VVER-440/213 MELCOR COR model for Gd2M fuel

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Content

- Main differences in Gd2M fuel design
- Comparison of the old and new COR input model
- Examples of results — differences due to changes in the input model options
- Conclusions

Main differences in Gd2M fuel design

- increased total UO_2 mass
  - increased length of fuel column (∼6 cm) in the fuel assembly:
    fuel column as well as fuel rod extended downwards at the expense of lower assembly head
  - increased length of fuel column (∼4 cm) in the movable tandem control and fuel assembly :
    fuel column extended upwards at the expense of the steel cylindrical spacer above the fuel column, fuel rod length remained same

  ⇒ in reactor shutdown configuration vertical space above the top of the active fuel column in the movable fuel assembly and the bottom of fuel column in the fuel assembly decreased
- thickness of canister of movable absorber assembly was decreased
- other changes of minor importance for severe accident simulation

VVER-440/213 MELCOR COR model for Gd2M fuel

Our existing MELCOR 1.8.6 COR model for Gd1 fuel type, prepared in ∼2008:

- was based on previous model for 1.8.5 — only formal conversion and changes in nodalization by recalculation of original data.
- was primarily designed to test new models in 1.8.6: molten pool in the lower head and lower head wall damage with/without IVR

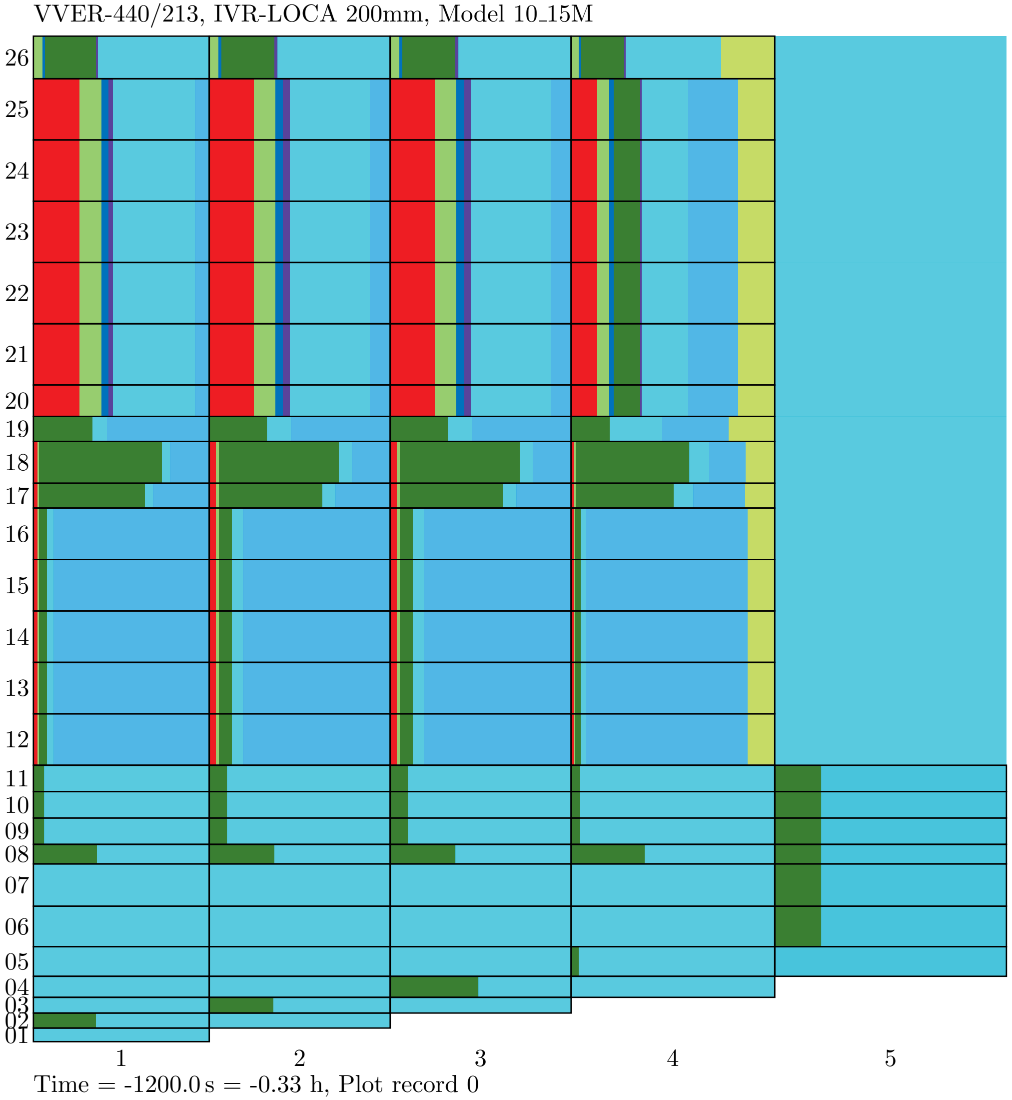
New model for Gd2M fuel was prepared with simplifying assumption:

- short term IVR is always successful when:
  - it is implemented after successful primary depressurization
  - and enough coolant inventory is provided to the reactor shaft

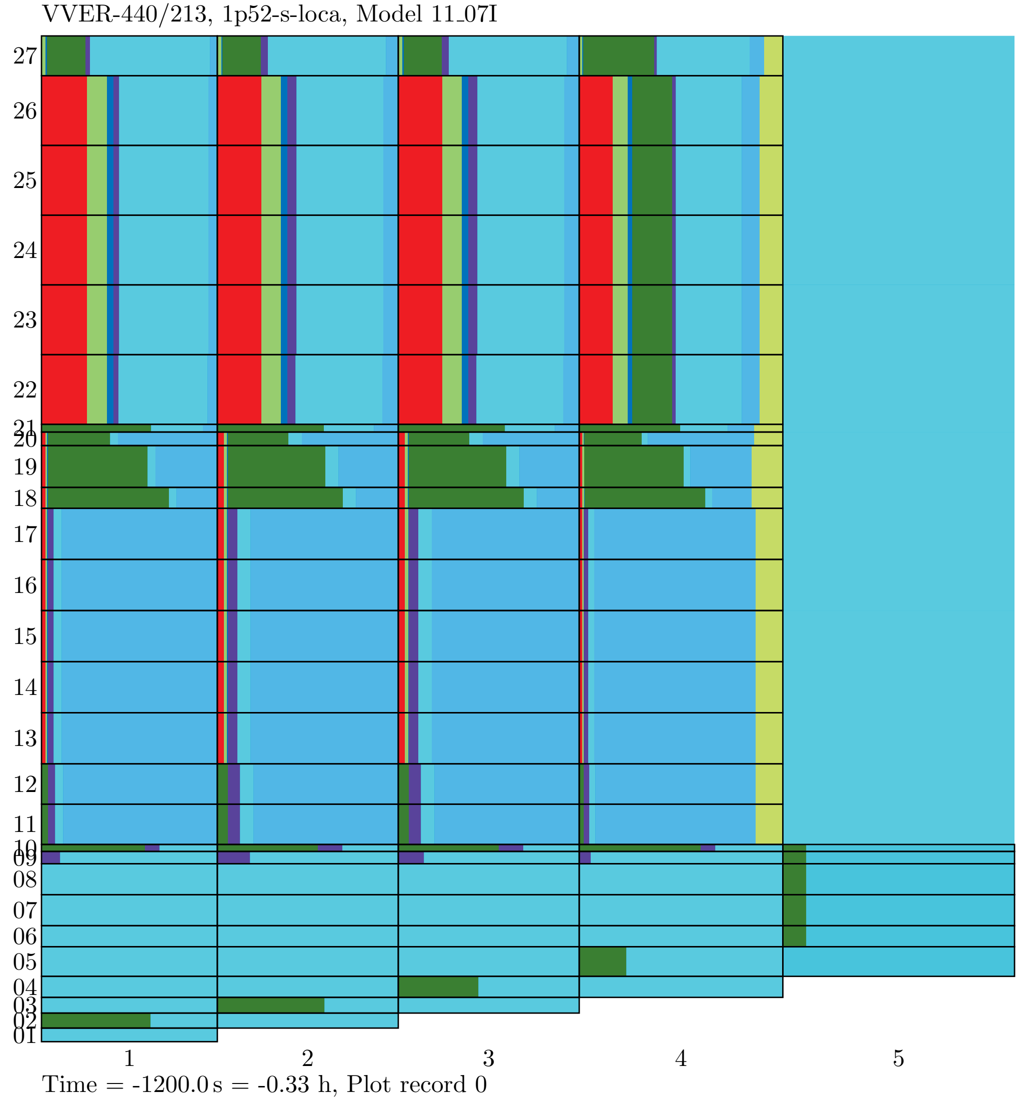
⇒ different approach to lower plenum height dilemma in the old and new input model
⇒ new input model developed from scratch:

- more detailed modeling of coolant inlet to movable assemblies
- more detailed model of protective tubes of movable assemblies
- grid supporting movable assemblies modeled as PLATE
- more detailed model of core support structures

VVER-440/213 MELCOR COR model for Gd2M fuel



Old Gd1 model



New Gd2M model

Schemes of **initial** component volume fractions in COR cells (COR-VOLF)

Color key: fu cl cn ss ns pb pd mb1 mp1 mb2 mp2 flc flb hs

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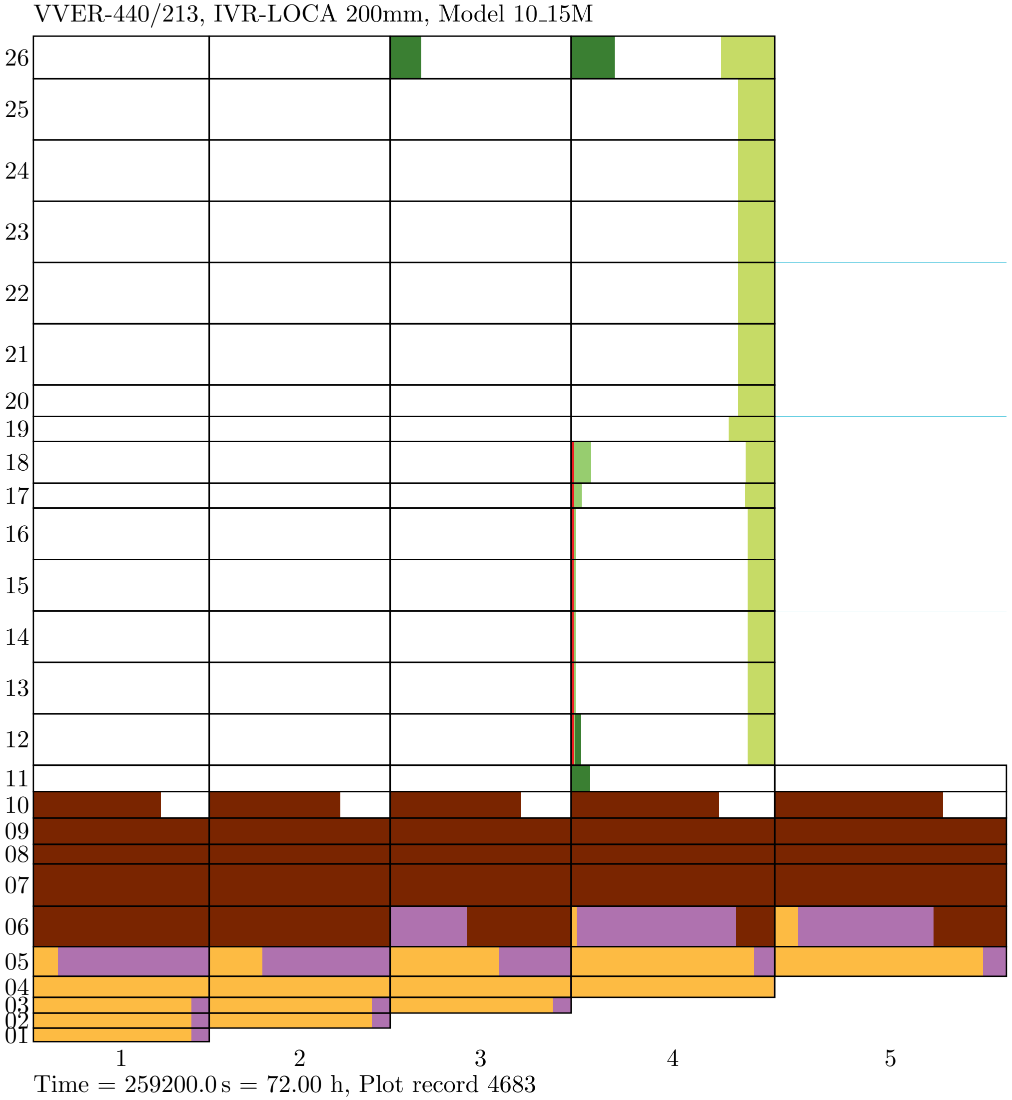
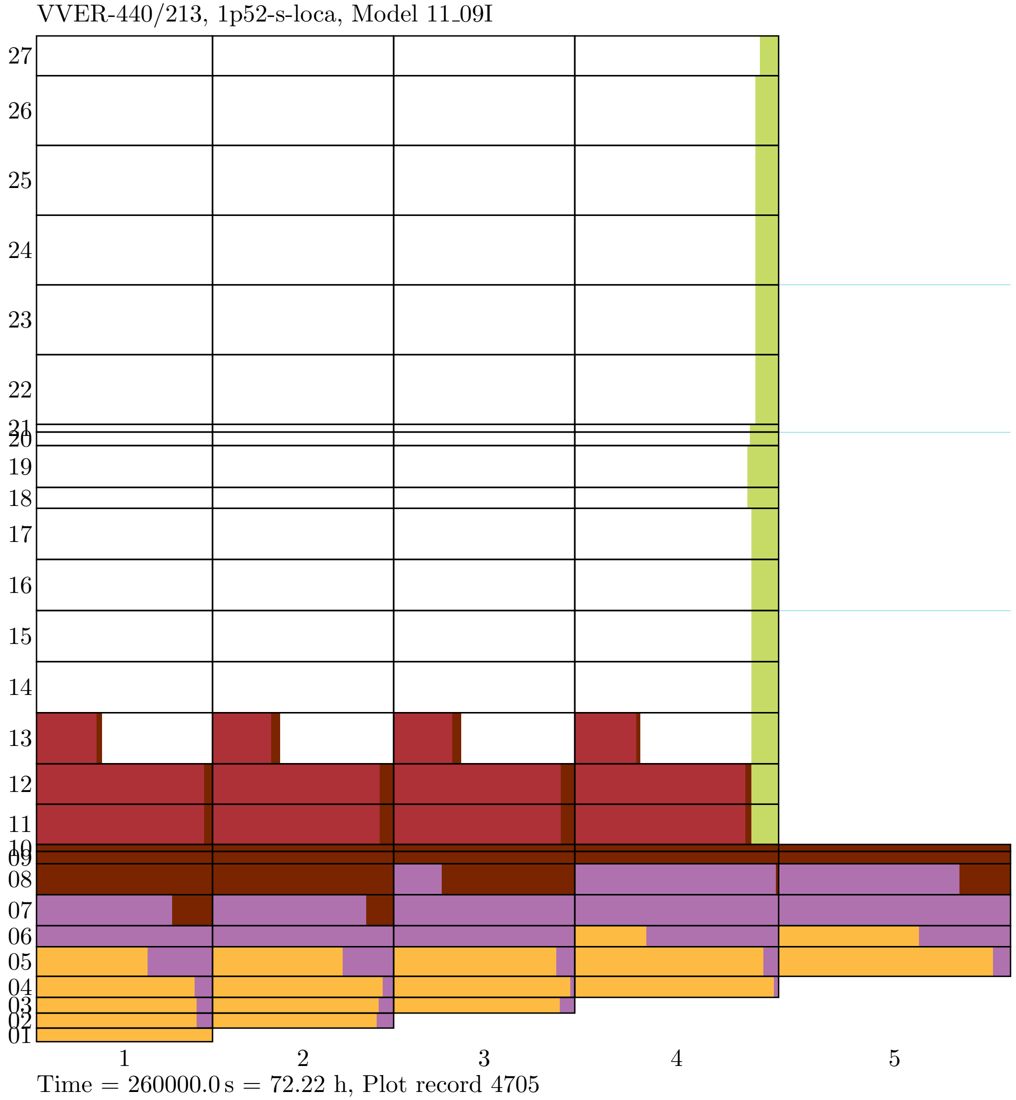


Old Gd1 model



New Gd2M model

5

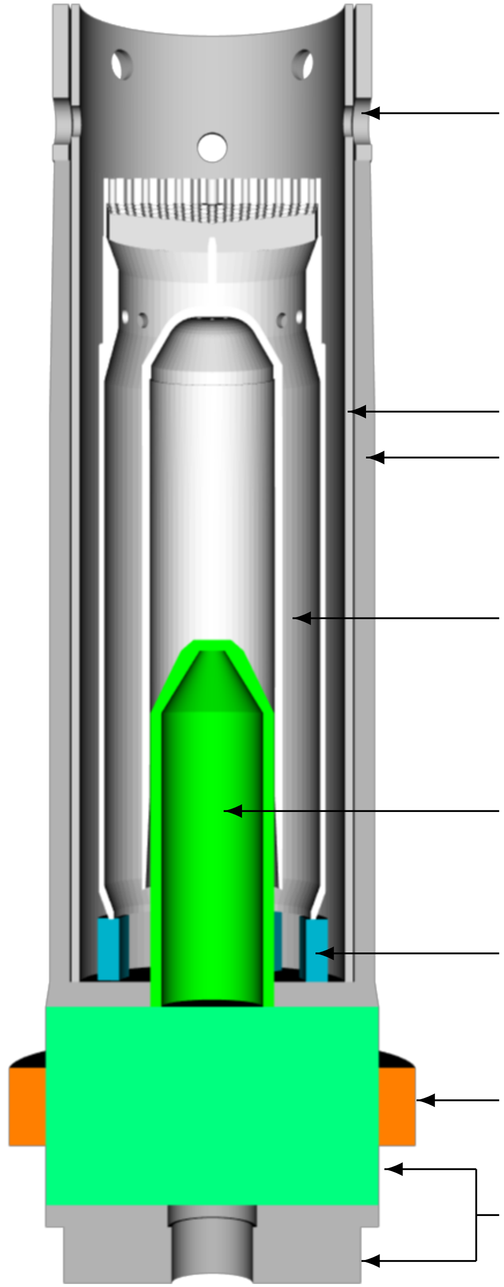
Schemes of **final** component volume fractions in COR cells for a scenario with **IVR**

Color key: fu cl cn ss ns pb pd mb1 mp1 mb2 mp2 flc flb hs

Detailed modeling of coolant inlet to movable assemblies (see figure at right)

- Old model - simple vertical flow-path from the bottom
- New model - horizontal flow path at elevation of holes in the protective tubes

Influence on simulated scenario — negligible (or obscured)



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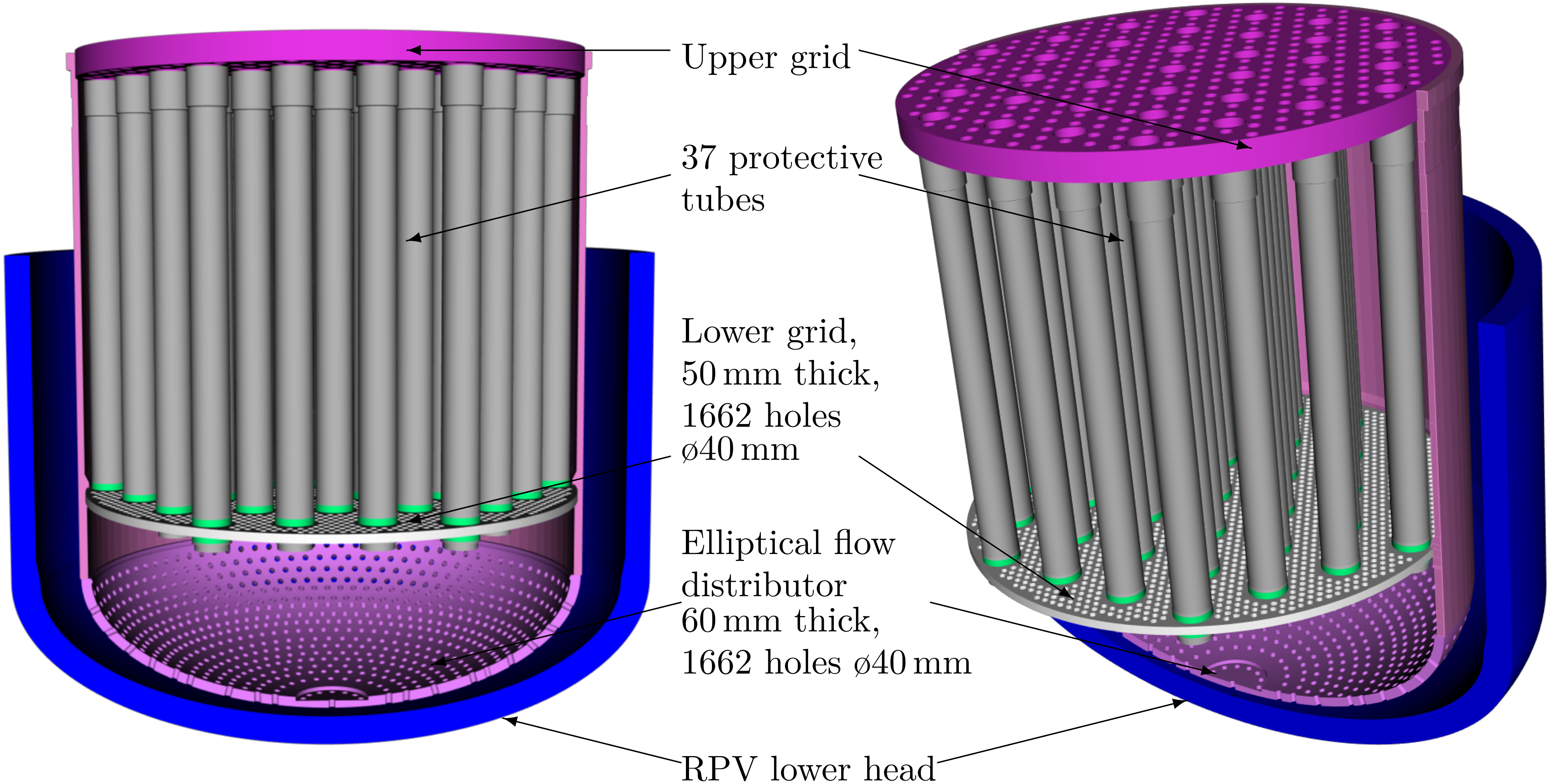
3D VTK model of the VVER-440 core barrel bottom and protective tubes

(there are 37 protective tubes for movable assemblies, there are 312 fuel assemblies in the core above)



Model of the core barrel bottom lower grid (grid supporting movable assemblies)

- Old model — user defined SS, failure criterion 1200 K, only self-support
- New model — PLATE type SS

Influence on simulated scenario — only about 3/4 h delay in the lower head failure for a low pressure scenario, but very large difference in the relocation process.

- Old model
  - melt and debris simply pass through the grid even when covered by liquid coolant (something like that occurred at TMI-2)
  - melt and debris are allowed to spread radially in the lower plenum
  - SSs in the lower plenum become embedded into debris/pool and subsequently fail by over-temperature
- New model
  - melt and debris are collected on the grid
  - melt and debris are stacked in the single ring

  ⇒ degradation of protective tubes and fuel followers is much faster

  ⇒ it may contribute to excessive oxidation of steel protective tubes (following slide)

  ⇒ relocation causes large pressure peaks, causing e.g.: lower head failure at IVR due to overpressure (at PPFAIL≤22 MPa in MELCOR, though 50 MPa static pressure limit was considered for AP600, Theofanous 1999)

Detailed model of protective tubes of movable assemblies

- Old model - movable assembly canister and protective tubes are lumped to single SS (containing both Zr and stainless steel mass)
- New model - canister is simulated by canister, protective tubes by NS (containing only stainless steel)

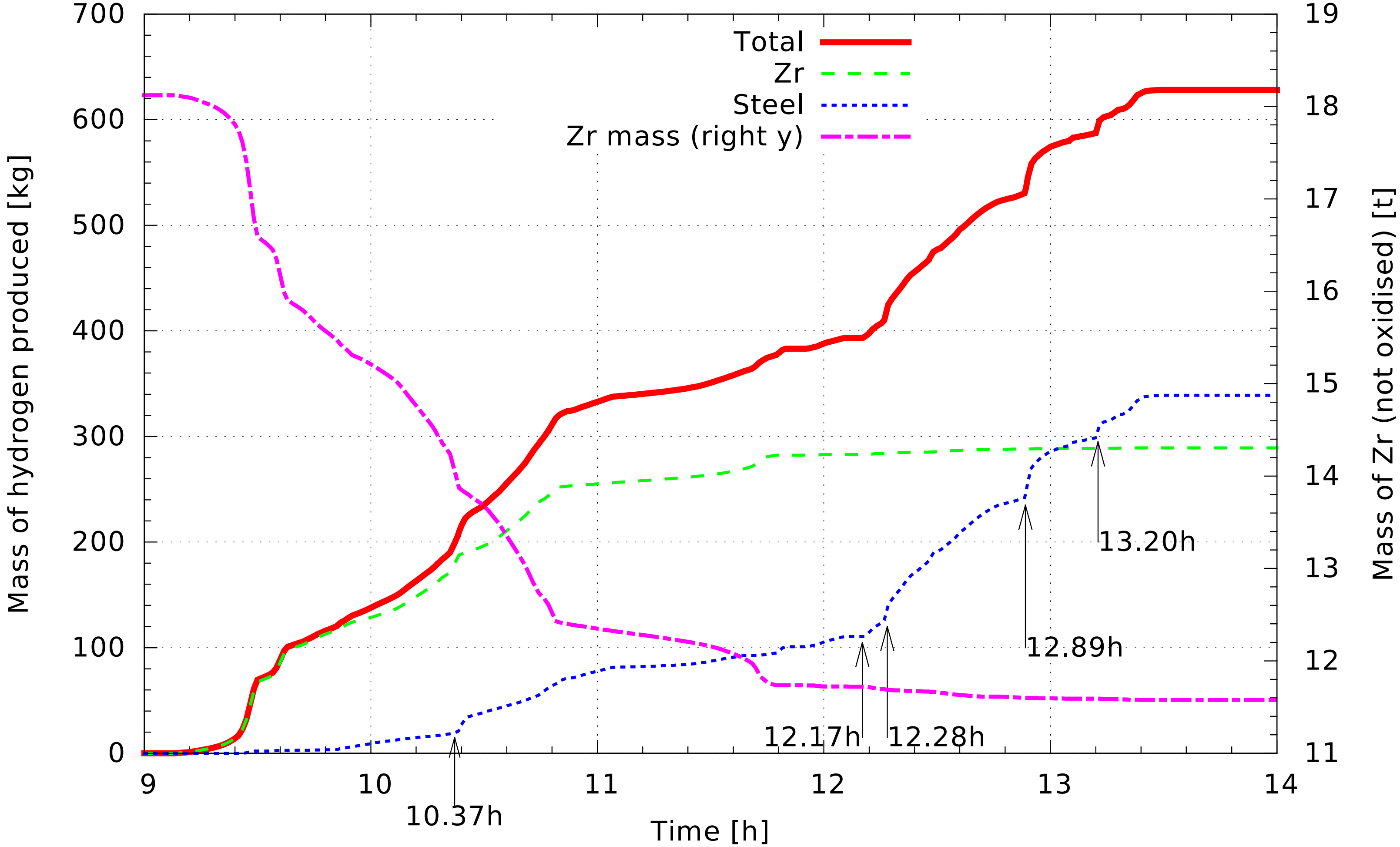
Influence on simulated scenario — very large difference in steel oxidation (if it is not caused by something else):

- Old model
  - hydrogen production from steel oxidation usually in range 20% – 25% of hydrogen production from Zr oxidation
  - both Zr and steel oxidation has similar timing
- New model
  - in some cases hydrogen production from steel oxidation exceeds that from Zr
  - steel oxidation is very fast and occurs when Zr oxidation had already ceased

⇒ these results are quite doubtful, fortunately steel oxidation has low impact on overall conclusions for the simulated scenario:

  * produced oxidation heat is small to influence progress of the core degradation
  * hydrogen risk for the containment is suppressed by installed PARs anyway

Example results of hydrogen production during small break LOCA



After 12 h, there is still more than half of original Zr inventory not oxidized, nevertheless Zr oxidation is negligible. Why is the steel oxidation so intensive? Core degradation events can be attributed to increase of oxidation rate (next two slides).

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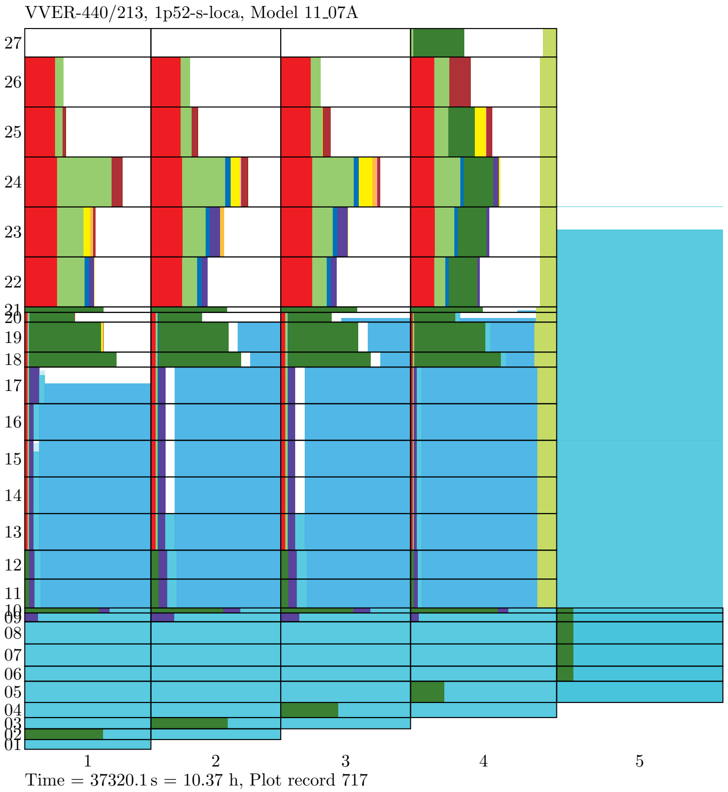
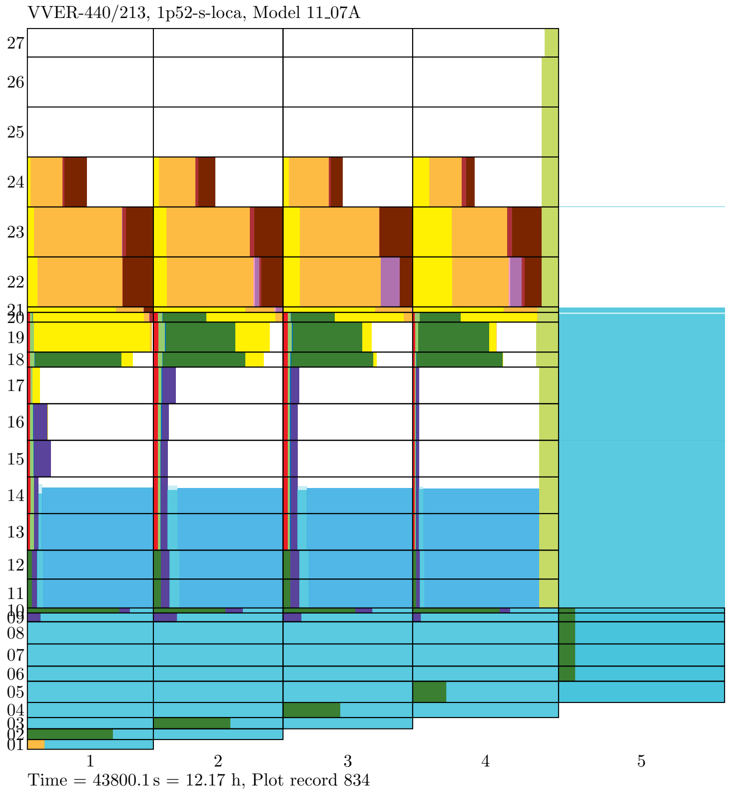
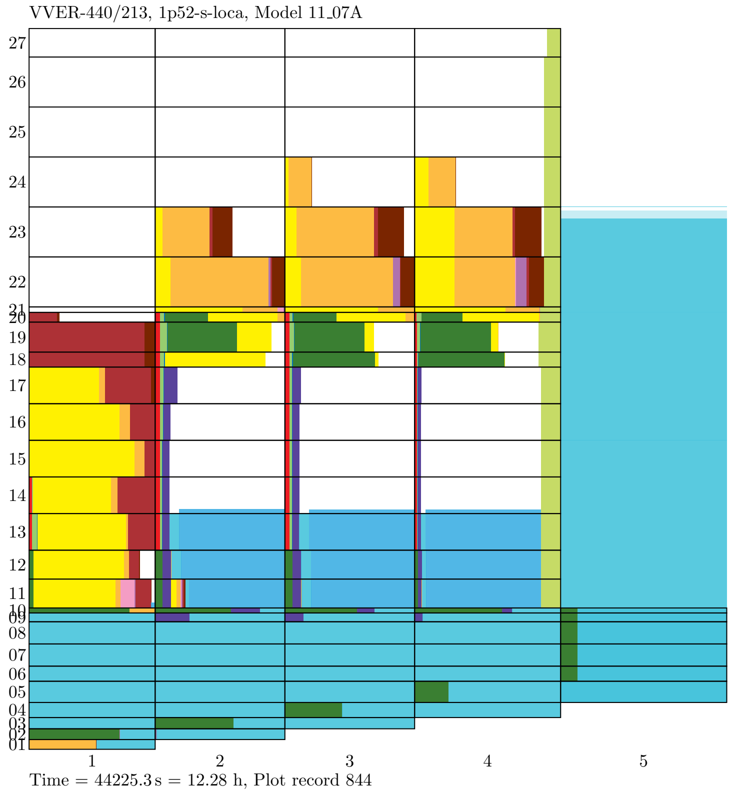


10.37 h
Start of candling on protective tubes in the first ring



12.17 h
Just before the core support grid failure



12.28 h
Relocation towards lower grid in the central ring complete

Color key: fu, cl, cn, ss, ns, pb, pd, mb1, mp1, mb2, mp2, flc, flb, hs

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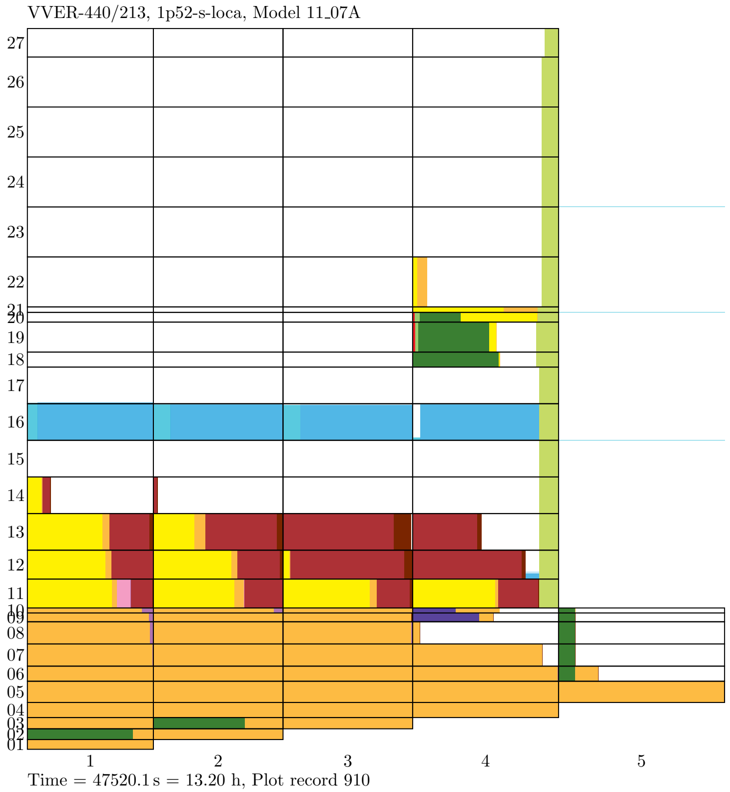
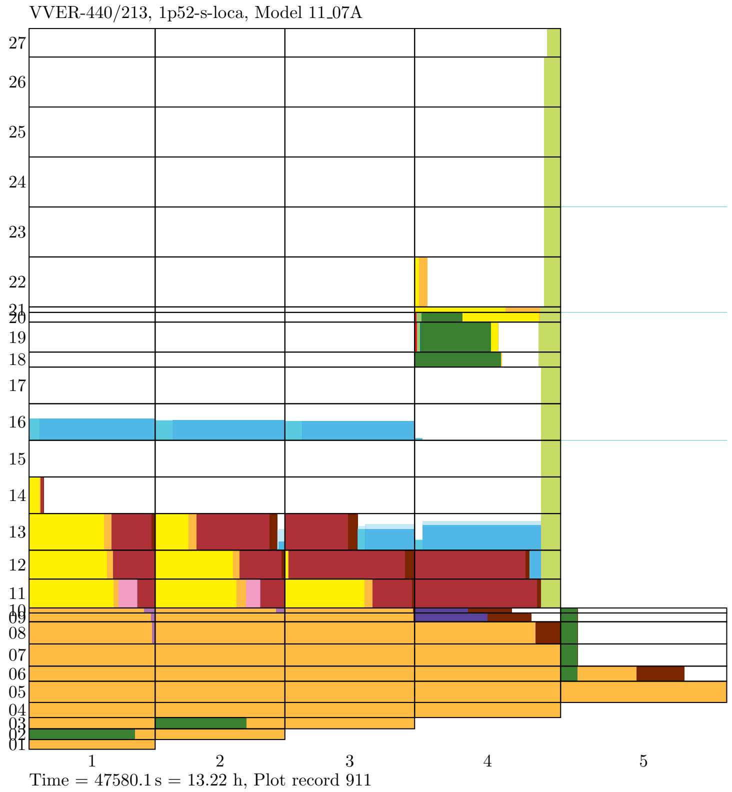
12.89 h
Just before the lower grid failure in the central ring



13.21 h
Just before the lower grid failure in the peripheral ring



13.22 h
Just after the lower grid failure in the peripheral ring

Color key: fu cl cn ss ns pb pd mb1 mp1 mb2 mp2 flc flb hs

Conclusions

Significant influence of certain input model options on simulated VVER-440 core degradation was found:

- support characteristics of the core barrel bottom lower grid for melt and debris

  this uncertainty is related to stochastic character of core degradation as the relocating material can be both:

  - melt with ability to penetrate steel plates and to flow on the surface of (and through openings in) steel constructions submerged in the liquid coolant (that is what happened during the TMI-2 accident)
  - debris bed of fragments larger than holes in the grid (ø40 mm)

- radial transport of debris and melt in the space among protective tubes

  it seems more likely that debris would relocate radially

- difference in (steel) oxidation of protective tubes when simulated by SS or NS

  excessive steel oxidation (possibly coming from NS) is caused by an error?

Thank you for your attention

Any questions? (anwers?)