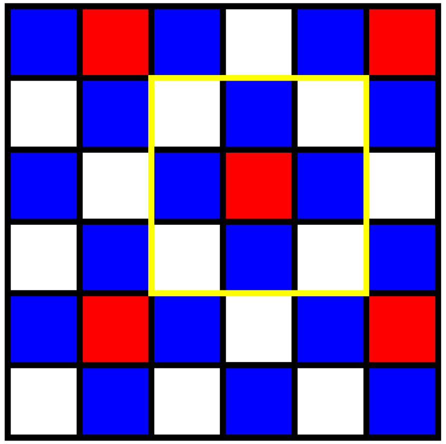
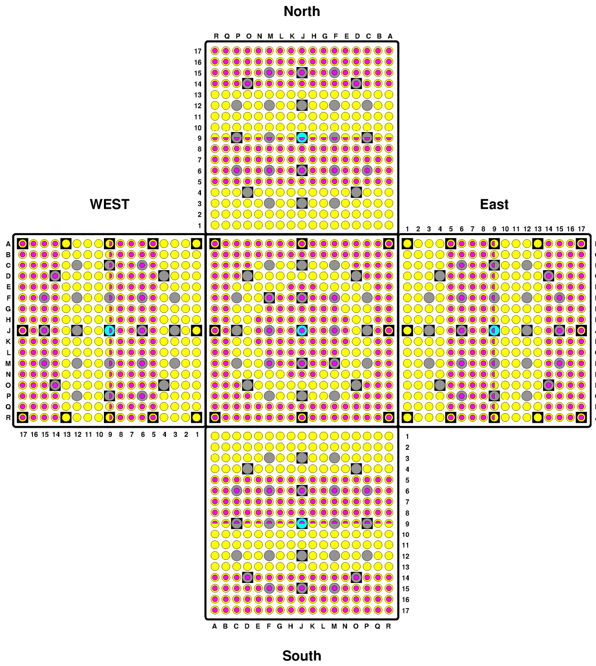
Spent Fuel under Severe Accident Conditions

Hot Neighbour



Cold Neighbour





Different storage policy will influence the heat up behaviour during an SFP accident, because cold neighbours can act as heat sink.
The distribution of hot fuel assemblies in the pool is a challenging task for the radial heat transfer between different groups of fuel assemblies with similar heat loads.

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Spent Fuel Pool Boil Down Accidents

Spent fuel pool contains about 1200 m^3 on water

Spent fuel pool area is about 100 m^2

Boil down velocity is 40 m^3 for each MW on total heat load in the pool

Heat losses to structures (concrete) may reduce boil down velocity

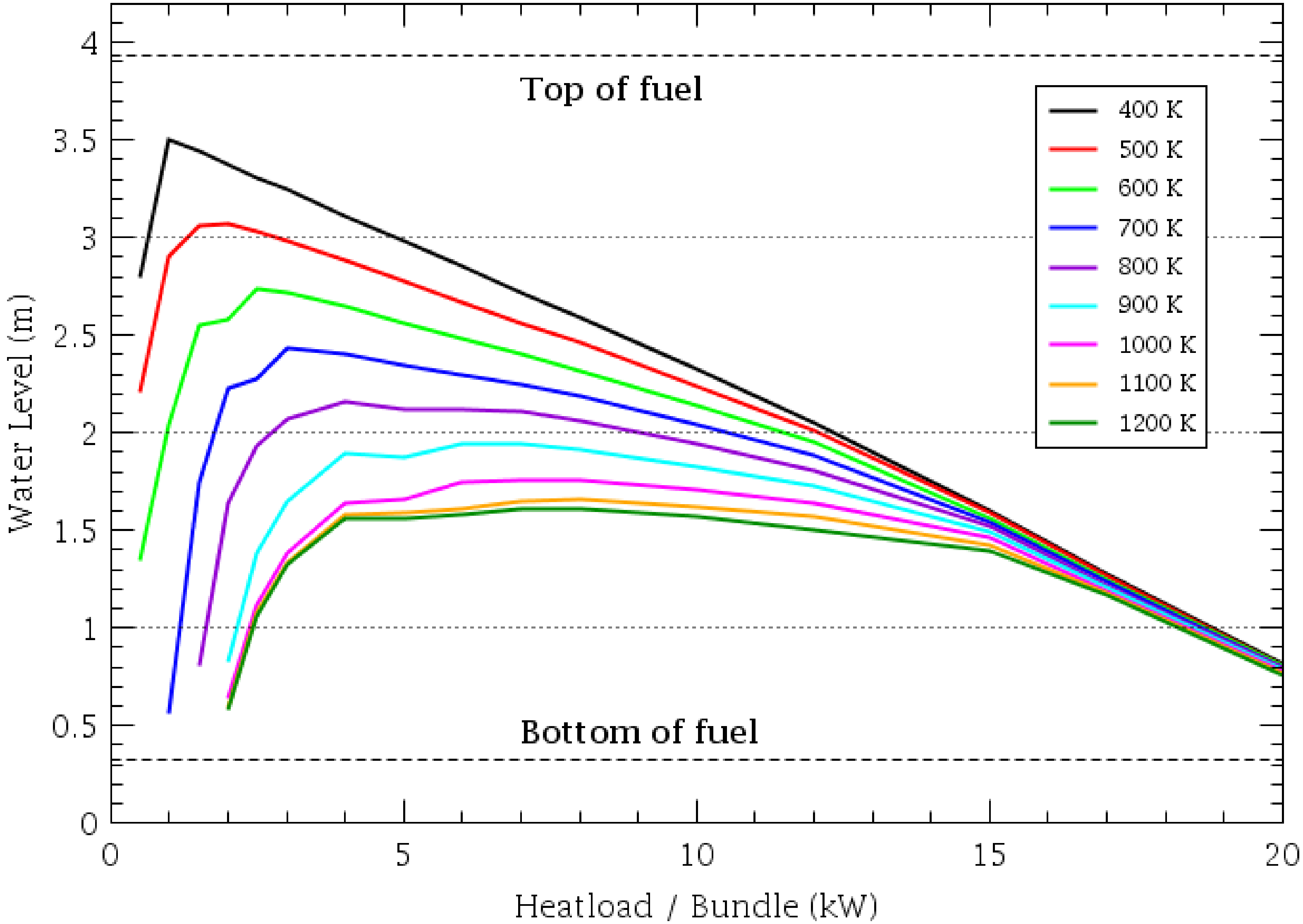
Top fuel level is at 4 m

About 2 days to reach boiling conditions at 1 MW heat load

Plus 15 days to start core uncovery

Hydrogen production in steam rich atmosphere

Spent Fuel Pool Boil Down Accidents



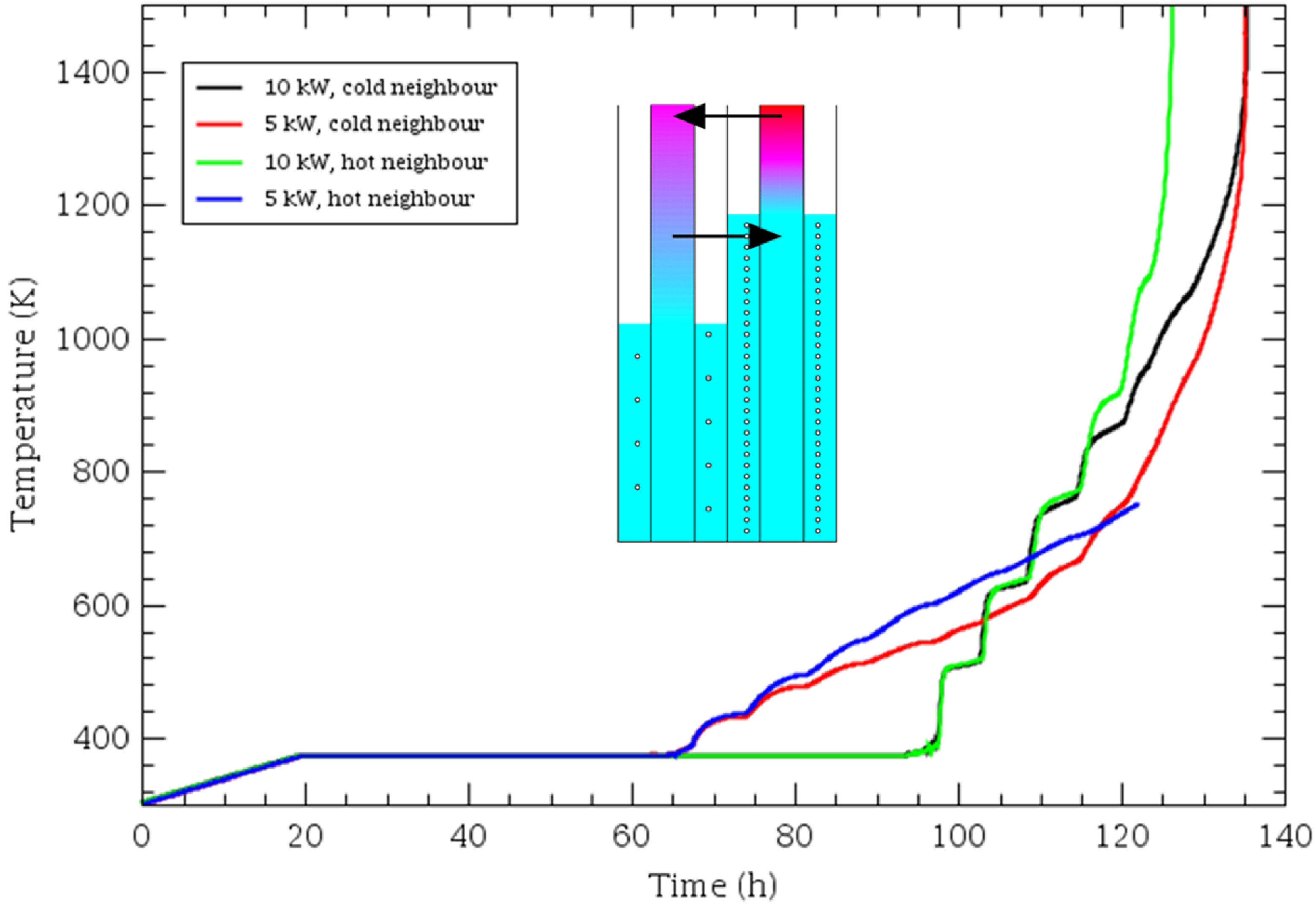
Spent Fuel Pool Boil Down Accidents

The swell level inside the spent fuel racks is independent in each rack.
It only depends on the heat load of the FA inside the rack.
As higher the heat load, so higher the swell level.
The collapsed level is identical for all FA's in the pool.

Firstly heat up starts at lowest heat load.
Heat up is faster with higher heat load.
Radial heat transfer influences heat up velocities.
PSI breakaway model calculates accelerated oxidation according to experiments.

Heat distribution in the pool does not influence the boil down until start of fuel uncovery.

Spent Fuel Pool Boil Down Accidents



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Total Loss of Coolant

Buoyancy driven air flow

No water available

Heat up proportional to heat load

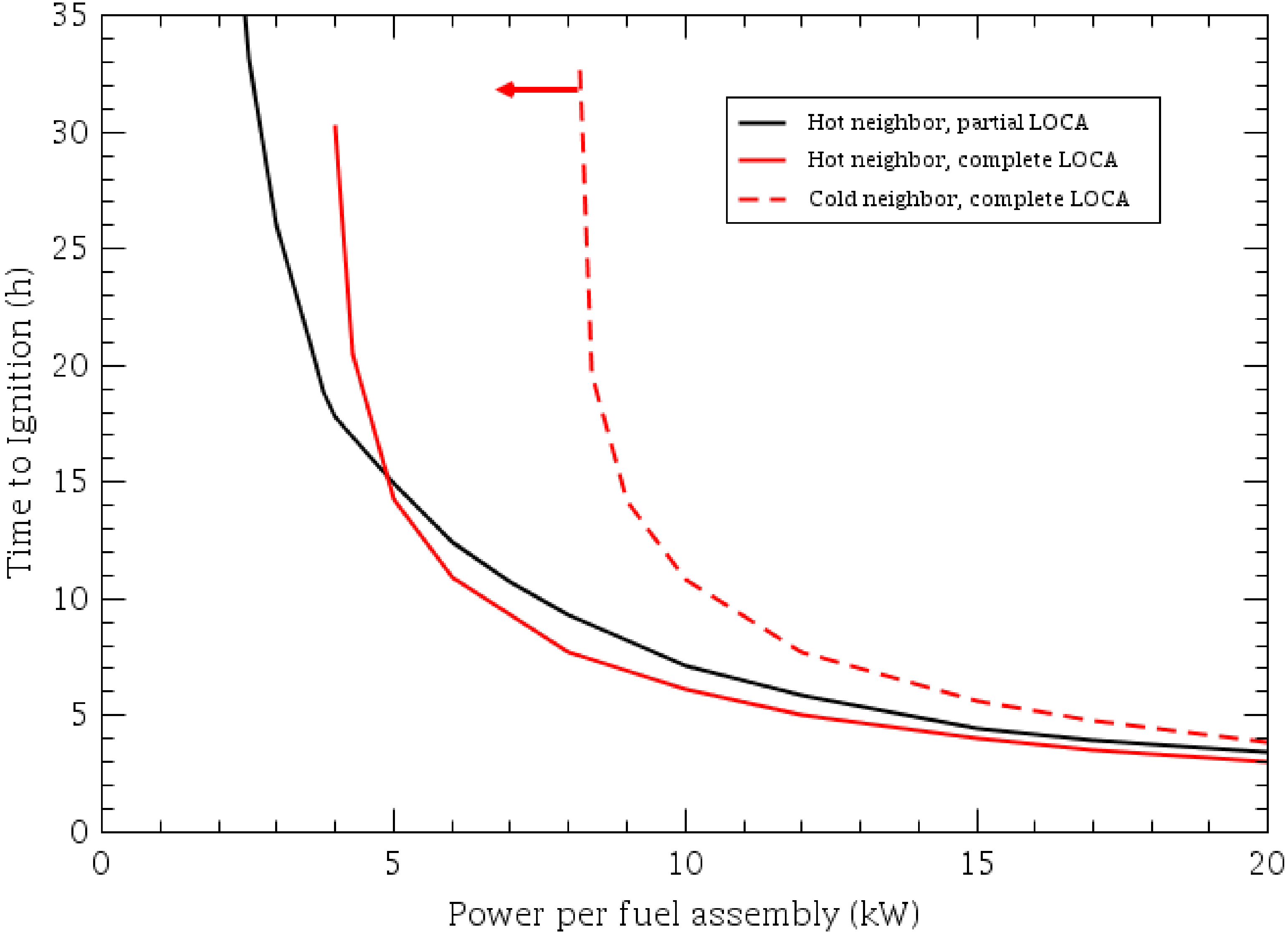
Strong heat radiation at higher temperatures to cold neighbours

Zirconium fire ignites above 1200 K

Oxygen and Nitrogen are reaction partners of Zirconium

No Hydrogen production

Total Loss of Coolant



Total Loss of Coolant

Instead of weeks the accident progresses in few hours

First fission product release after cladding failure at about 1000 K

Zirconium fire almost impossible to extinguish

If Zirconium fire is ignited it spreads horizontally and vertically over the whole pool

Cladding may fail due to complete oxidation even if maximum temperatures will stay below 900 K

If heat load is above 4 kW per assembly in hot neighbour storage or above 8 kW in cold neighbour storage the spent fuel cannot be cooled by air flow

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Partial Loss of Coolant

Worst possible scenario without cooling gas flow at low water level

Water is blocking the bottom nozzle

Atmosphere contains mixture of steam and air or nitrogen

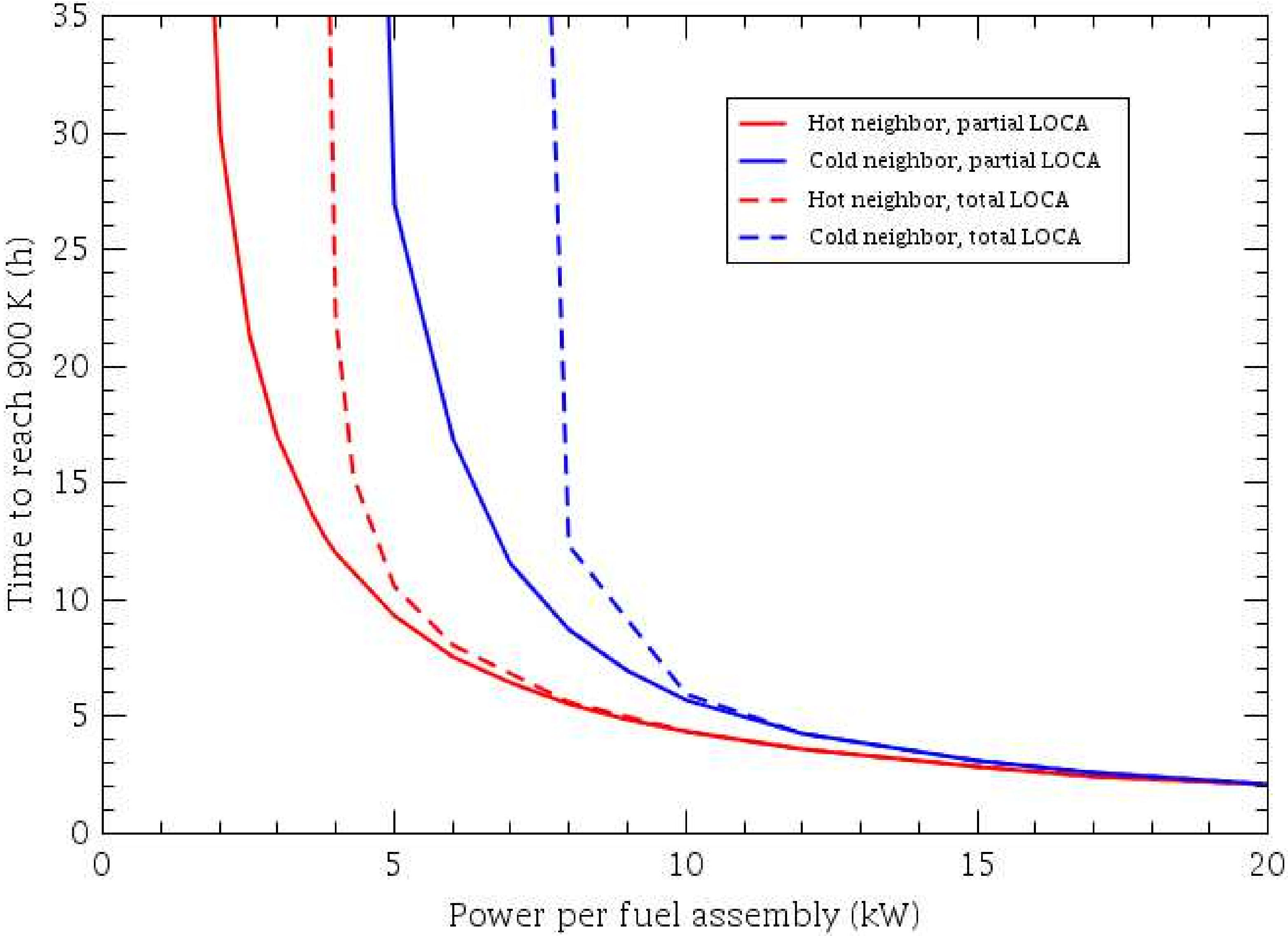
Strong heat radiation at higher temperatures to cold neighbours

Zirconium fire ignites above 1200 K if oxygen is available

Steam, Oxygen and Nitrogen are reaction partners of Zirconium

Hydrogen production

Partial Loss of Coolant



Partial Loss of Coolant

Accident progresses even faster as in total loss of coolant scenario

Zirconium fire possible only in presence of oxygen

Oxidation by steam can be accelerated due to presence of nitrogen

Cladding may fail due to complete oxidation even if maximum temperatures will stay below 900 K

If heat load is above 2 kW per assembly in hot neighbour storage or above 4 kW in cold neighbour storage the spent fuel is running into temperature escalation

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Conclusions

The strong increase of the flow resistance due to the presence of the spent fuel rack leads to a lower heat loss due to convection and therefore to a faster heat up as calculated from standard boundary conditions of severe accident codes.

Conclusions that spent fuel can be cooled by air alone is only valid for heat loads of PWR fuel of less than 2 kW/FA.

Cold neighbour storing policy can only delay the heat up after fuel uncovery, but does not influence the boil down velocity of the spent fuel pool.

PSI breakaway model shows in estimation with experimental data, that cladding integrity can be lost, even if temperatures of 900 K will not be exceeded.

Thank you for your attention