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PSI air oxidation model in MELCOR: Part 1: Implementation and verification

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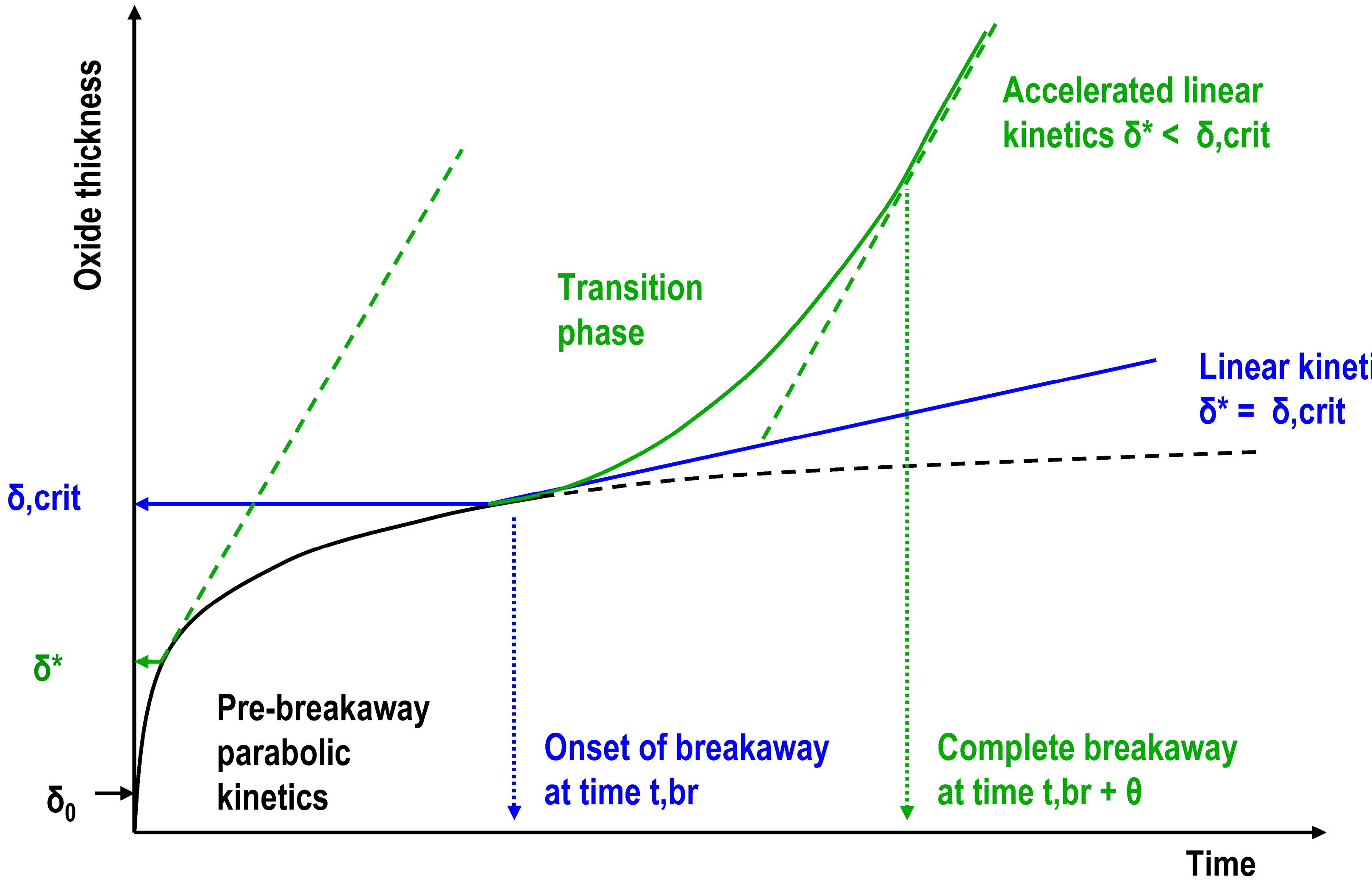
Outline

- Recap of model concept
- Implementation challenges
- Verification studies
- Other items

Model concept



Implementation challenges

- It looks simple, just set an upper limit to oxide layer protectiveness, “breakaway”
  - define a time constant for the transition to linear
  - do it separately for steam and air
  - MELCOR already recognises oxygen as an active species
- Must be able to handle changes in temperature and composition
  - necessary to include coding to manage transitions in gas environment, etc
  - take account of past oxidation history
- Difficulties because MELCOR uses mass gain and a constant user-defined surface area, whereas the model was written to use oxide thickness on a cylindrical cladding and a changing area
- With the coding performed by IBRAE and testing by PSI we got it done (at last)
- Must give same results as standard MELCOR when breakaway turned off and expected breakaway behaviour when it is turned on

Implementation features

- Special version of MELCOR: option of PSI or Sandia model (card CORPSI)
  - PSI model on: option to apply breakaway
    - both steam and air, only air, neither
  - PSI model on: options for to base on different kinetic parameters
    - Urbanic-Heidrick, Cathcart-Pawel, etc
    - default in steam: Cathcart-Pawel/Urbanic-Heidrick
    - default in oxygen: Uetsuka-Hofmann/Cathcart-Pawel/Urbanic-Heidrick
    - sensitivity cards for alternative user-specified kinetic parameters
- Precedence: oxidation by steam only if oxygen starved
- Kinetics modified according to presence/absence of nitrogen (not oxygen)
  - nitrogen not consumed
- At present applies only to intact cladding
  - in principle could apply to also intact guide tubes, channel boxes, etc

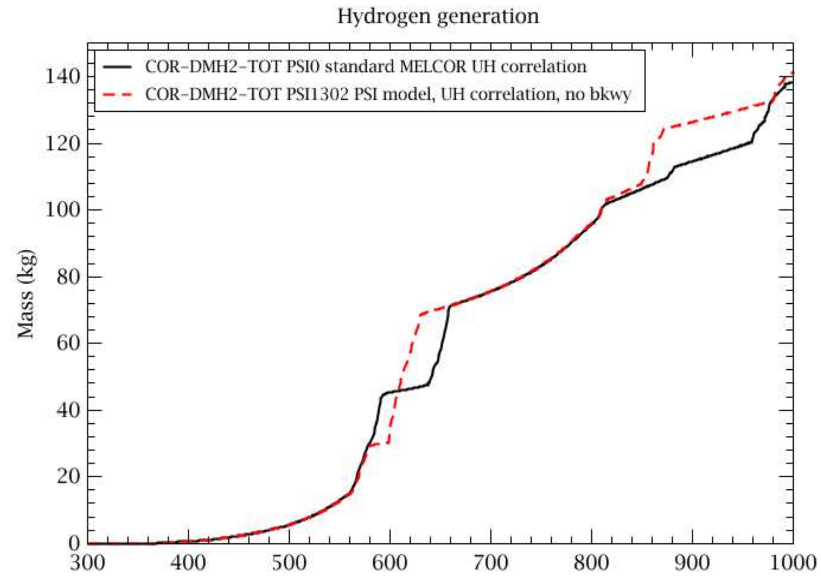
Verification studies

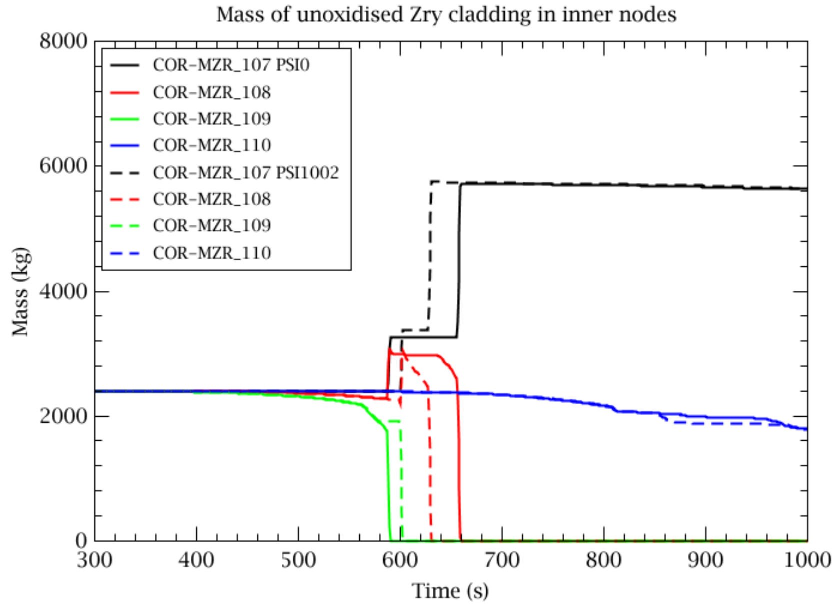
- Now implemented in trial versions of MELCOR 1.8.6 and 2.1
- Calculations for selected cases
  - simulation of conceptual sequence
  - simulations of idealised experimental conditions
- BWR SBO sample problem
- QUENCH-10, -16 (air ingress experiments)
- SFP heat-up

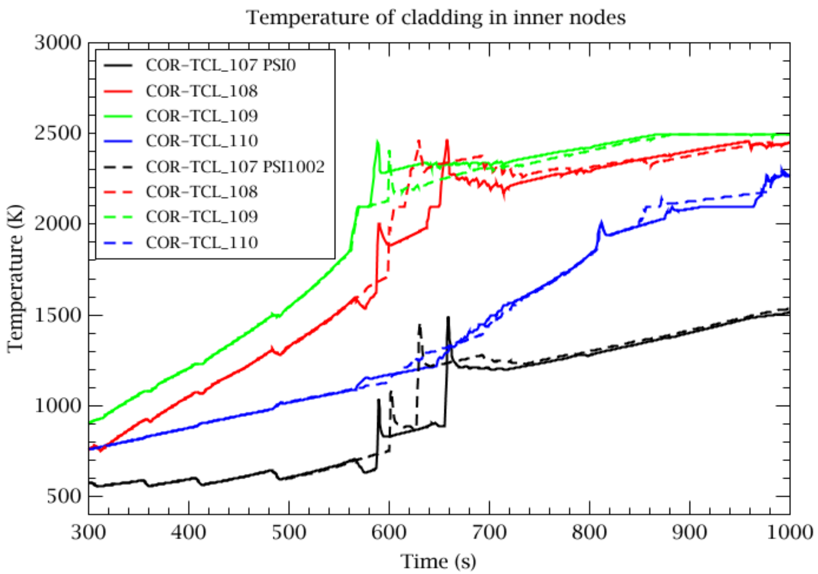
Standard and PSI model comparison

- PSI0 → PSI model not chosen, standard MELCOR model used
- PSI1000 → PSI default model chosen (breakaway in steam and air)
- PSI1001 → PSI default model chosen (breakaway in air)
- PSI1002 → PSI default model chosen (no breakaway)
- Kinetics
  - steam: Cathcart-Pawel/Urbanic Heidrick
  - oxygen: Hofmann-Uetsuka/Cathcart-Pawel/Urbanic-Heidrick

BWR SBO sample problem (steam)





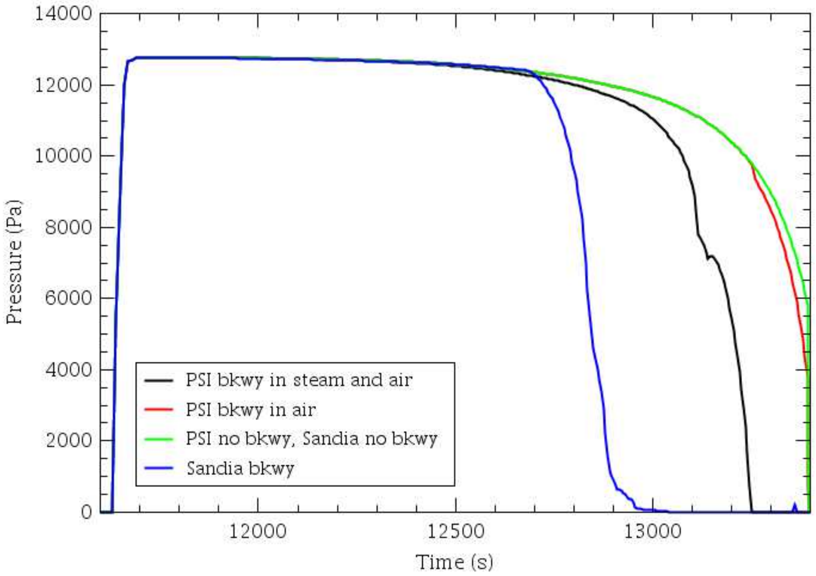


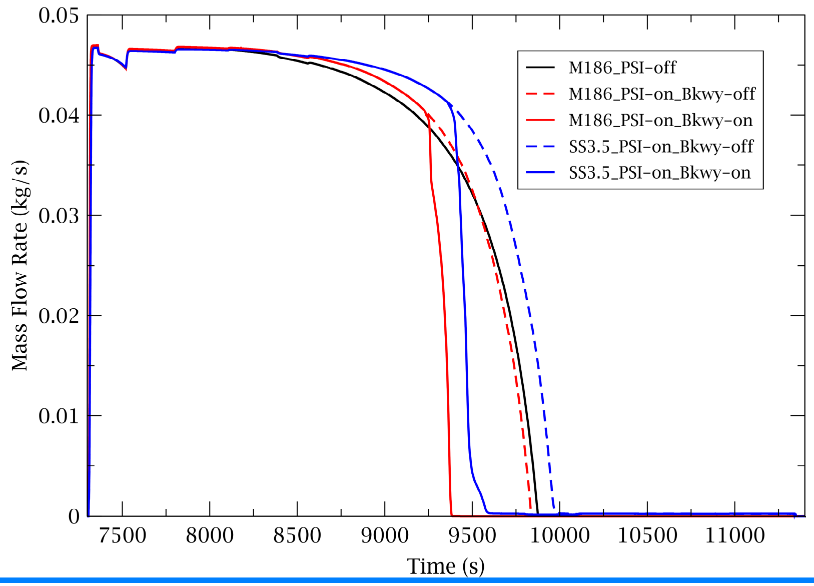
Before degradation, temperatures and oxidation are reproduced by the PSI model: same kinetics (Urbanic-Heidrick) and breakaway turned off

Minute differences in the coding result in timing differences once degradation starts

Core boundary conditions not fixed: relief valve cycling, etc

QUENCH-air simulation





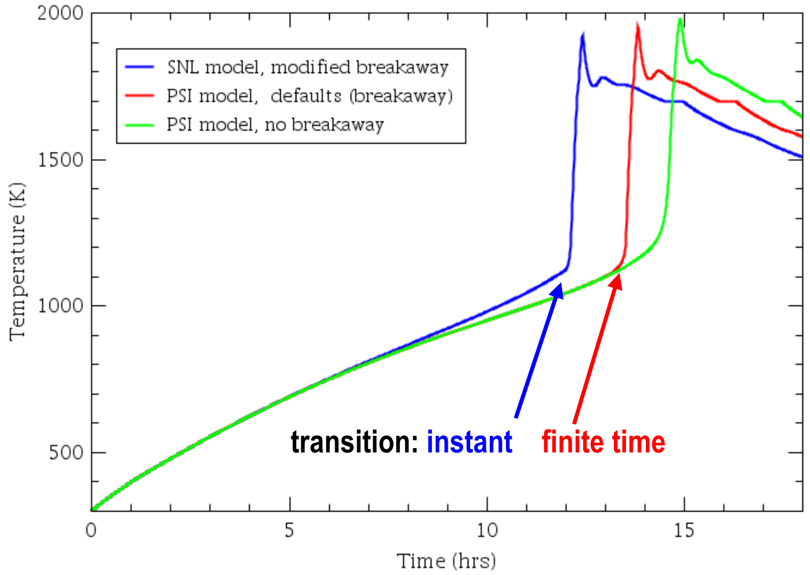
Calculated oxygen consumption in QUENCH-10, comparison of breakaway oxidation options

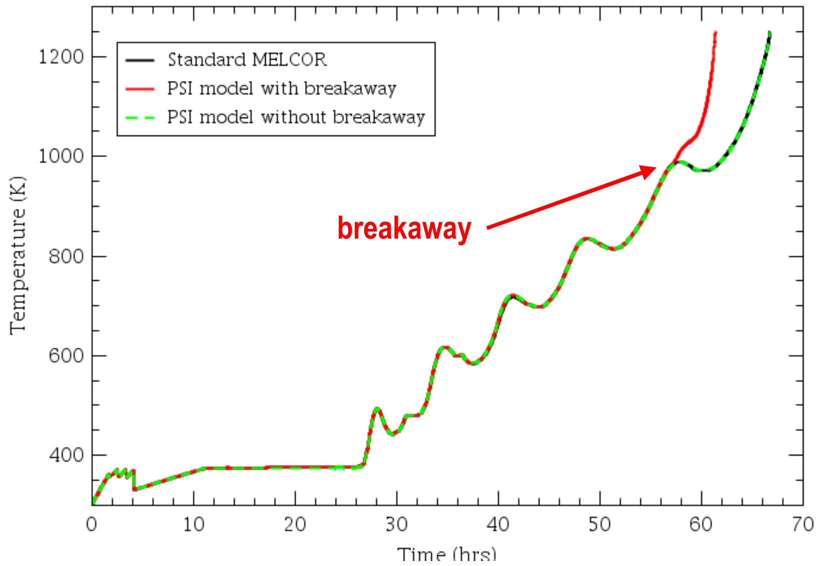
- PSI steam and air
- PSI air
- PSI and Sandia, no breakaway
- Sandia breakaway

Calculated oxygen consumption in QUENCH-16, code-code comparison for PSI breakaway oxidation in air

- MELCOR standard
- MELCOR PSI model: breakaway on/off
- SCDAPSim PSI model: breakaway on/off

SFP heat-up





Breakaway observed during heat up in dry air

Simulated sequence similar to SFP phase I
- PSI model breakaway off
- PSI model breakaway on
- Sandia breakaway model

Minor differences in pre-breakaway kinetics

Post breakaway temperature ramp controlled by oxygen availability

Boildown of SFP

Breakaway in steam is not observed above 1300 K but occurs at lower temperatures important in SFP sequences
- PSI model breakaway on
- PSI model breakaway off
- standard MELCOR (no breakaway)

Availability

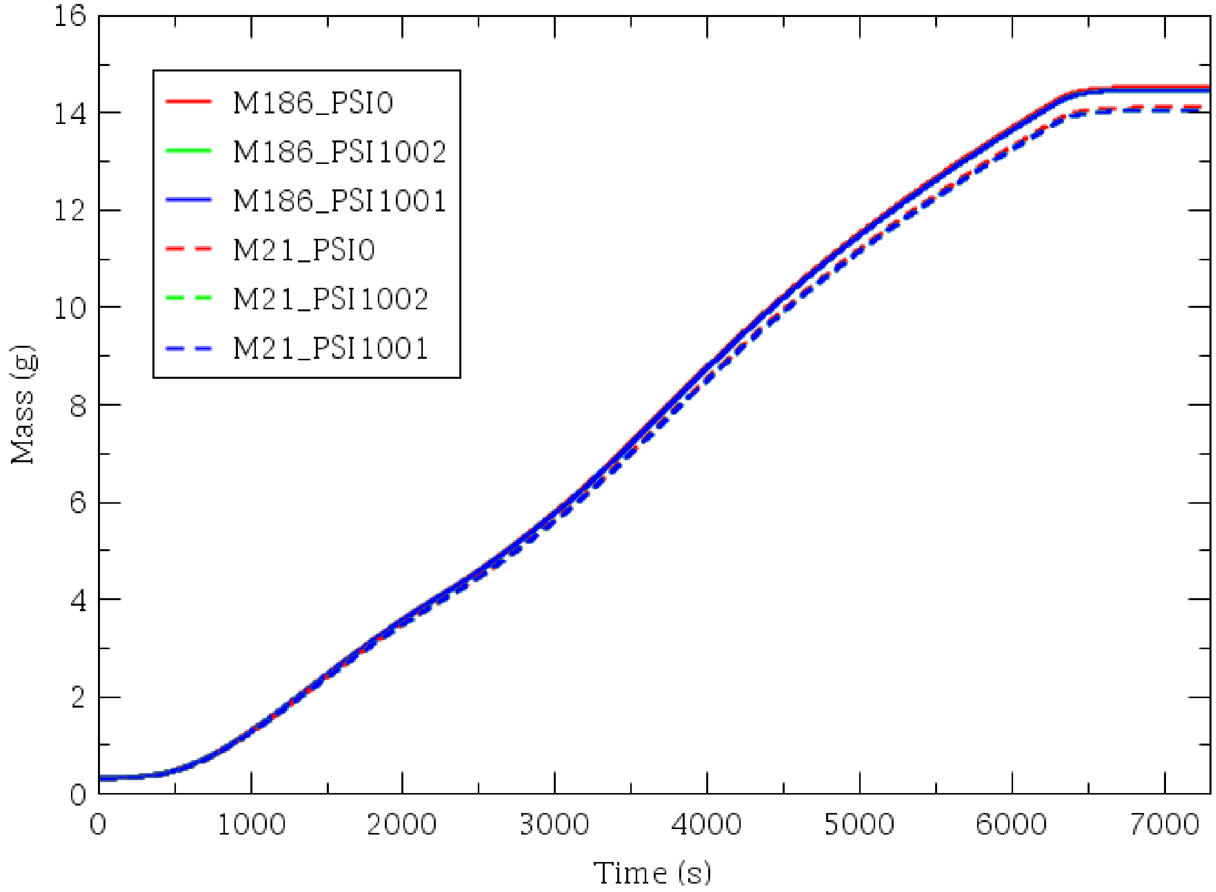
- PSI can provide executables of the modified MELCOR 1.8.6 to other users
  - Hossein, Larry is that OK with you?
  - If OK I suggest you send email request to PSI

    jonathan.birchley@psi.ch
  - and copy to USNRC and SNL
  - PSI will make essential corrections as needed
  - PSI does not undertake to provide user support

MELCOR 1.8.6/2.1 comparison

- QUENCH-16
- Code versions compared
- Models as before
  - PSI0
  - PSI1002
  - PSI1001

Steam preoxidation

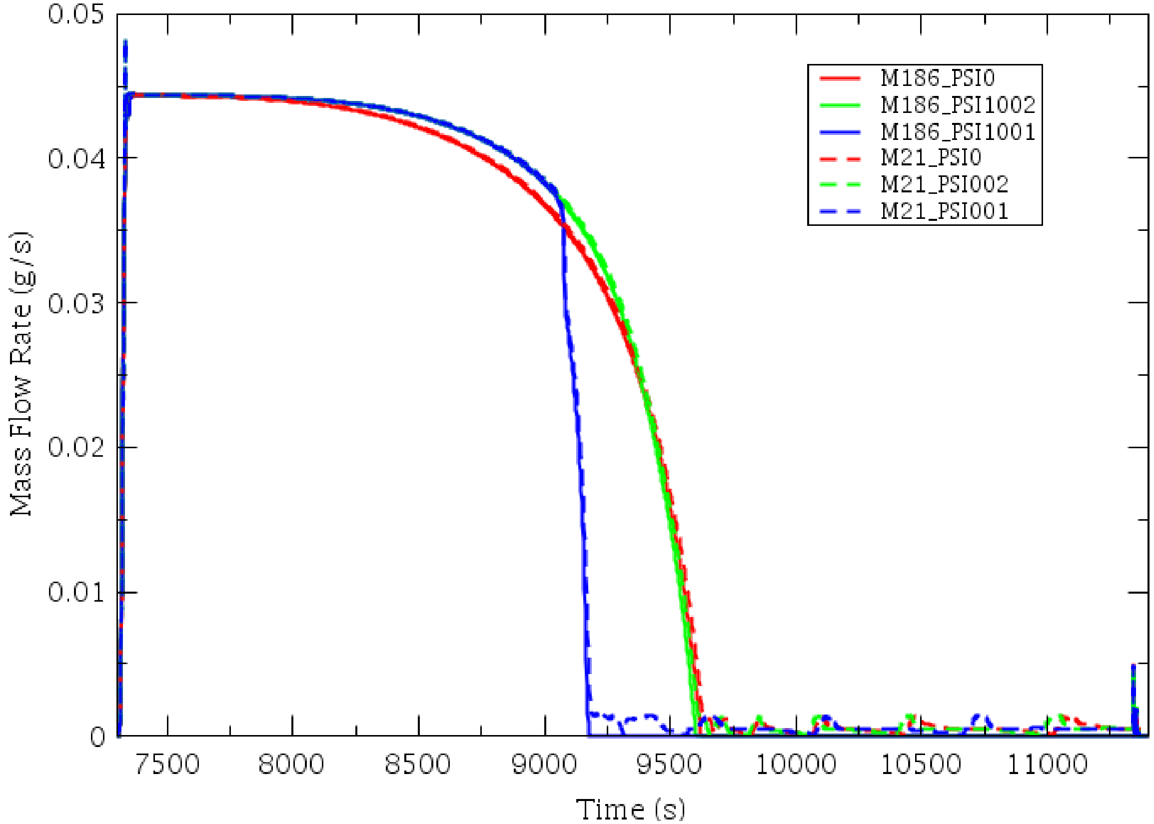


Standard (PSI0), PSI without breakaway (PSI1002), with breakaway in air(PSI1001)

Consistent results between models

Slight difference between 1.8.6 and 2.1 due to difference in heater rod model

Oxygen consumption

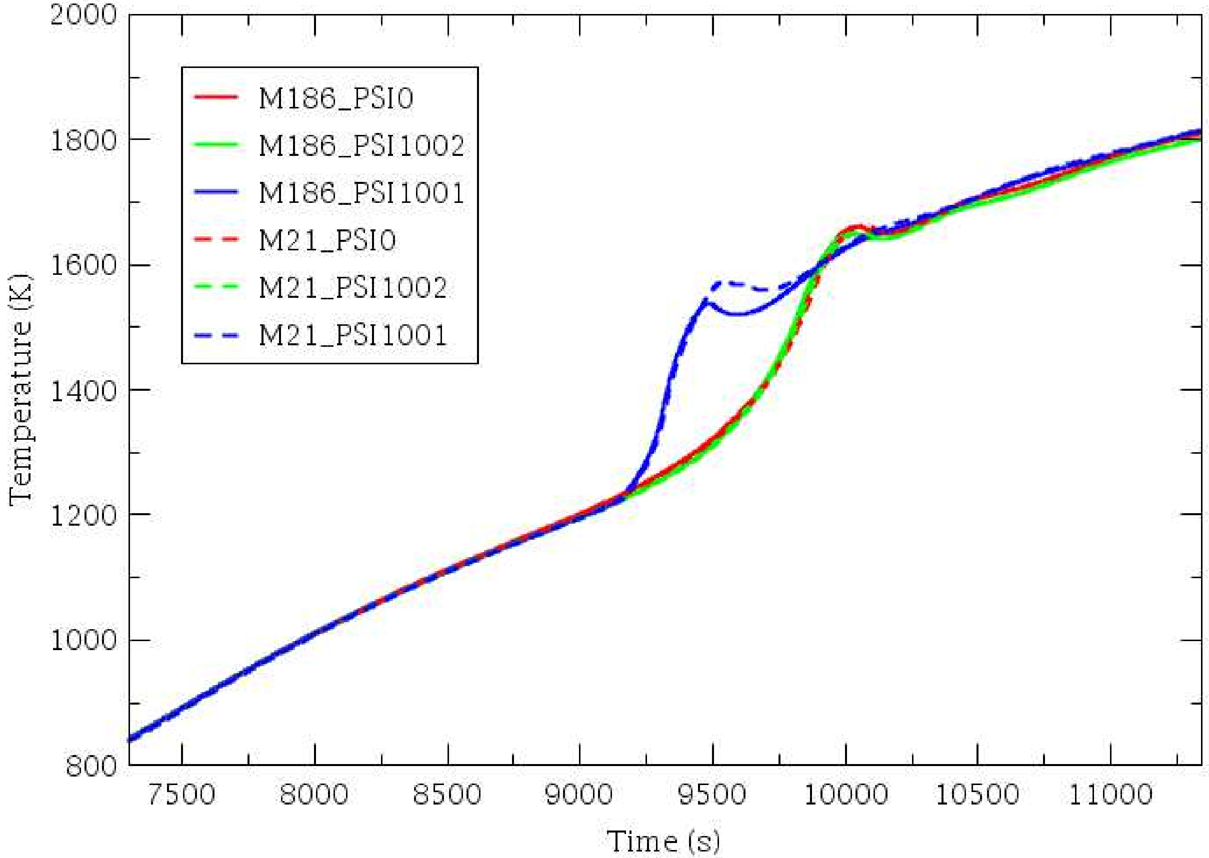


No noticeable dependence on code version

Clear effect of breakaway in air (PSI1001)

Difference between standard (PSI0) and PSI model (PSI1002) due to small differences in default kinetic parameters for oxidation by oxygen for T < 1323 K

Cladding temperature at 550 mm



Minor effect of code version

Clear effect of breakaway in air (PSI1001)

No noticeable effect of model when breakaway disabled (PSI0, PSI1002)

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Thank you for your attention

Other items

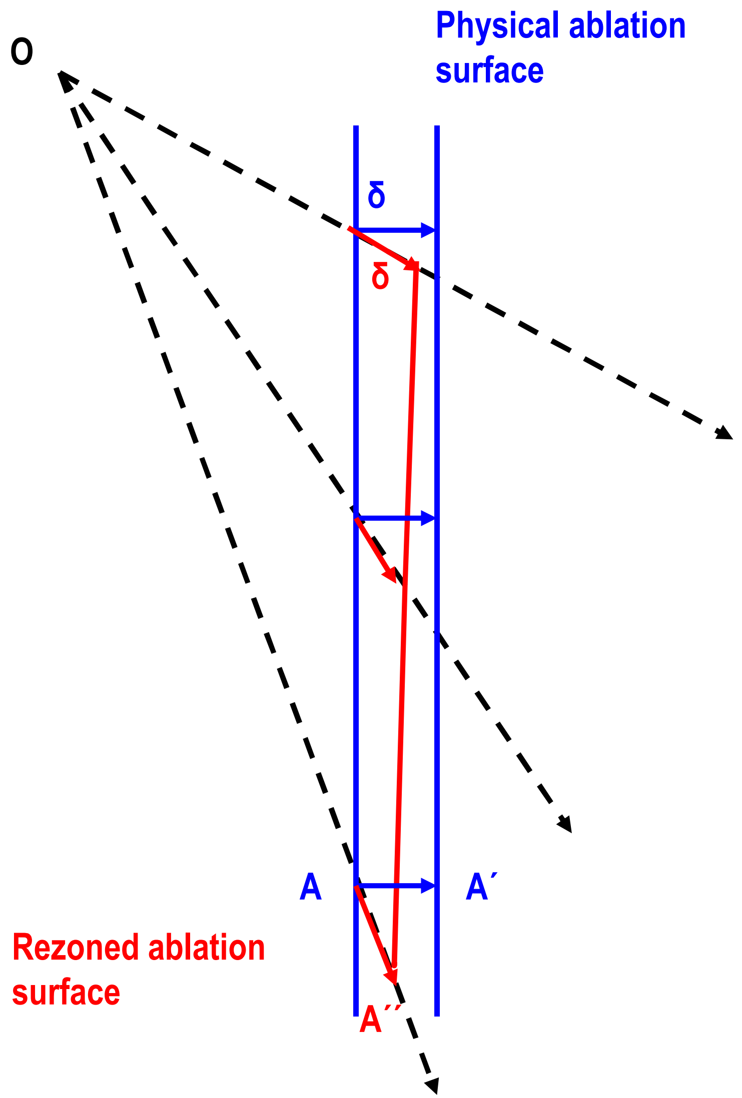
- Plot output
- Ablation surface in CORCON
- RN class 17

Other items – plot output

- The MELCOR development has moved towards making the plotfile more selective; this seems a logical development (we have cases where the .ptf is ca. 3 GB)
- Removing some "populous" quantities and allowing them to be inputs to control functions, which can then be plotted
- We encourage for making all plotfile variables also available to control function input (e.g. COR-DMH2-ZR)
- We would be sympathetic towards removing some additional variables from the plotfile, as long as they can be input to control functions

Other items – cavity erosion

- The cavity boundary is defined by points which in principle track the concrete erosion
- The User Guide states "for reasons of numerical stability" the points are rezoned onto rays from a user chosen origin
- This has the consequence that the space inside the cavity is out of step with the total amount of concrete ablated
- A vertical surface ablates δ in some time interval; the calculated surface moves back a smaller amount, so when the melted concrete is added it raises the level



Other items – RN class 17

- MELCOR 1.8.6 and 2.1 guidelines are to model all Cs that is not CsI as Cs_2MoO_4, denoted by the symbol CsM and not CsOH as in MELCOR 1.8.5
- Cs can then be a mix of class 2 (Cs ➔ CsOH), class 16 (CsI) and class 17 (CsM)
- One way of modelling is to input the inventory with as much CsI as the iodine inventory can support, and the rest as CsM (typically there is excess Mo over Cs)
- In one of our decks we do that but no class 17 Cs appears released, instead there is lots of class 2 Cs
- We find no reason for this (no Transfer Process input); maybe something in the code needs to be looked at

Other items – anomalous events

- A plant calculation gave core support failure (cell ia=17, ir= 4) at 225814 s
  - restart dump triggered
- Shortly after (226221 s) MELCOR failed – T convergence
- Restarted from 225814 s at reduced DT
- MELCOR then ran without failing
  - but calculated core support failure (cell ia=17 ir= 4) at 225853 s
- Question, did MELCOR calculate core support failure at 225814 s or not?

Other items – anomalous events

Case A:

Listing written TIME= 2.25779E+05 CYCLE= 2306624
Restart written TIME = 2.257789E+05 CYCLE= 2306624
/SMESSAGE/ TIME= 2.25814E+05 CYCLE= 2307451
COR0005: MESSAGE FROM CORE PACKAGE
CORE SUPPORT STRUCTURE (PLATE) HAS FAILED IN CELL IA=17 IR= 4
FAILURE WAS BY OVERTEMPERATURE
Listing written TIME= 2.25814E+05 CYCLE= 2307451
Restart written TIME = 2.258142E+05 CYCLE= 2307451
Listing written TIME= 2.26221E+05 CYCLE= 2315777
Restart written TIME = 2.262209E+05 CYCLE= 2315777
Calculation terminated by: COREU3 T CONVERGENCE
TIME= 2.26221E+05 CYCLE= 2315777 CPU = 2.34404E+05

Case B:

Listing written TIME= 2.25814E+05 CYCLE= 2307451
/SMESSAGE/ TIME= 2.25853E+05 CYCLE= 2309117
COR0005: MESSAGE FROM CORE PACKAGE
CORE SUPPORT STRUCTURE (PLATE) HAS FAILED IN CELL IA=17 IR= 4
FAILURE WAS BY OVERTEMPERATURE
Listing written TIME= 2.25853E+05 CYCLE= 2309117
Restart written TIME = 2.258531E+05 CYCLE= 2309117