PAUL SCHERRER INSTITUT PSI

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Fuel Integrity Under Dry and Wet Storage

Nuclear Science and Technology Symposium, Helsinke, Finland, 30-31 October 2019

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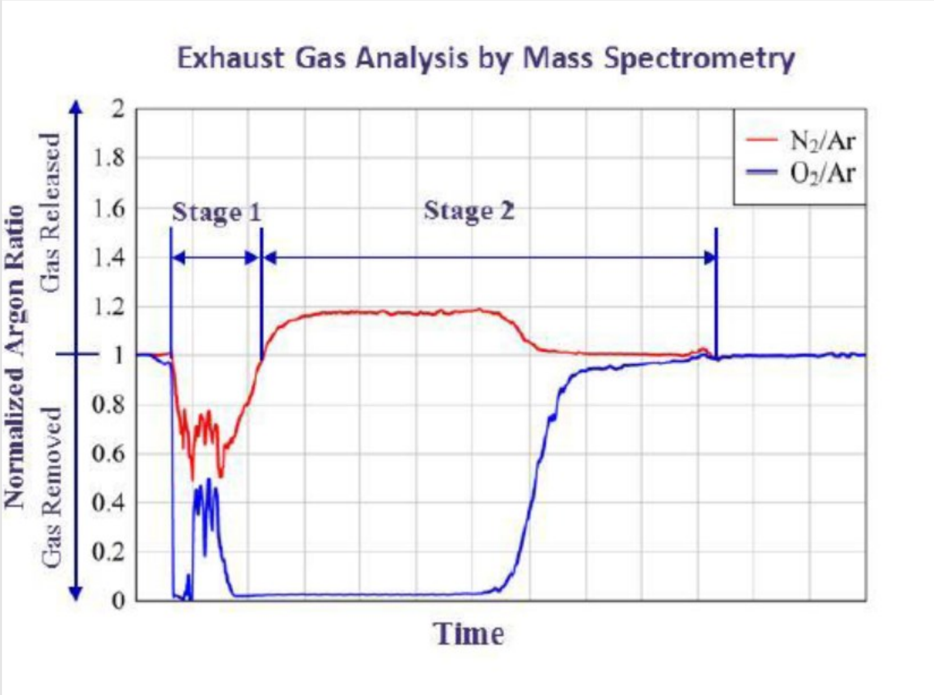
Content

1. Motivation
2. Fuel Assemblies
3. Input Decks
4. Data Comparison
5. Sandia Fuel Project
6. Conclusions

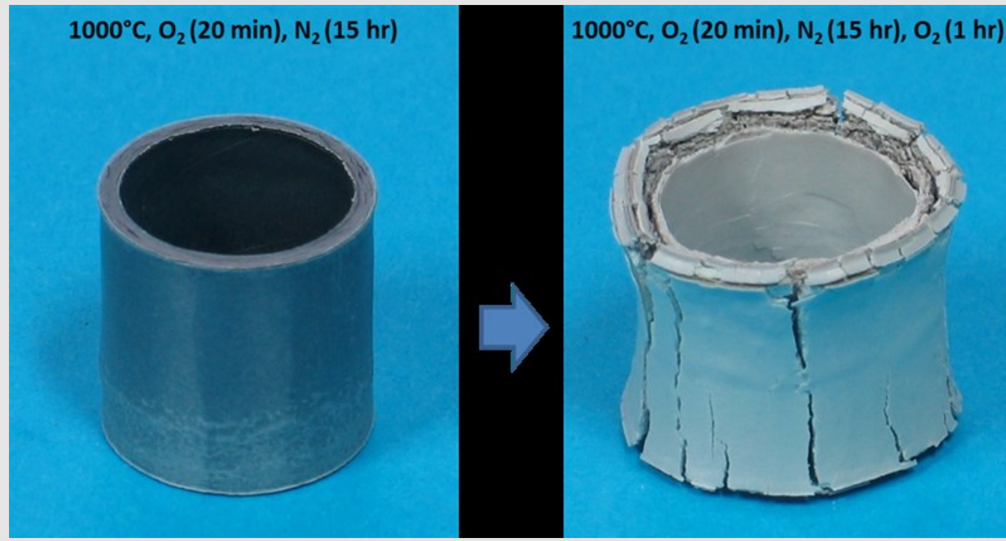
Sandia Fuel Project (2011)



NUREG/CR 7216

Motivation

Separate-effect tests at KIT, Germany



A fresh sample compared with a pre-oxidized and nitrided sample and finally a sample after re-oxidation with oxygen.

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Fuel Assemblies

BWR:	**Mühleberg**	**9x9 part length with 2 water rods**
		10x10 part length with 2 water rods
		10x10 2 part length with 2 water rods
	Fukushima	**9x9 full length with 1 water channel**
PWR:	**Beznau**	**14x14 full length**
	Gösgen	**15x15 full length**
	SFP	**17x17 full length**

The calculations are prepared for SFP environment after loss of coolant.

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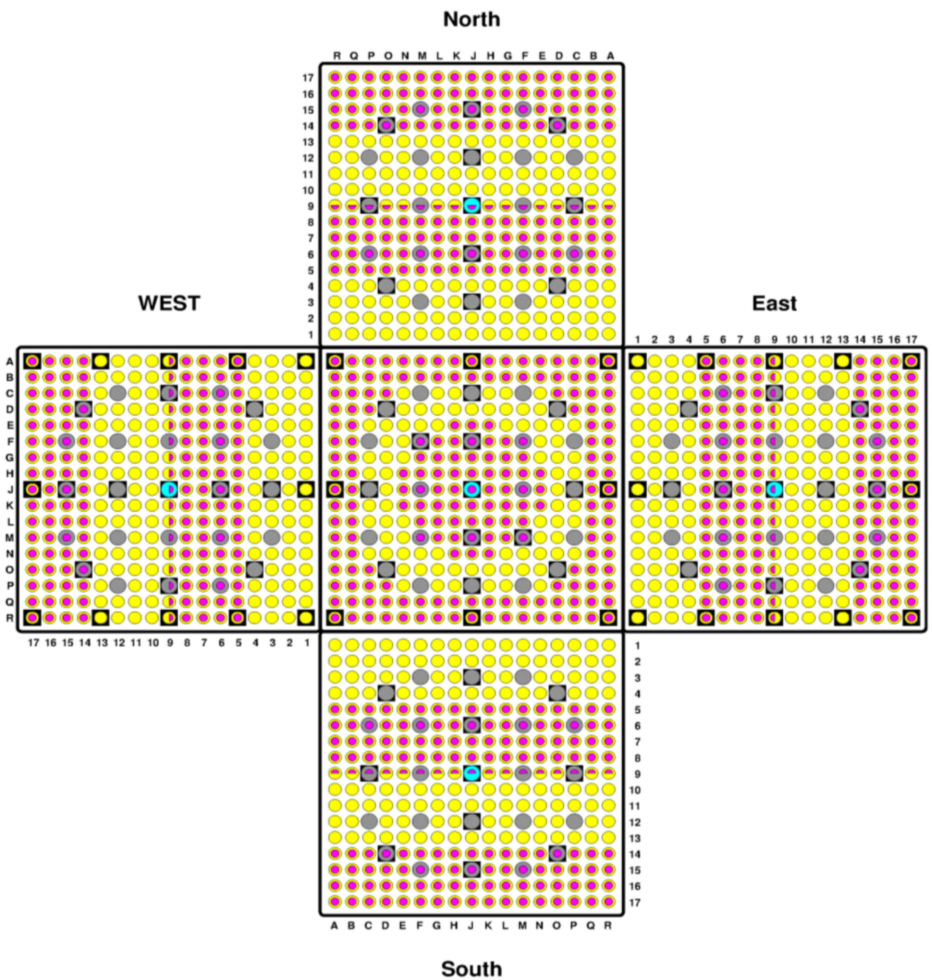
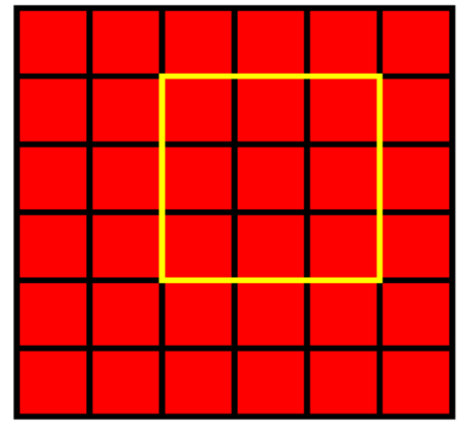
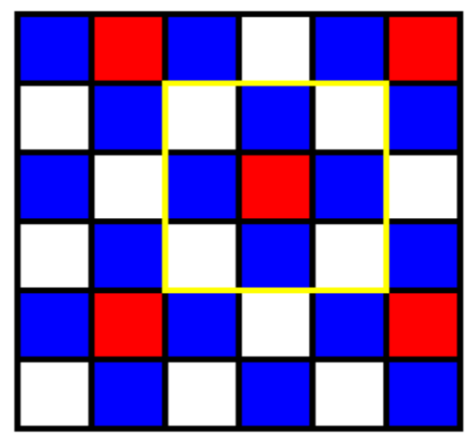
Input Decks



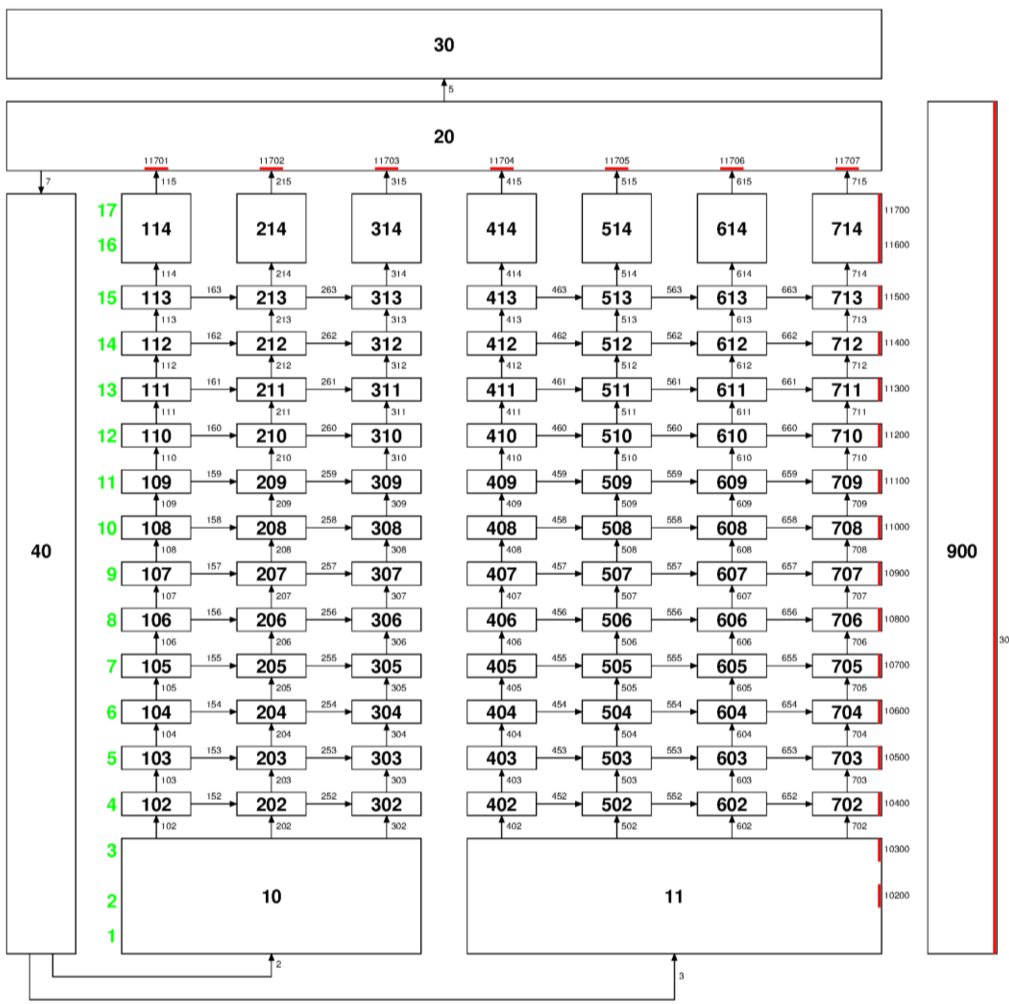
Hot Neighbour



Cold Neighbour



Input Decks



One or two radial nodes (hot and cold neighbor)

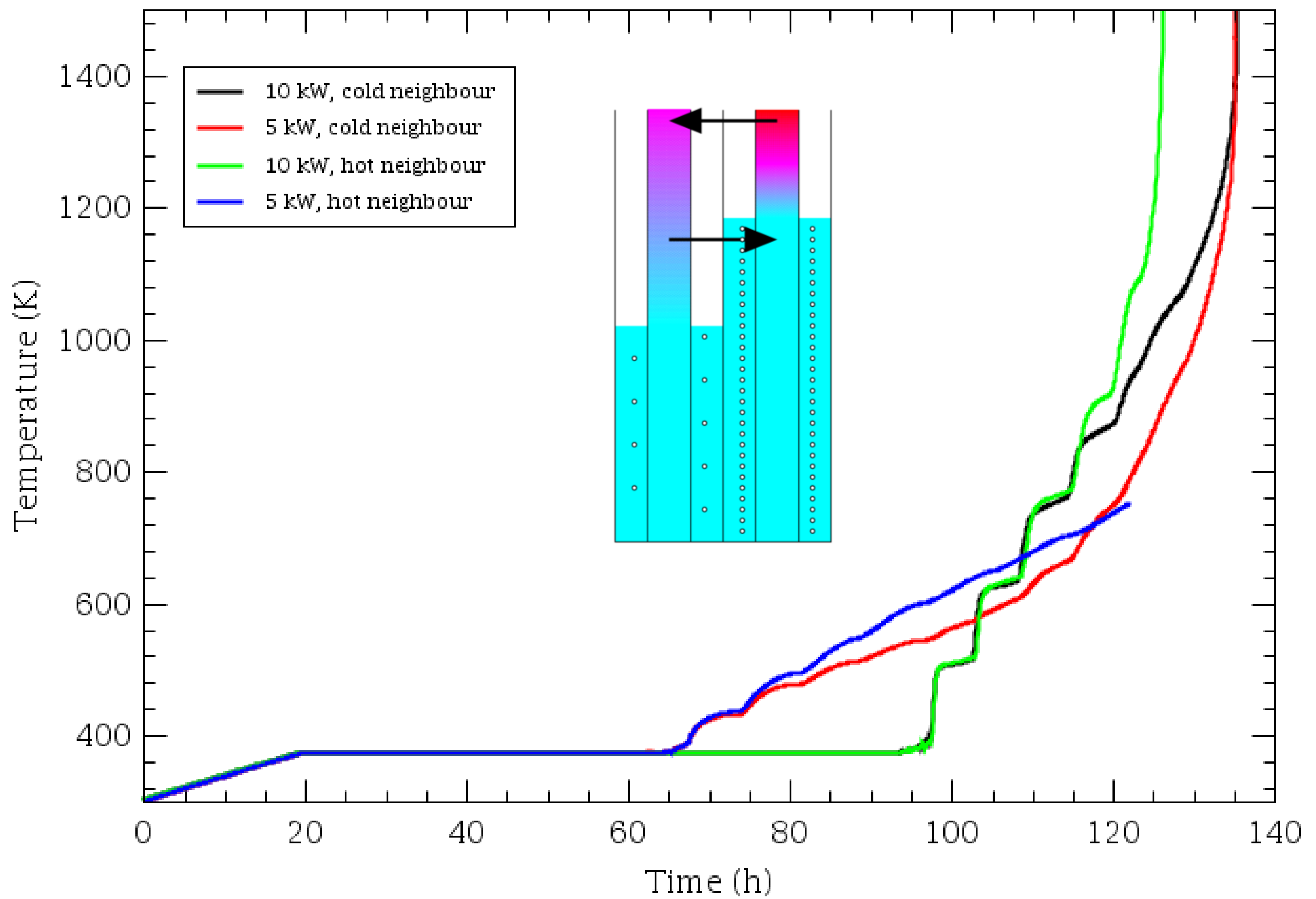
16 axial nodes:
gas input node
support plate
lower nozzle
unfueled cladding
10 active fuel nodes
unfueled cladding
upper nozzle + handle

each core cell one volume

only vertical flow pathes

Input Decks

5 kW and 10 kW FA's



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Input Decks

The input decks for the MELCOR version of the new nitriding model are identical with the standard MELCOR 1.8.6 input deck.

The input decks for the MELCOR 2.1 version are translated via the SNAP software.

One problem was identified with the hydraulic diameter for PWR fuel assemblies which had to be corrected manually.

The input decks for MELCOR 2.2 are identical with the 2.1 input decks.

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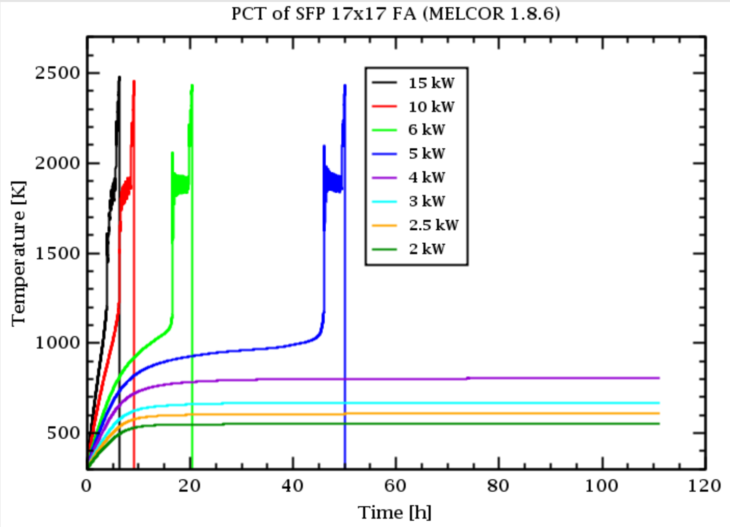
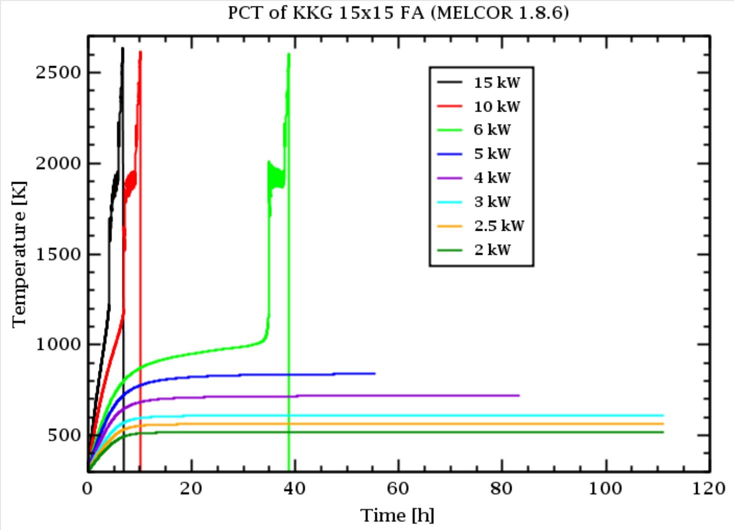
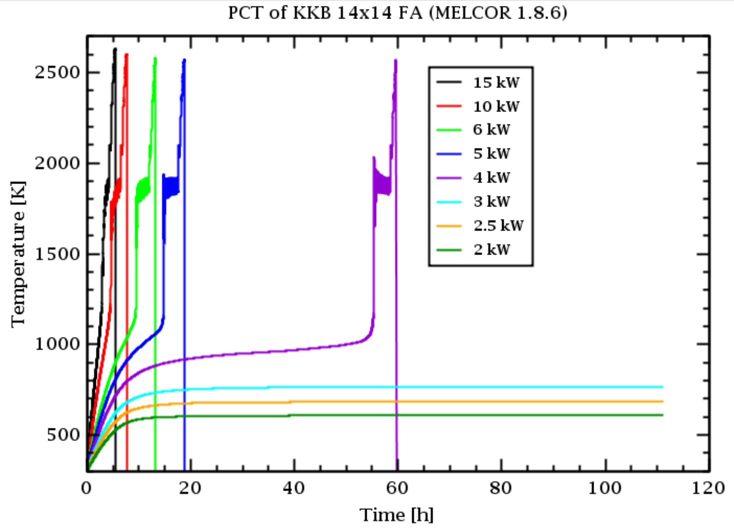
Hot Neighbor Configuration, PWR







Fuel Assemblies

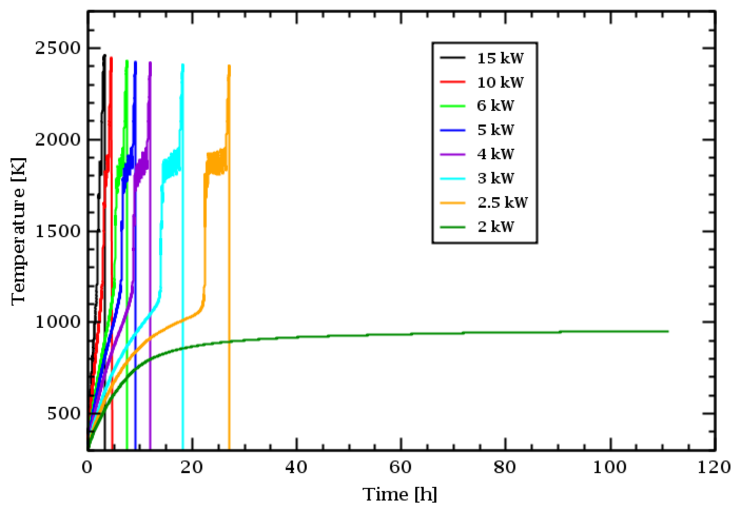
Plant	Configuration	Fuel Pins	Fuel Mass	Zr Surface	Hydraulic Ø	Heat / Mass
1F4	9x9-9	72	240 kg	16.9 m^2	1.12 cm	2.050
KKM	9x9-7	66/8	199 kg	15.7 m^2	1.14/1.30 cm	2.472
KKM	10x10-8	78/14	206 kg	16.9 m^2	1.03/1.25 cm	2.388
KKM	10x10-8	78/8/6	210 kg	16.8 m^2	1.03/1.12/1.25 cm	2.343
KKB	14x14-17	179/17	377 kg	20.8 m^2	1.28 cm	1.305
KKG	15x15-20	205/20	503 kg	29.0 m^2	1.40 cm	0.978
SFP	17x17-25	264/25	492 kg	30.2 m^2	1.24 cm	1.000

The larger hydraulic diameter of KKG FA leads to higher convectional heat loss and therefore better coolability.

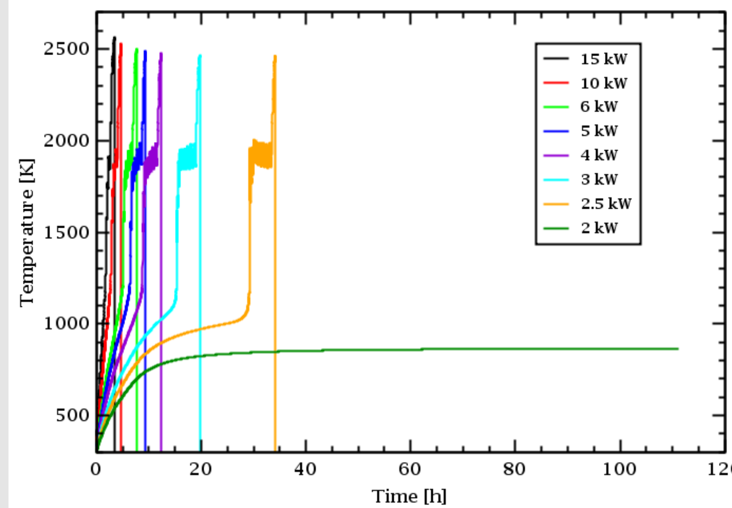
The higher heat density of KKB FA leads to stronger heat up at almost equal hydraulic diameter compared to SFP FA.

Hot Neighbor Configuration, BWR

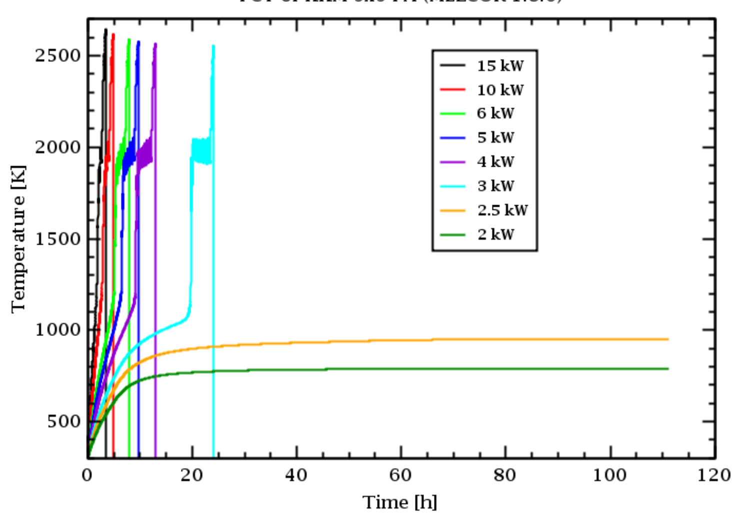
PCT of KKM 10x10 FA, 3 length (MELCOR 1.8.6)



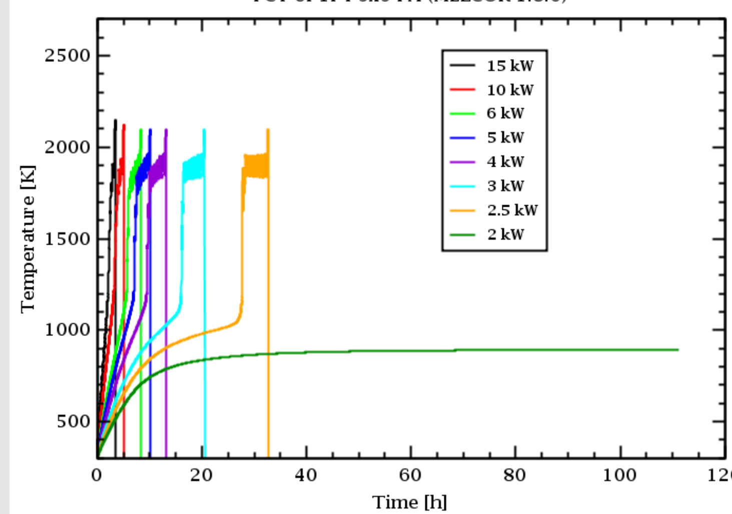
PCT of KKM 10x10 FA, 2 length (MELCOR 1.8.6)



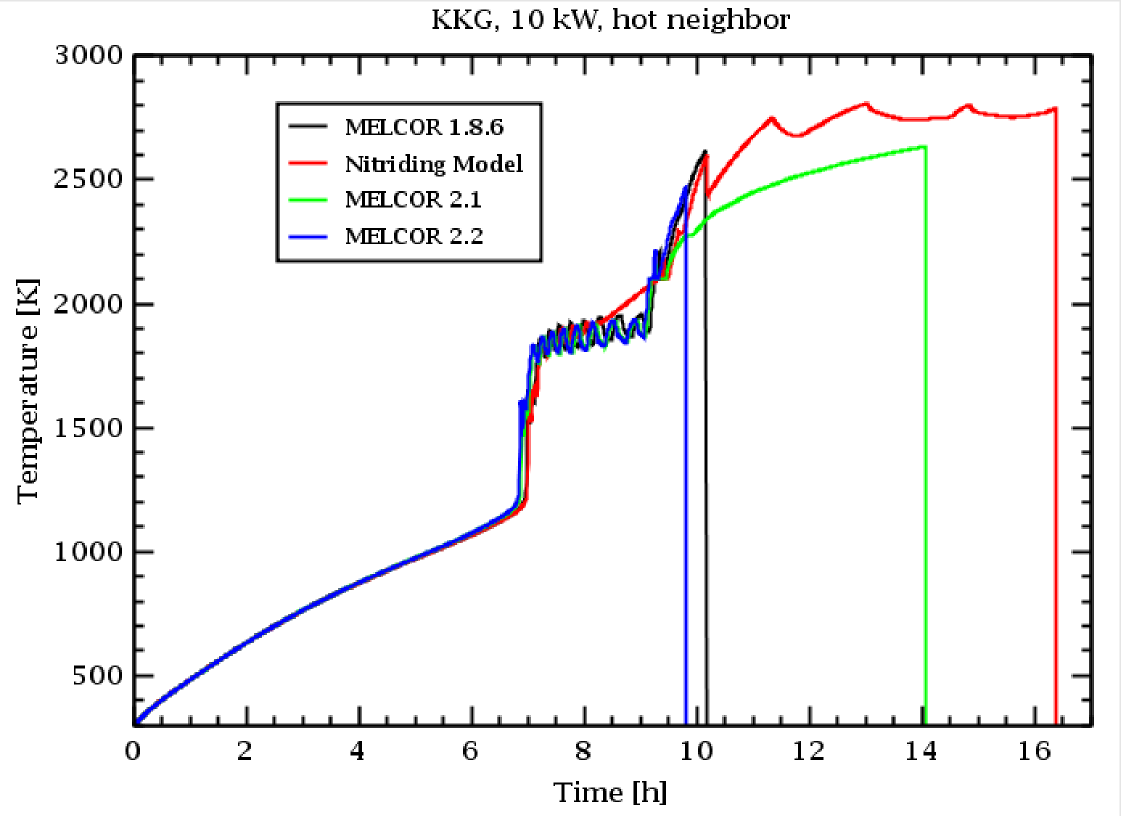
PCT of KKM 9x9 FA (MELCOR 1.8.6)



PCT of 1F4 9x9 FA (MELCOR 1.8.6)



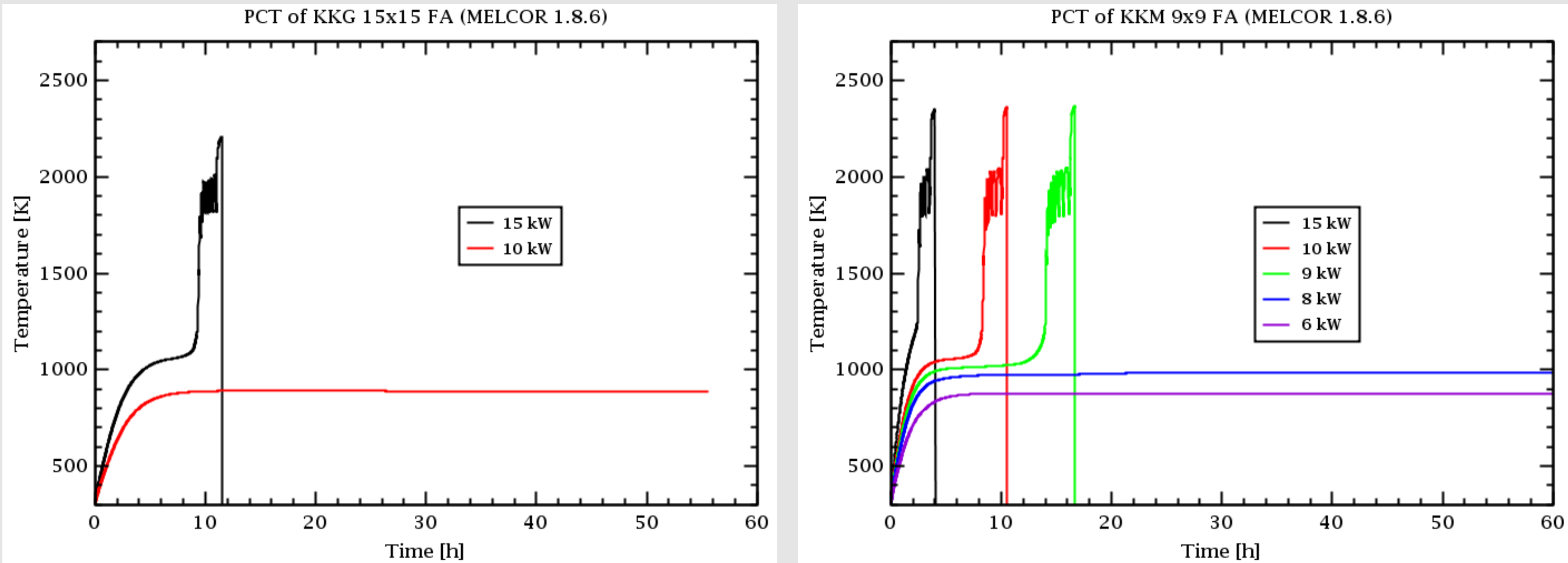
Comparison of Code Versions



Updates in the heat conduction model regarding the quench effects are responsible for the differences between version 1.8.6 and 2.x.

The nitriding model has no influence on the accident progression as long as there is no starvation of oxygen.

Cold Neighbor Configuration

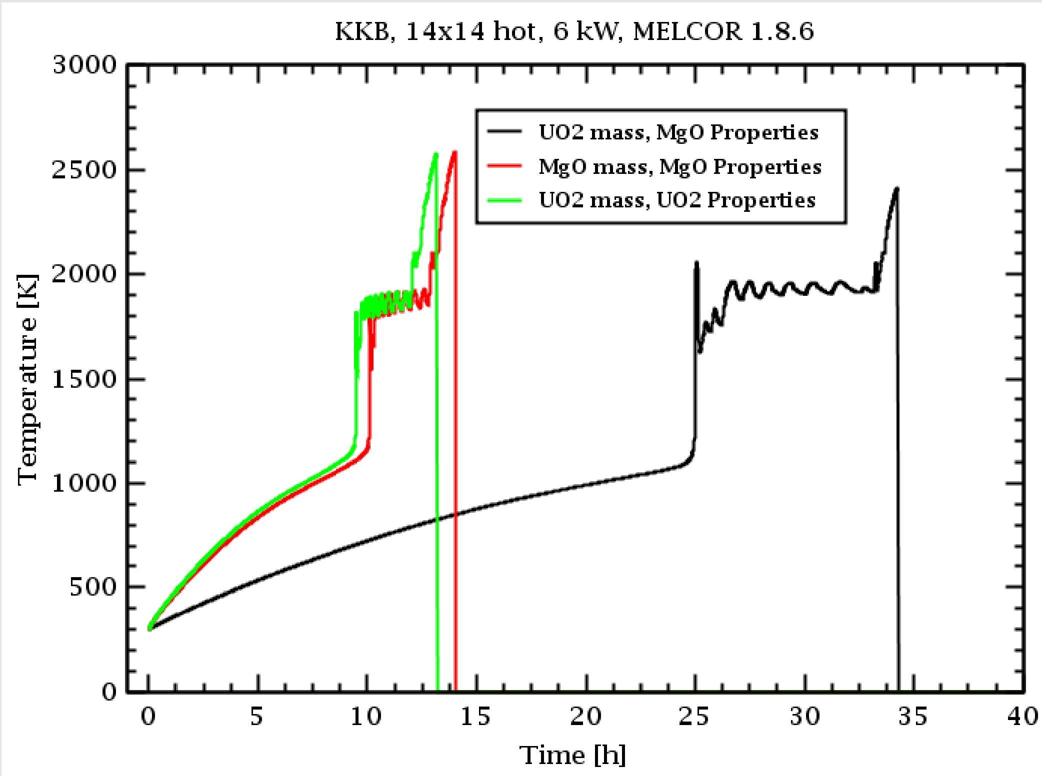


The onset of the temperature escalation is strongly changed due to the cold neighbor storage.

KKG: from 5-6 kW to 10-15 kW
KKM: from 2.5-3 kW to 8-9 kW

Content

Material Properties: MgO versus UO_2

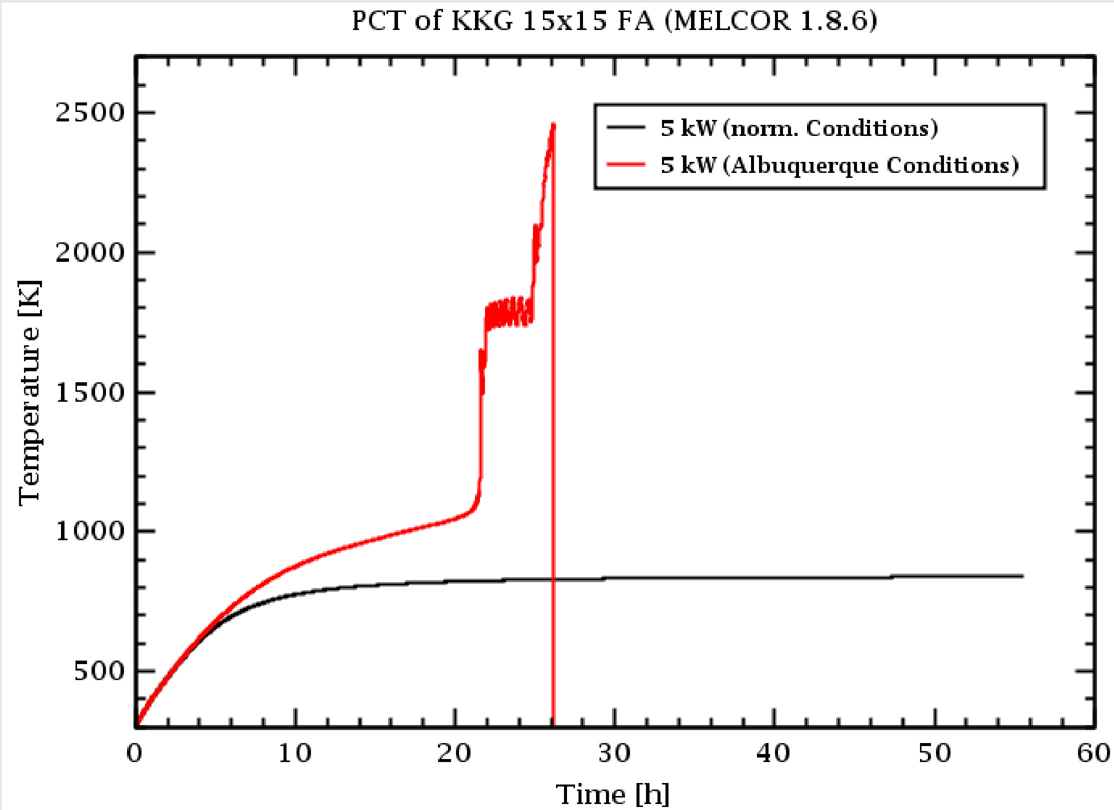


T_{melt}: UO_2 3138 K
MgO 3125 K
Zr 2128 K
ZrO_2 2988 K, ZrN 3253 K

The very similar results using the UO_2 masses and properties against the MgO masses and properties shows that MgO is a perfect model for fuel in the Sandia Fuel Project (SFP).

The disadvantage of MgO is the absence of eutectic reactions with the cladding material.

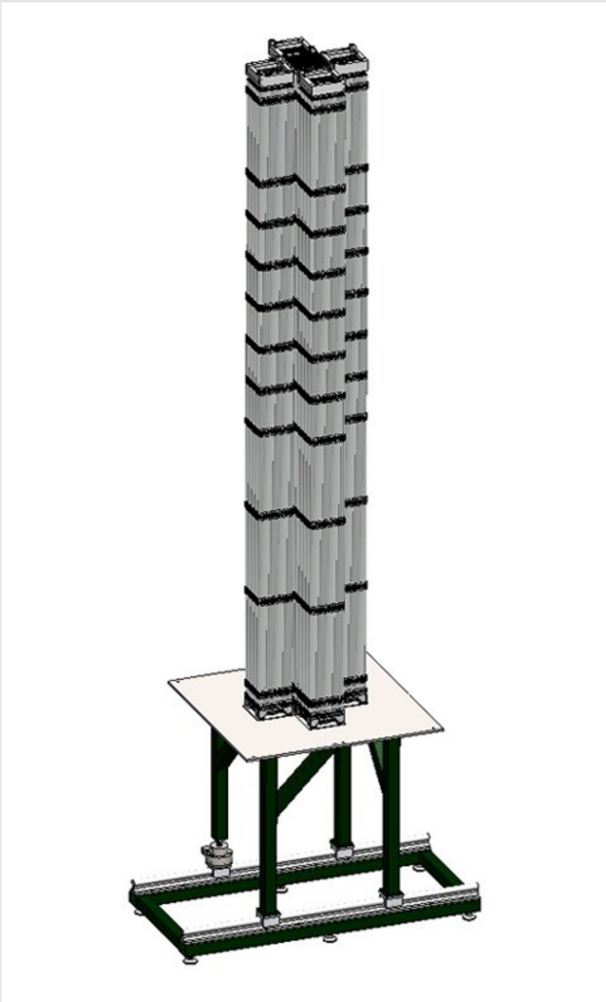
Albuquerque Conditions



The, about 20% lower, air pressure has a strong influence on the cooling process.

Less heat capacity and less pressure difference are resulting in much lower convectional heat loss.

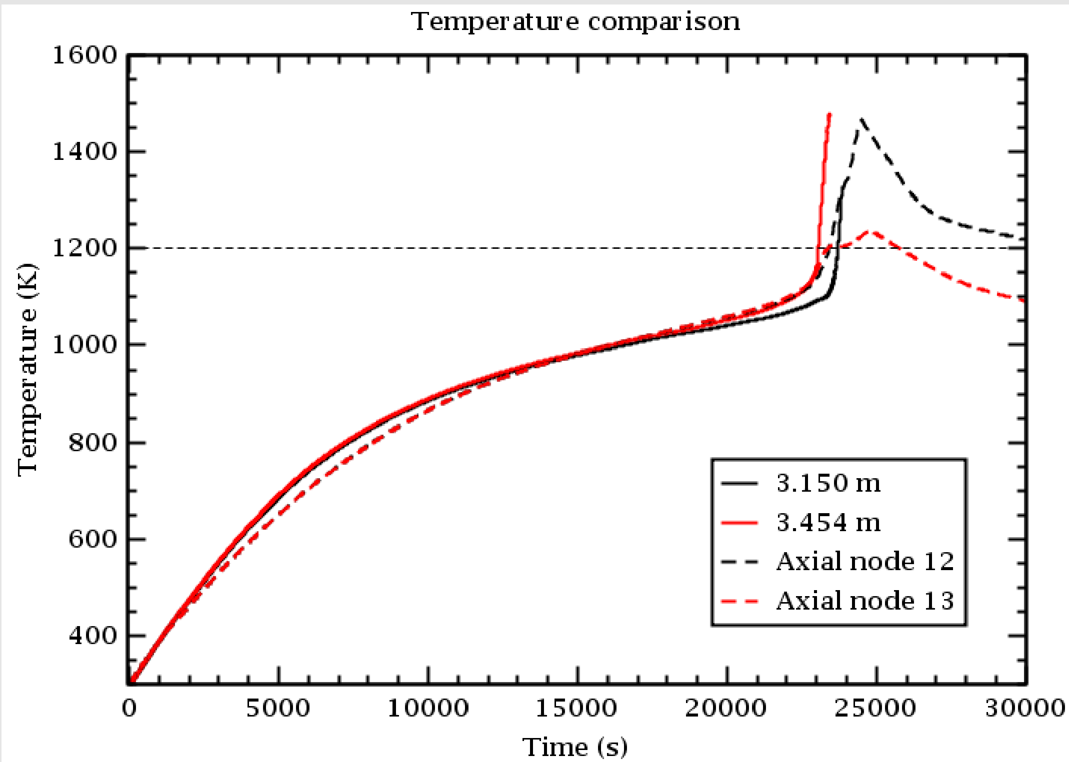
Sandia Fuel Project Phase II



Five full length fuel assemblies, one heated in the center and four unheated in the periphery, cooled by buoancy driven air.

Heating power of 15 kW simulates FA three month after outage.

Sandia Fuel Project Phase II

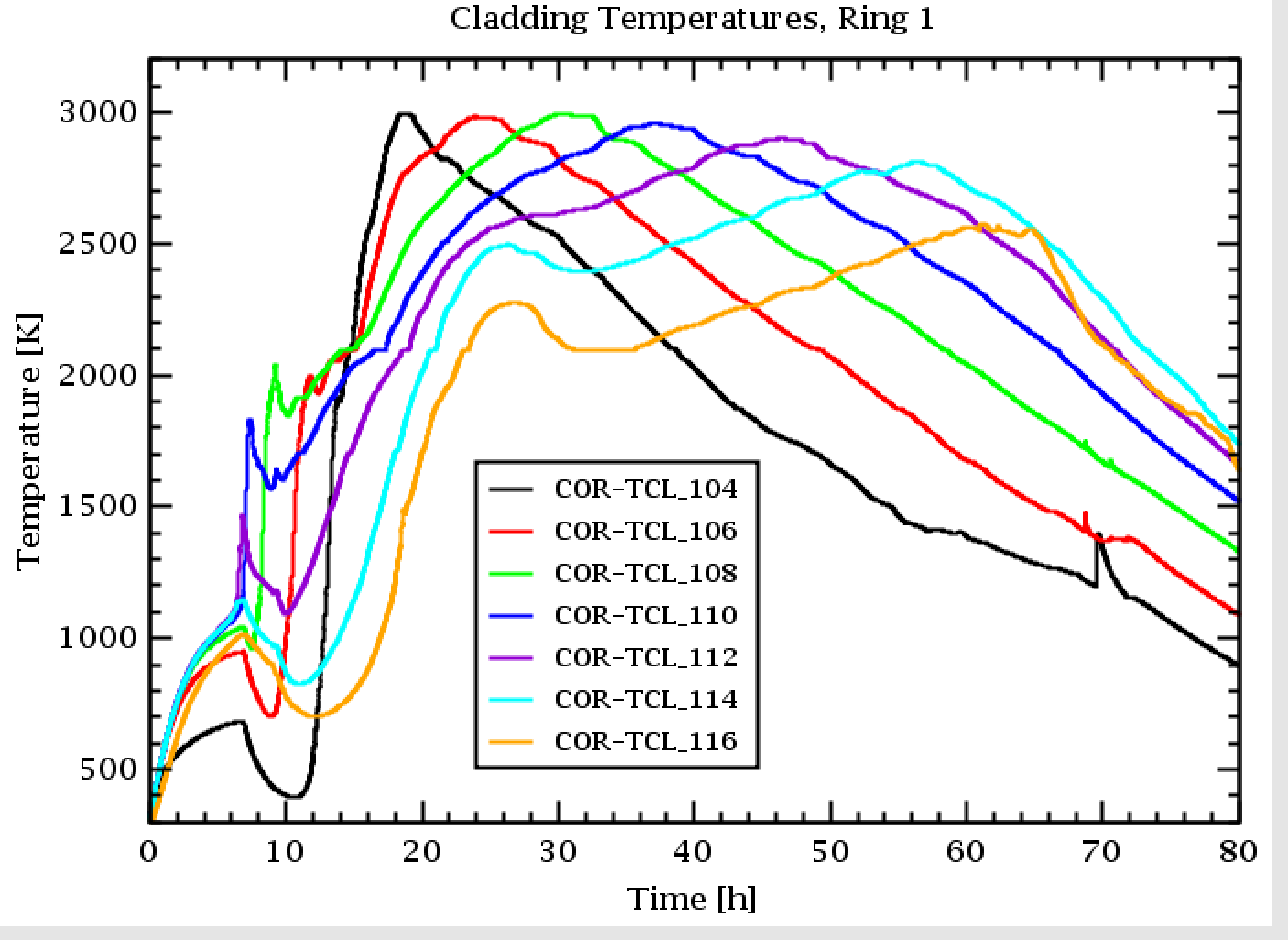


Nitriding reaction in nodes 12 and 13 not self sustaining because of low temperatures.

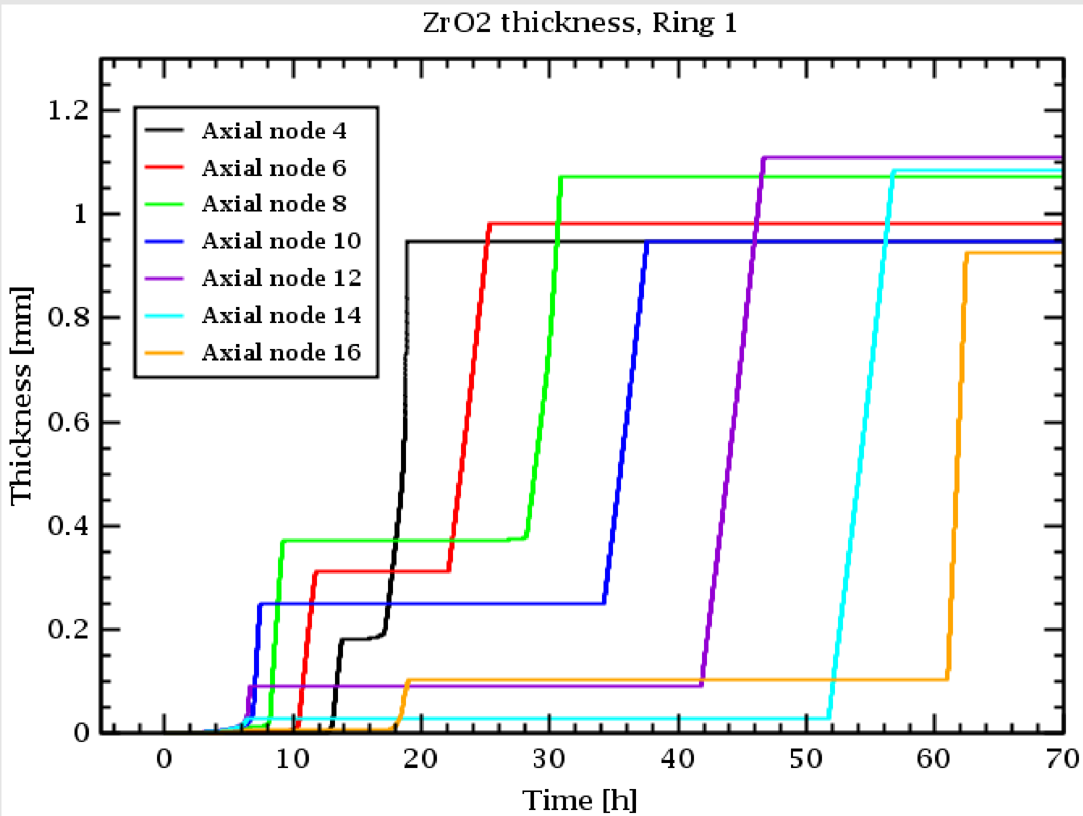
The experimental data are reasonably met until failure of the thermo-couples.

calculated by MELCOR code with nitriding model (MELCOR 1.8.6 PSI)

Sandia Fuel Project Phase II



Sandia Fuel Project Phase II

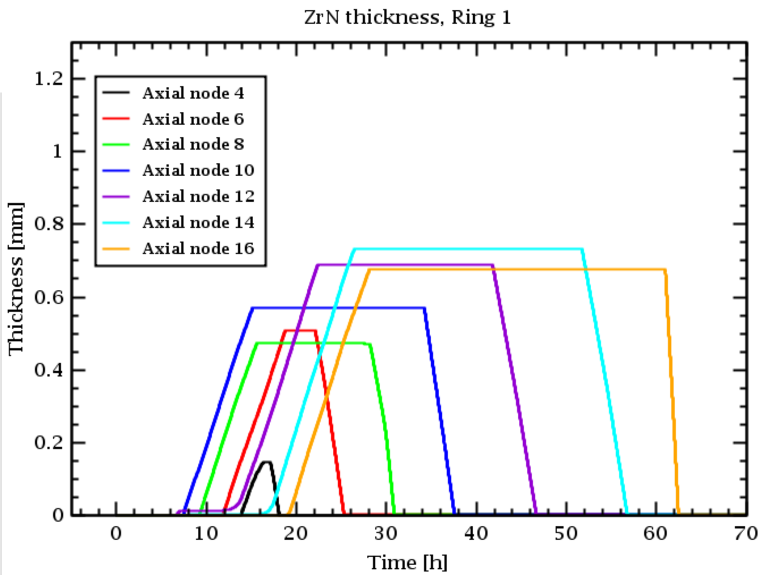


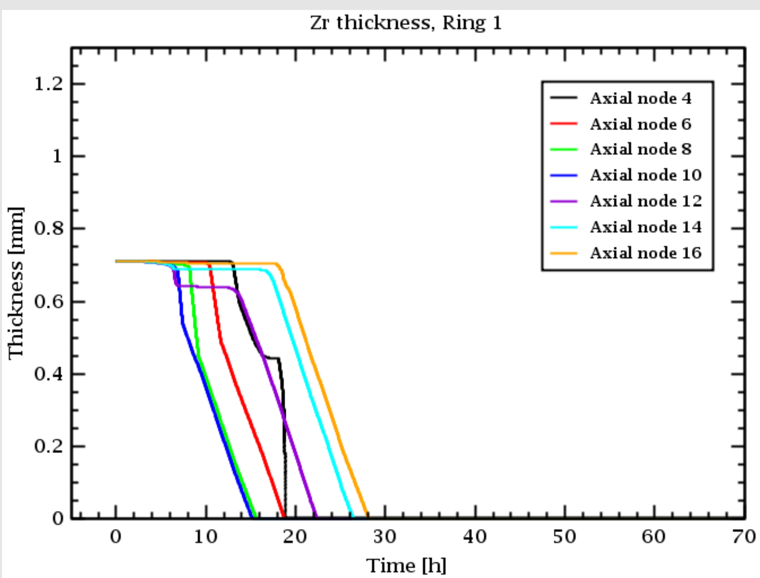
Mass loss by relocation may explain the different thickness of the oxide layer after full oxidation.

The zirconium fire firstly propagates downwards and then, after complete oxidation of the zirconium, upwards again.

After about three days all the zircaloy was oxidized.

Sandia Fuel Project Phase II





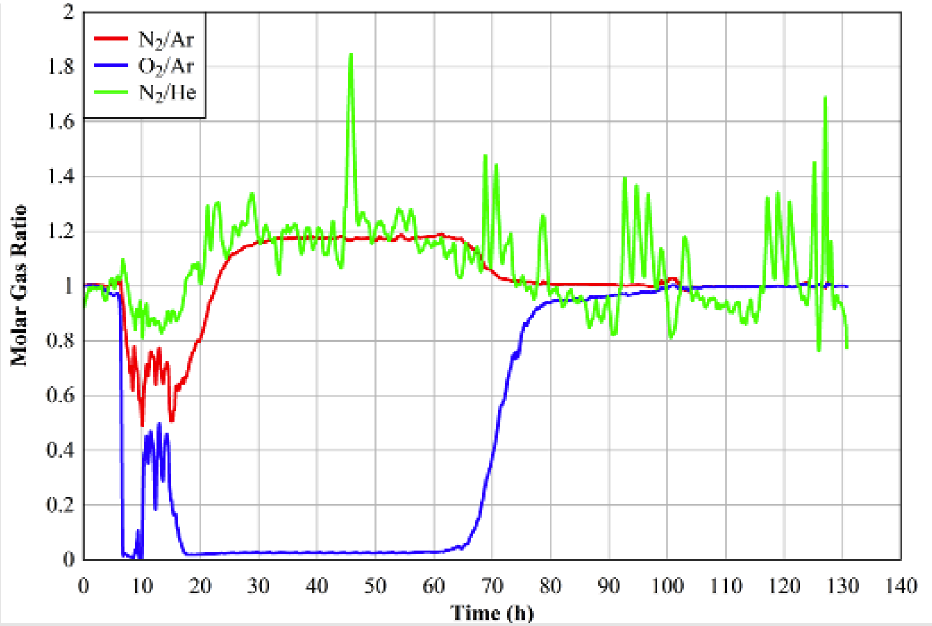
In contrary to the MELCOR calculation without nitriding model, the metal is completely consumed after about 30 hours.

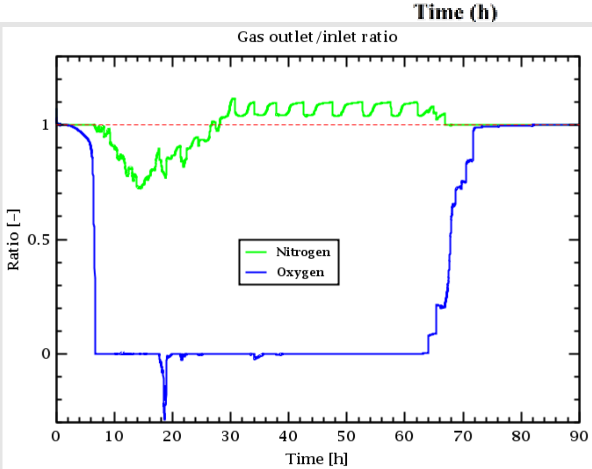
All the remaining metal in the center region of the heated fuel element is nitrided.

After metal consumption the zirconium nitride is re-oxidized.

Limiting factor of the re-oxidation is the air flow through the bundle.

Sandia Fuel Project Phase II





The relative gas composition at the outlet of the centered bundle is calculated as normalized ratio between the reacting gases and argon from the experimental data.

This is compared with the ratio of outlet and inlet mass flow calculated from the MELCOR code.

The qualitativly good estimation shows the capability of the nitriding model to describe the chemical behaviour of the zirconium during the SFP experiment.

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Conclusions

- **Cold neighbor strategy is a good possibility for storage of spent fuel**
- **Ignition of zircaloy cladding in air happens at temperatures above 1200 K**
- **Nitriding model calculates reasonable behavior during oxidant starvation**
- **During hot neighbor strategy half of the decay heat reaches for cladding ignition in air**

Questions?