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Wir schaffen Wissen – heute für morgen

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Influence of B_4C oxidation on transient behaviour at ACRR DF-4

OUTLINE

- Introduction
- Modelling of ACRR DF-4
- Sensitivity studies
- Conclusions
- Outlook

General Approach

- Plant analysis strategy is based on use of MELCOR as front line tool
  - MELCOR 1.8.5 has been used by PSI in applications
  - MELCOR 1.8.6 is being assessed for use as the production version
    - improved models for late phase/in-vessel retention and CRP release
  - MELCOR 2.1 is the code for future model development
    - part of 2 tier strategy (System level, subsystem/component level)
- Activities have include plant application, support to experimental programmes, code assessment and model development
- Assessment activities were performed in the frame of international collaborations: SARNET, USNRC/CSARP, ISTC, ISTP, PHEBUS FP and QUENCH

EXPERIMENT DESCRIPTION

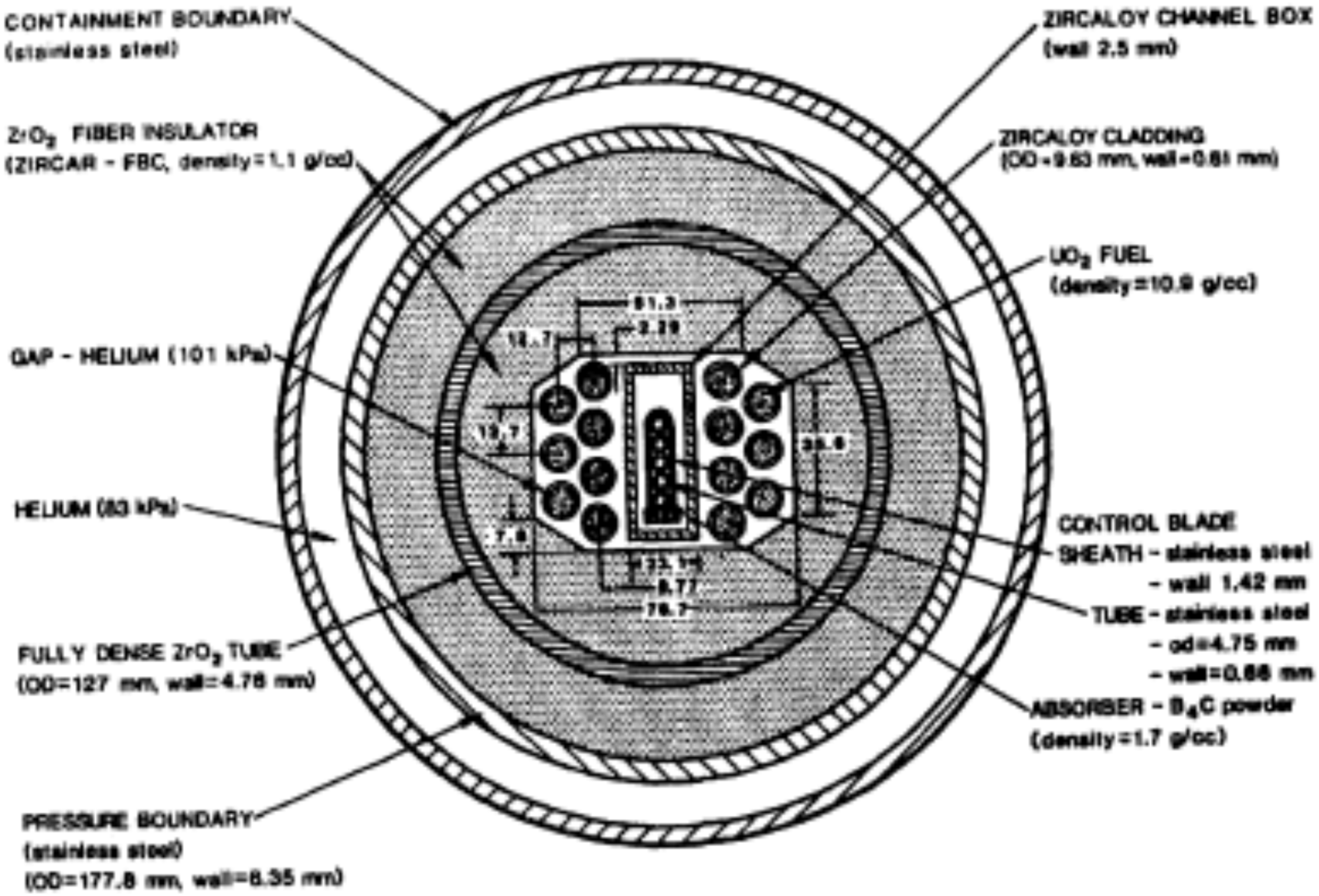
ACRR DF-4 was conducted 1986 at Sandia National Laboratories

ACRR: Annular Core Research Reactor

DF-4: Damaged Fuel Experiment Nr. 4

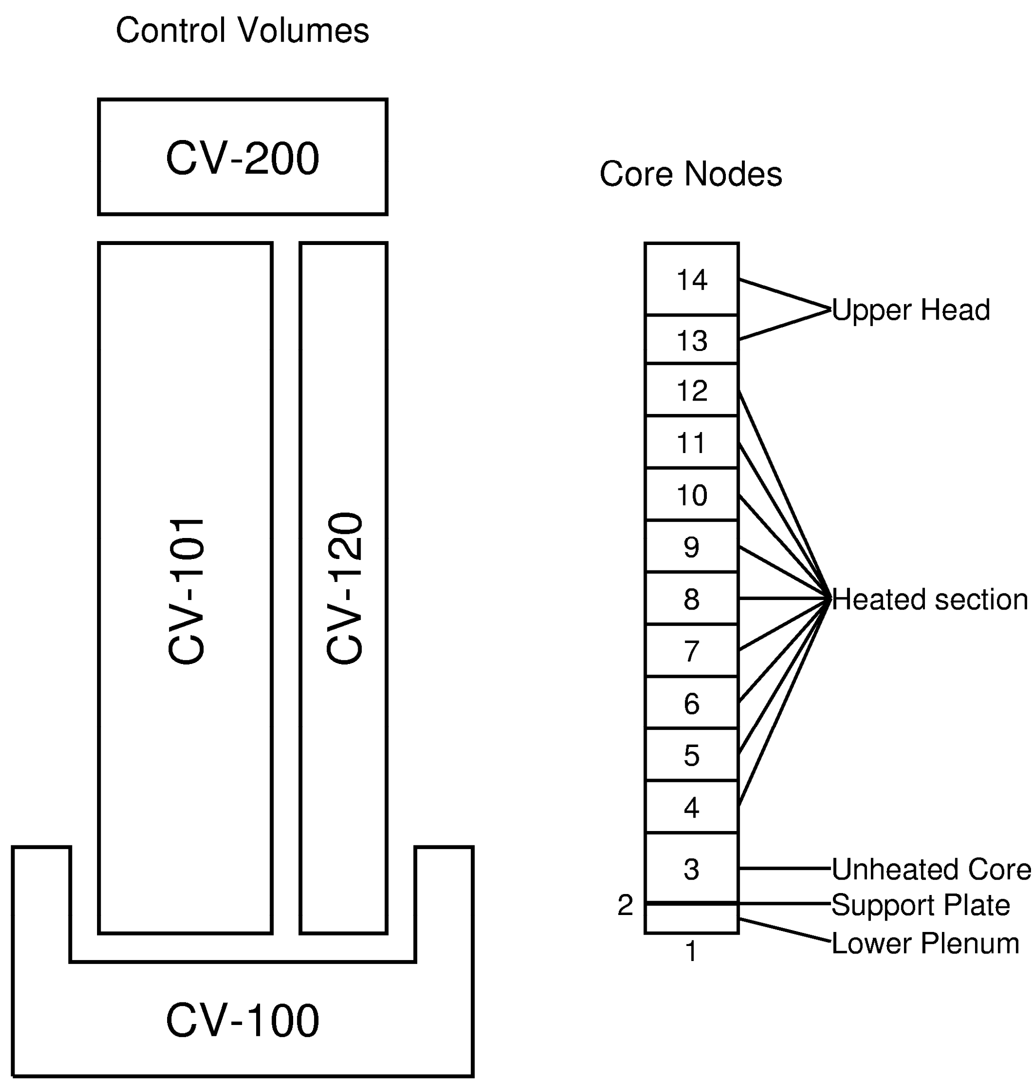
Heated height:	0.5m	Diameter:	~8cm
Nr. UO_2 fuel rods:	14		
Mass UO_2:	4.13kg		
Mass zircaloy:	1.88kg		
Mass stainless steel:	570g		
Mass B_4C:	40g	(max. Mass CO: 20g, H_2: 10g)	
Source:	SANDIA REPORT SAND93-1377 UC-610		
	MELCOR 1.8.2 Assessment: The DF-4 BWR Damaged Fuel Experiment		

ACRR DF-4



CONTAINMENT BOUNDARY
(stainless steel)
ZrO_2 FIBER INSULATOR
(ZIRCAR - FBC, density=1.1 g/cc)
GAP - HELIUM (101 kPa)
HELIUM (83 kPa)
FULLY DENSE ZrO_2 TUBE
(OD=127 mm, wall=4.76 mm)
PRESSURE BOUNDARY
(stainless steel)
(OD=177.8 mm, wall=6.35 mm)
ZIRCALOY CHANNEL BOX
(wall 2.5 mm)
ZIRCALOY CLADDING
(OD=9.63 mm, wall=0.61 mm)
UO_2 FUEL
(density=10.9 g/cc)
CONTROL BLADE
SHEATH - stainless steel
- wall 1.42 mm
TUBE - stainless steel
- od=4.75 mm
- wall=0.86 mm
ABSORBER - B_4C powder
(density=1.7 g/cc)

NODALIZATION OF ACRR DF-4



BASE CASE VALUES

- Sensitivity parameters:
- Available boron carbide fraction for oxidation (2%)
- Oxidation reaction threshold temperature (1500K)
- Reaction rate parameter (1.662E5 s-1)
- Start temperature for eutectic reaction between steel and B_4C (1570K)
- Intact steel remaining 90%
- Time step and noding

- Sensitivity study on above parameters calculated all with MELCOR 1.8.5 RD
- Using different code versions for base case calculation (1.8.5 RD, 1.8.6, 2.1)

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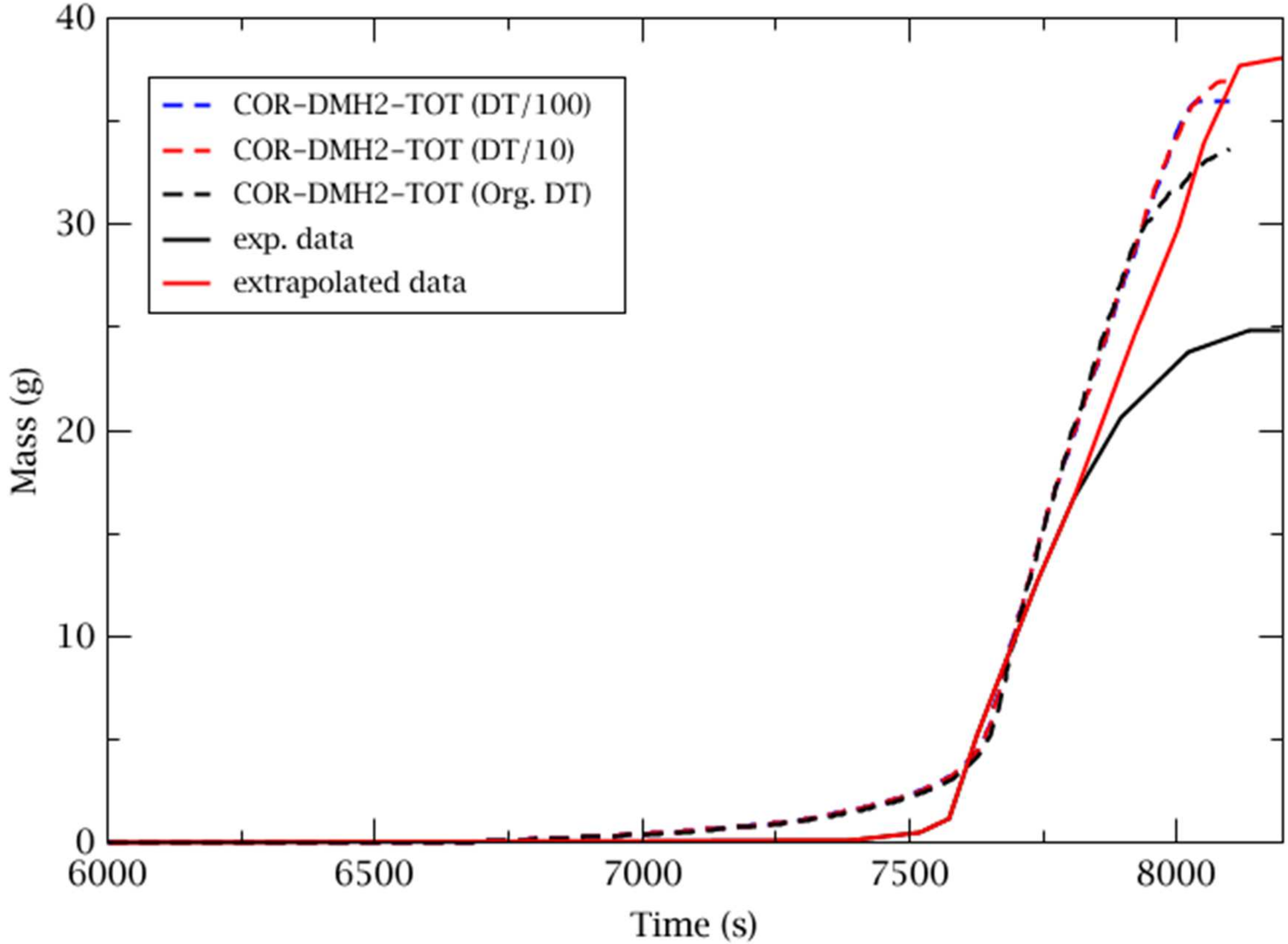
HYDROGEN GENERATION: BASE CASE

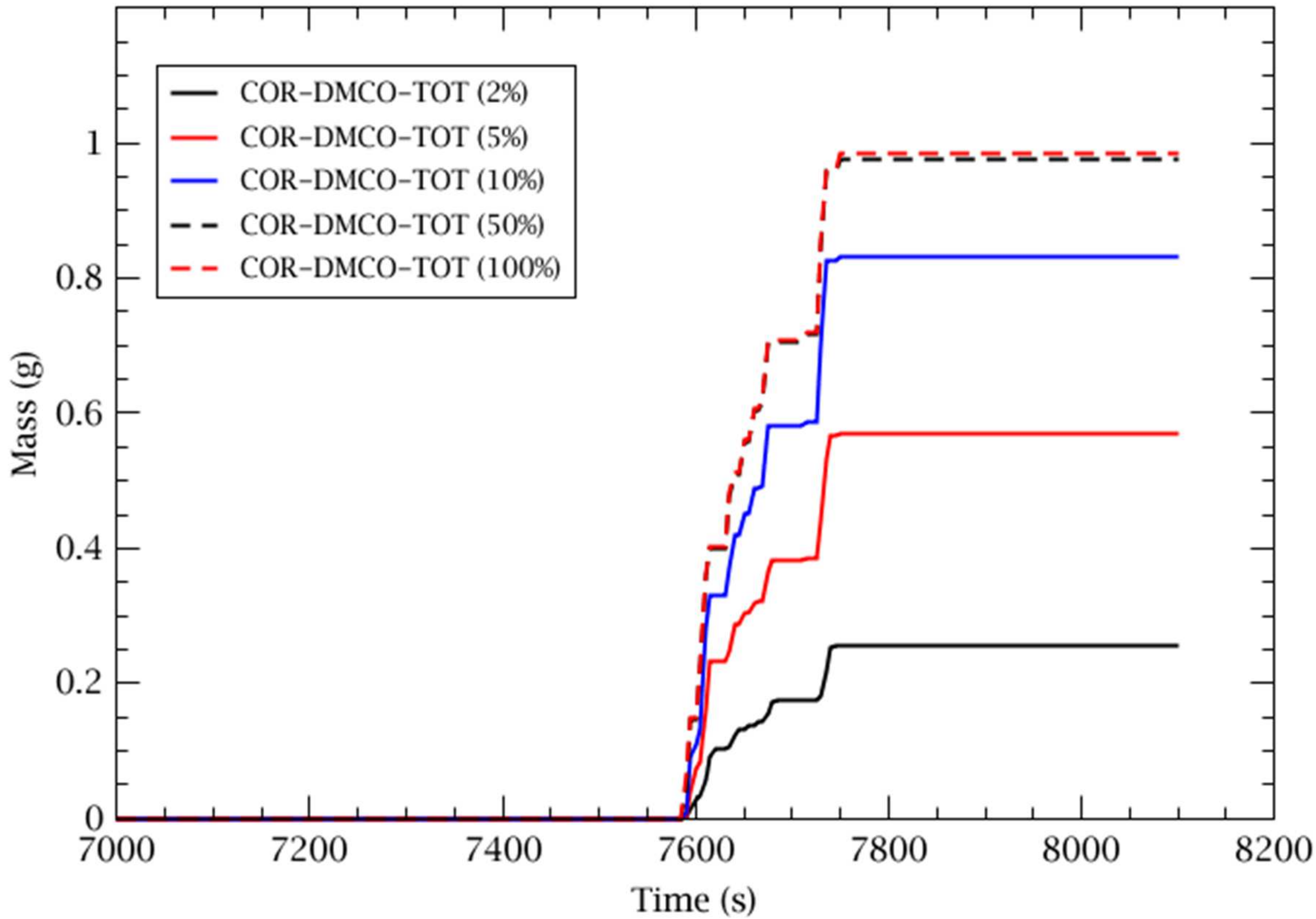


BORON CARBIDE FRACTION

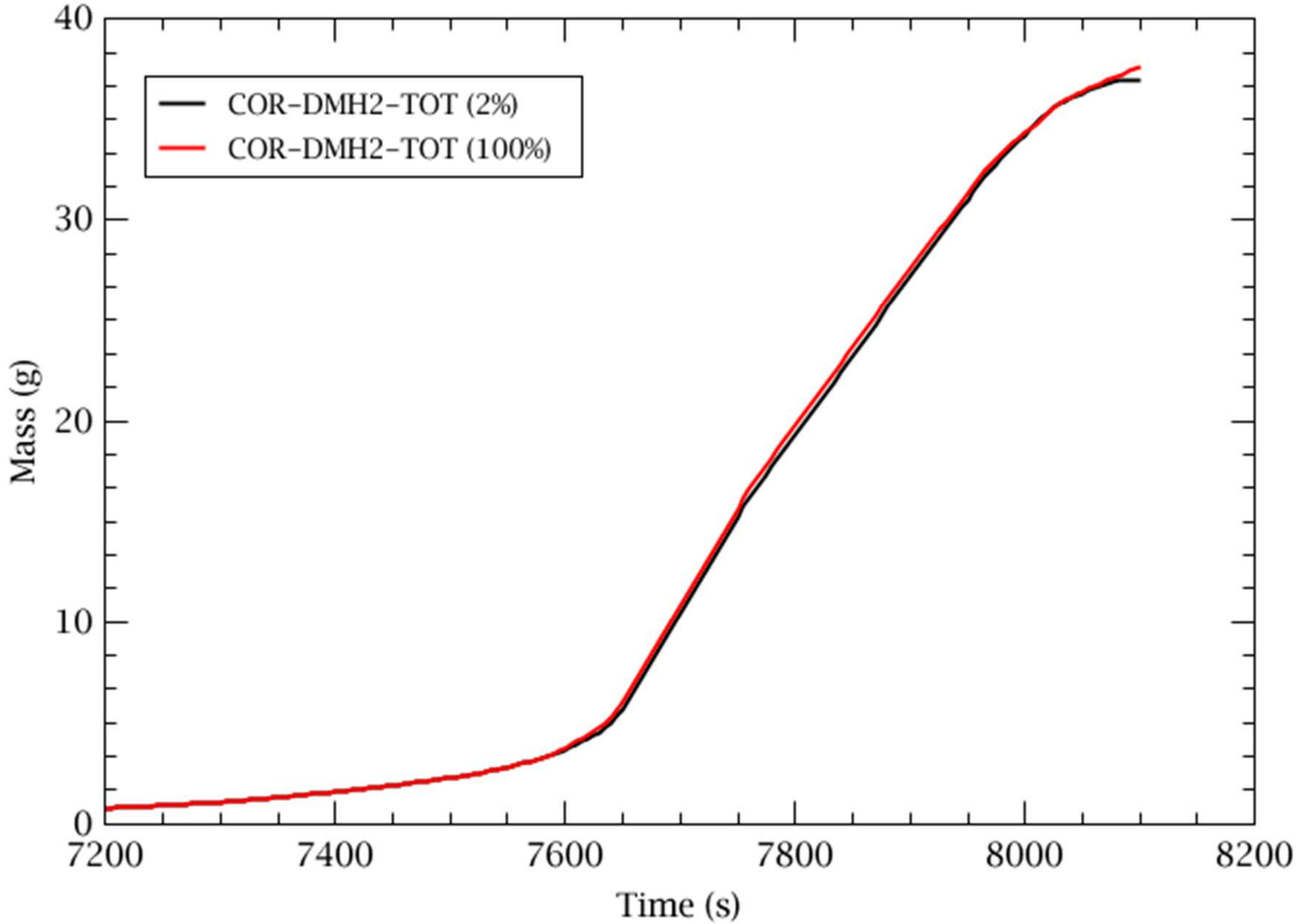
Available fraction of boron carbide for the oxidation with steam - effect on the mass of carbon gases and hydrogen

2%, 5%, 10%, 50%, 100%

AVAILABLE B_4C FRACTION - CO MASS



AVAILABLE B_4C FRACTION – H_2 MASS



THRESHOLD TEMPERATURE

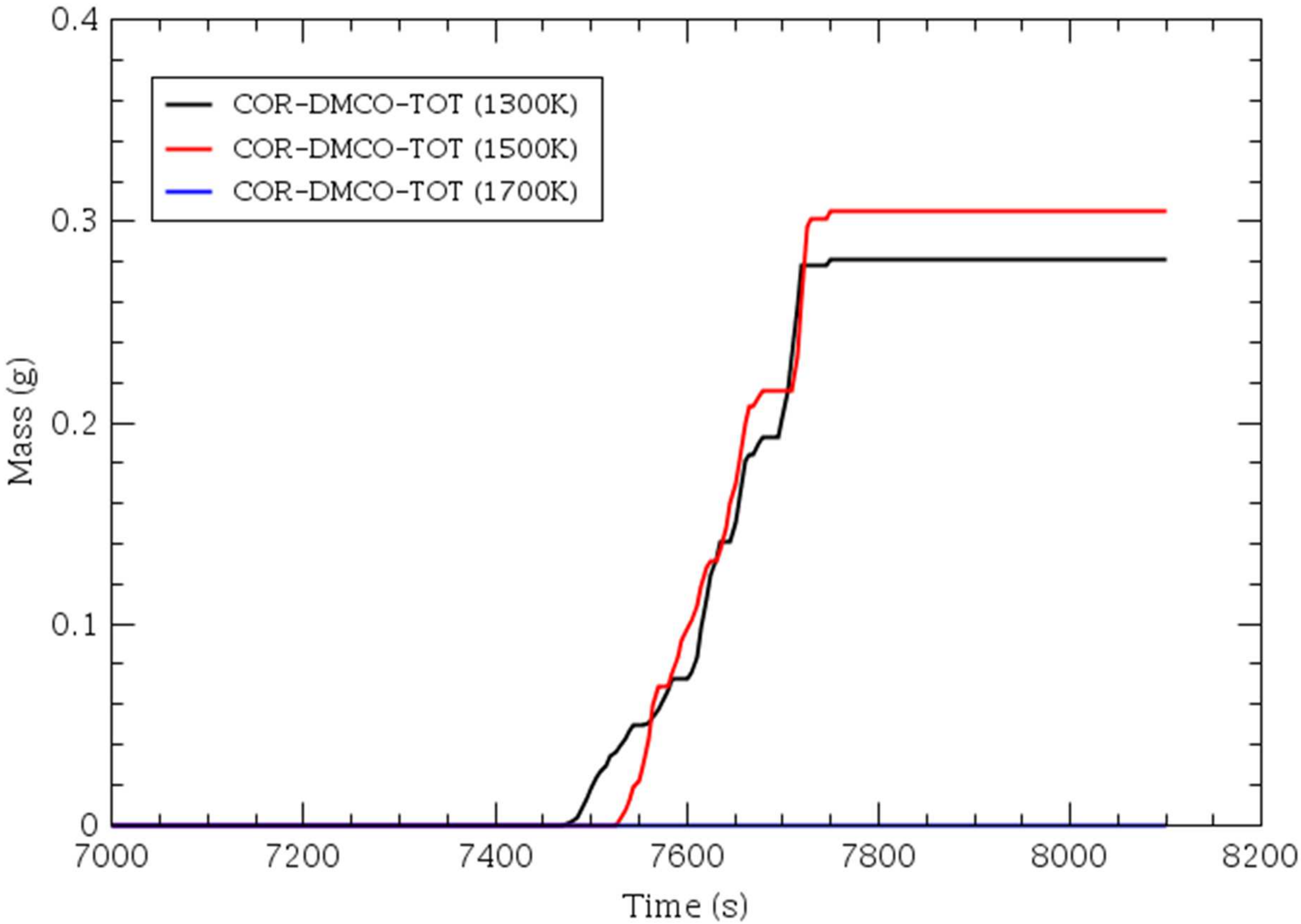
Threshold temperature for oxidation of boron carbide - effect on the mass of carbon gases and hydrogen

1300K, 1500K, 1700K

Additional change: 'Intact steel failure fraction' from 90% to 99%

Reason: No effect could be observed with 90% case

OXIDATION THRESHOLD TEMPERATURE - CO MASS



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REACTION RATE

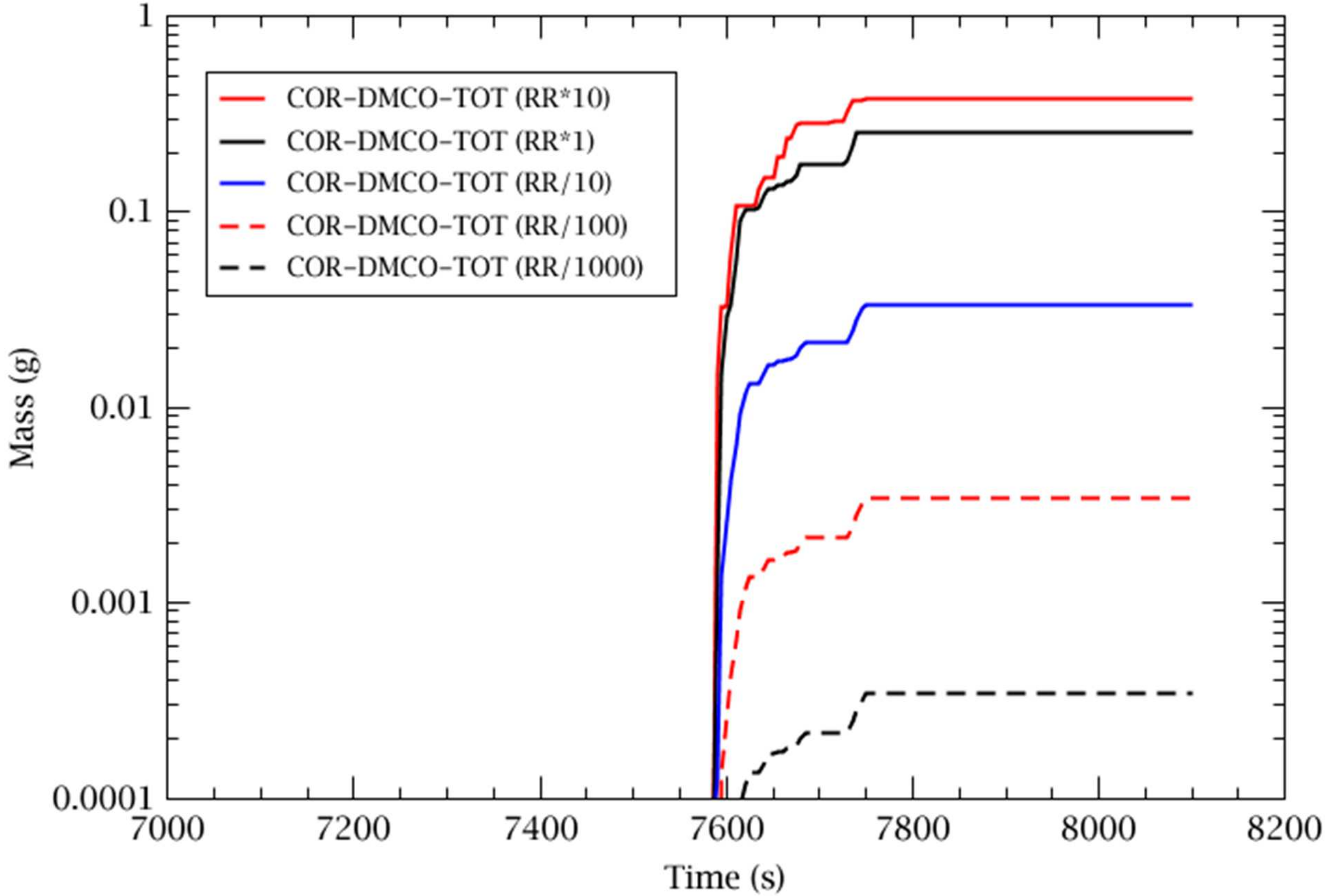
Reaction Rate: $d(M/M0)/dt = A1 \exp(-A2/T)$

A1: 1.662E2, 1.662E3, 1.662E4, 1.662E5, 1.662E6

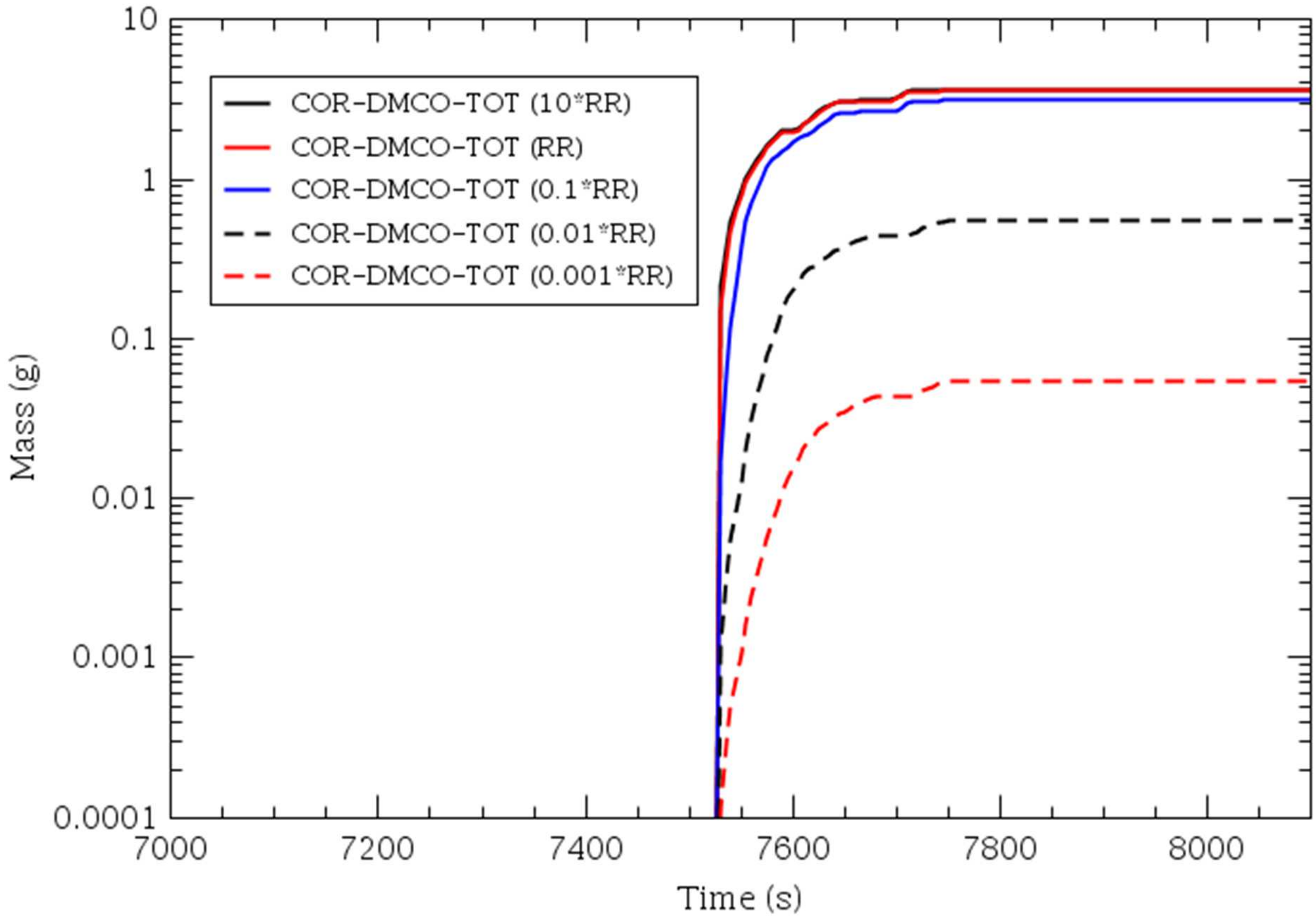
A2: 22647.2K

Additional change: available B_4C for oxidation 2% and 100%

REACTION RATE (2% B_4C) - CO MASS



REACTION RATE (100% B_4C) - CO MASS

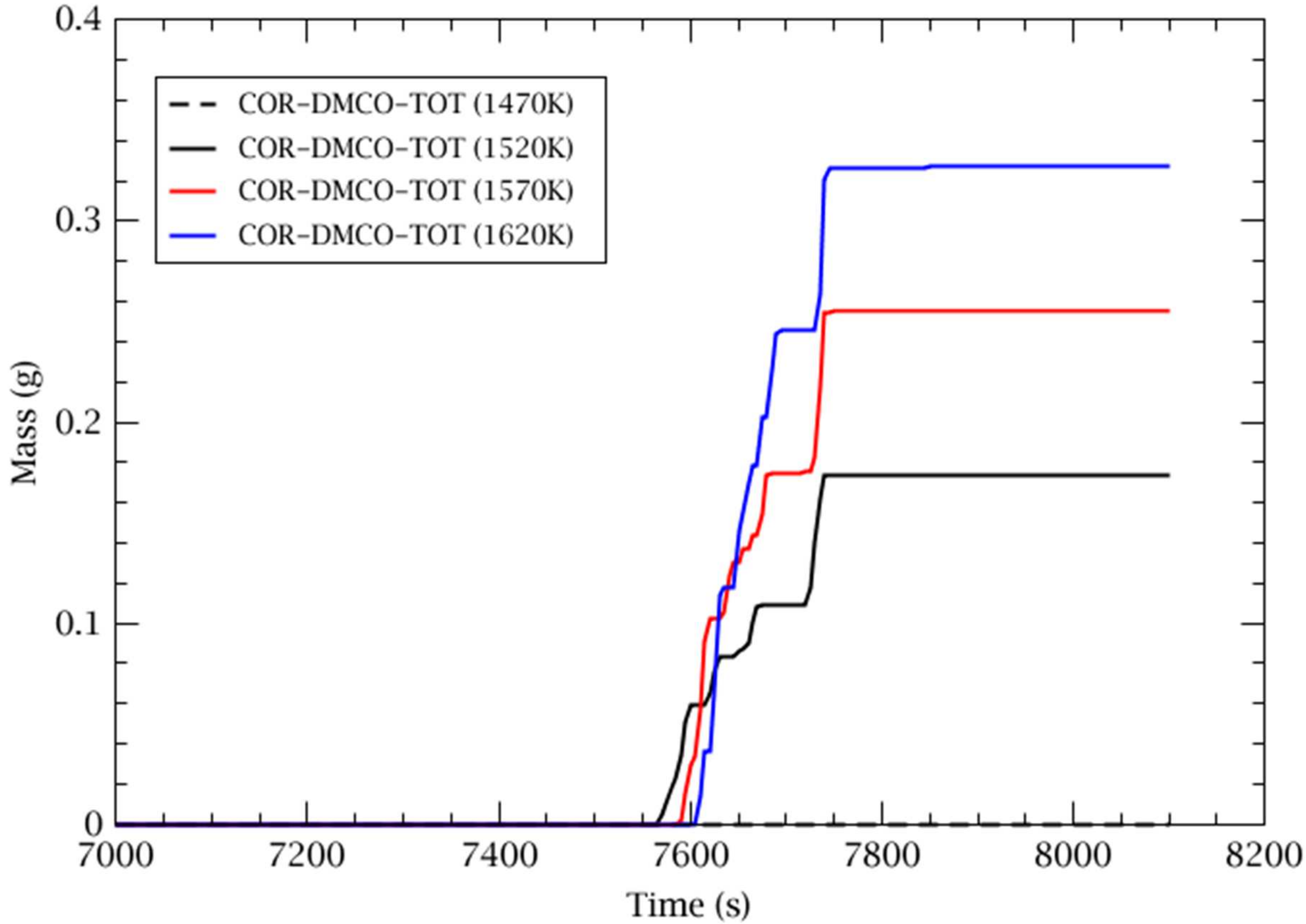


EUTECTIC TEMPERATURE

Start temperature for eutectic reaction between steel and B_4C - effect on carbon gas

1470K, 1520K, 1570K, 1620K

START TEMPERATURE OF EUTECTIC REACTION -CO MASS

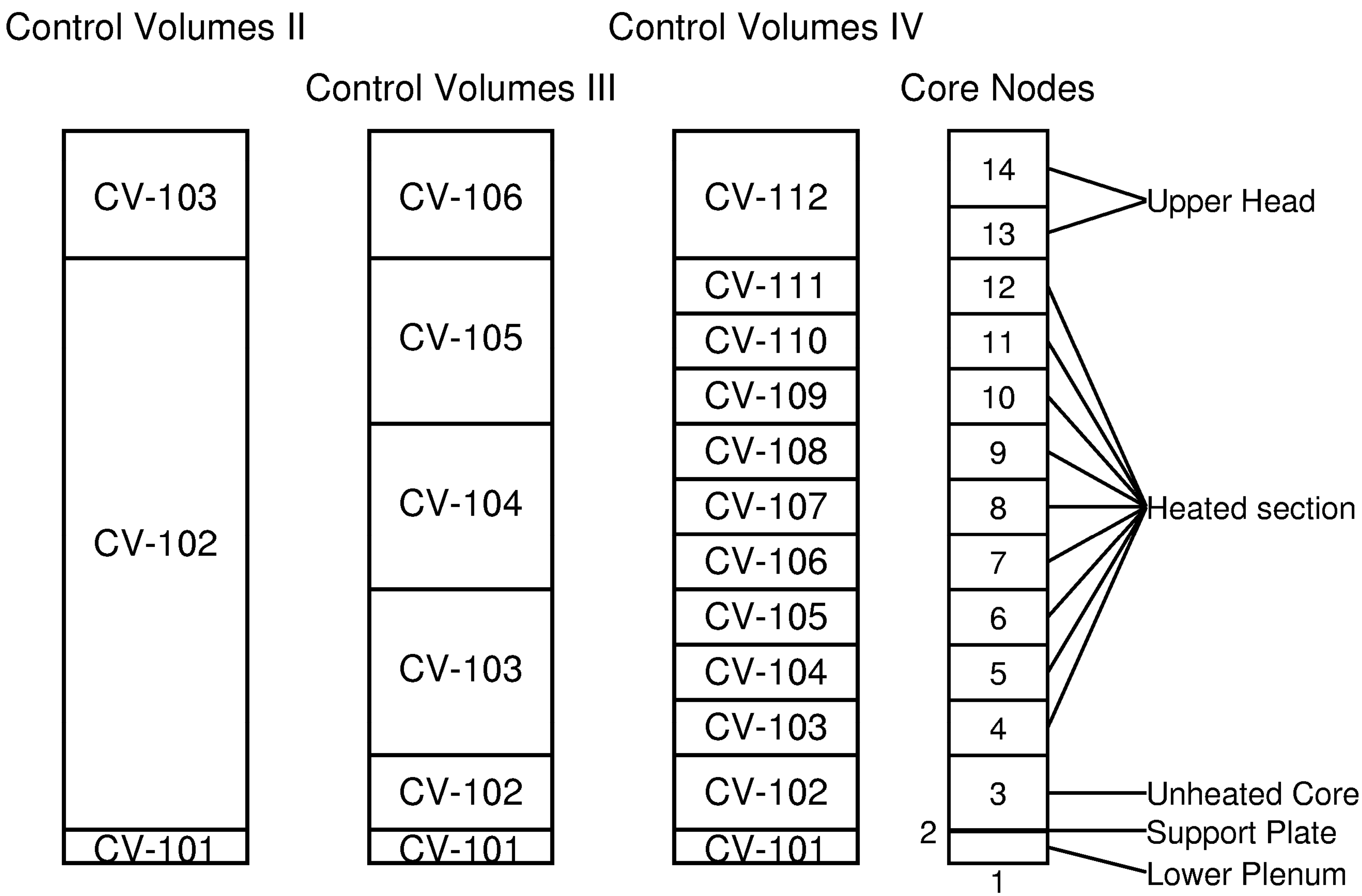


ADDITIONAL CONTROL VOLUMES

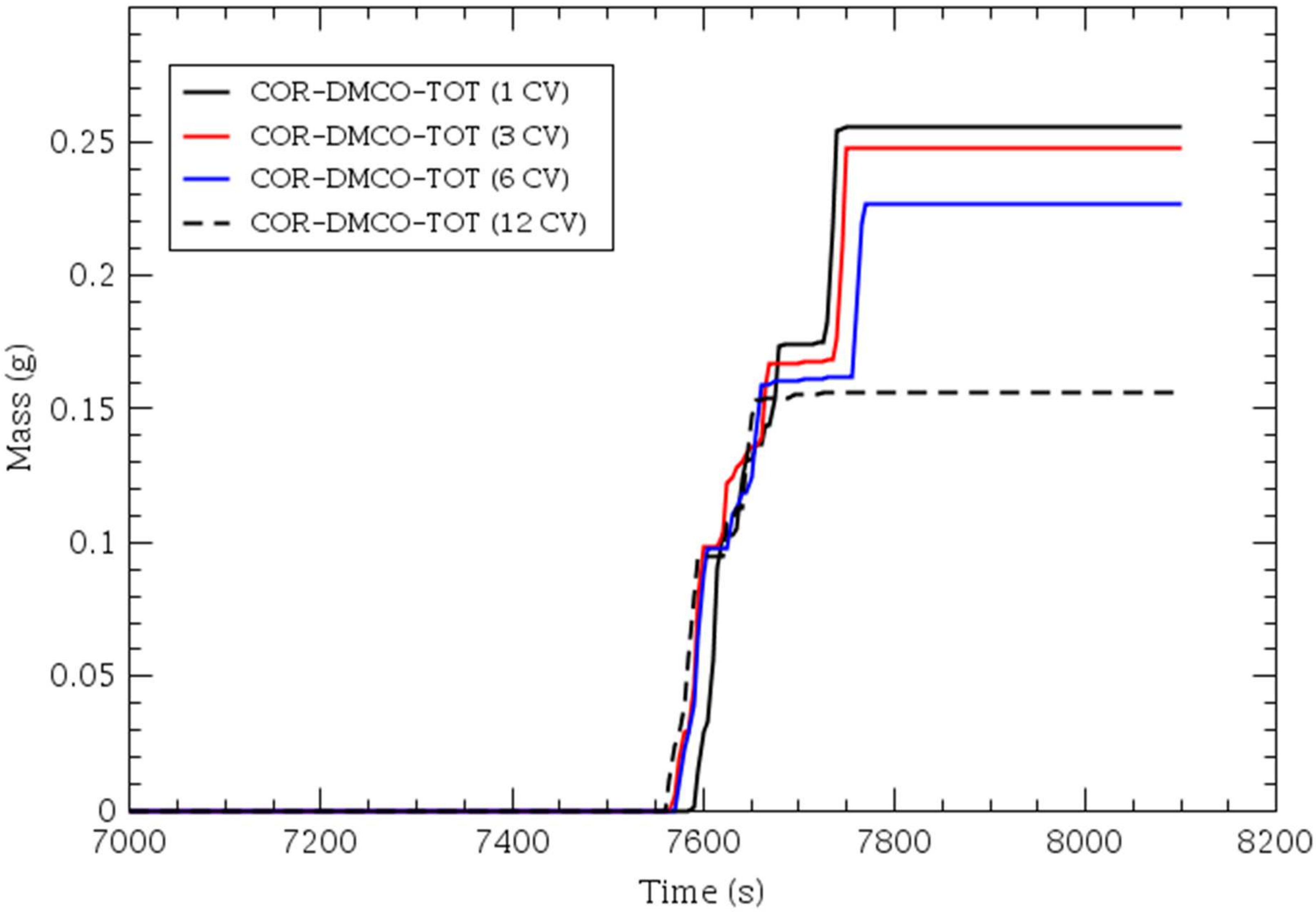
Modeling different number of control volumes for experimental section

1CV, 3 CV‘s, 6 CV‘s, 12CV‘s

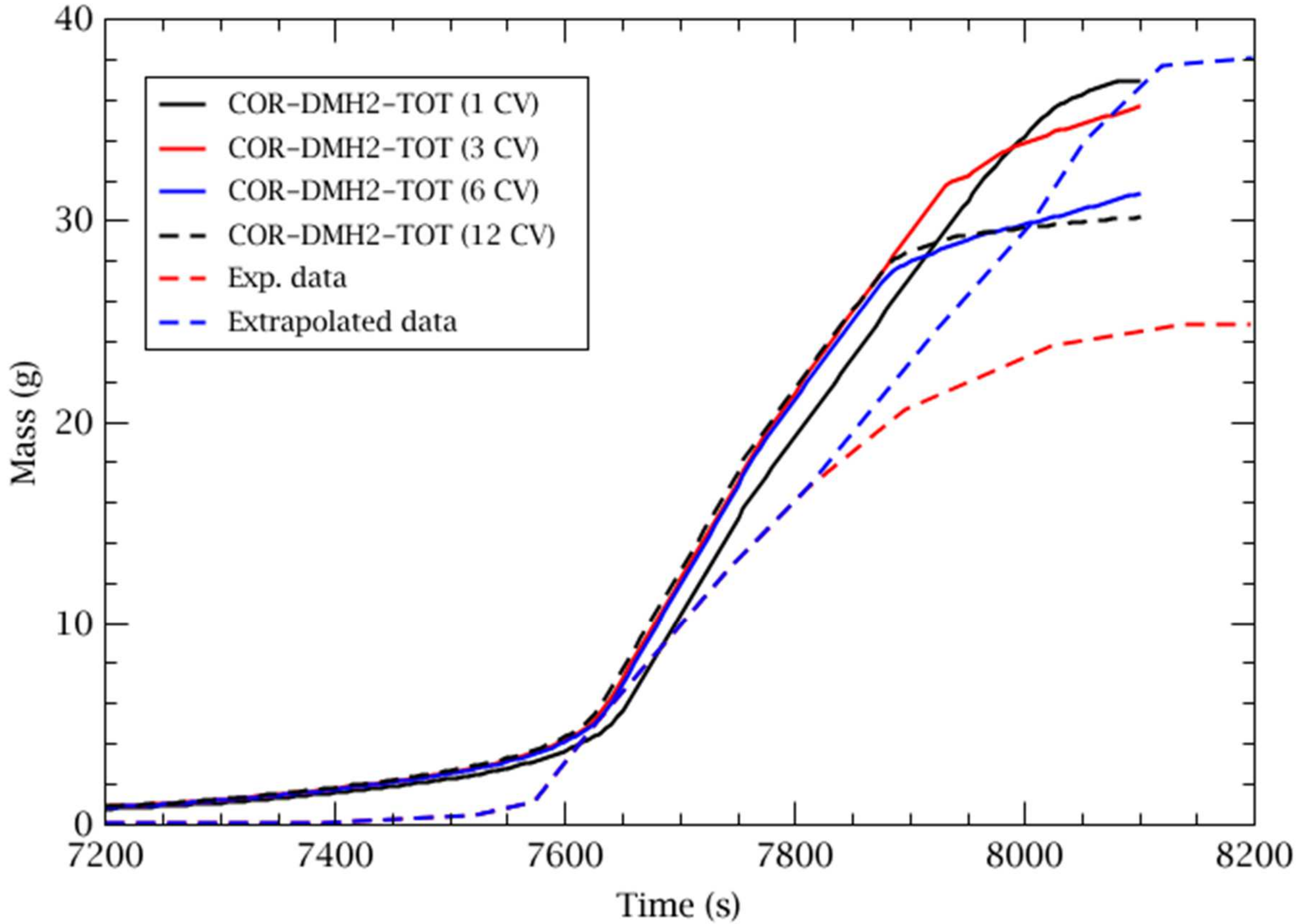
CONTROL VOLUME NODALIZATION



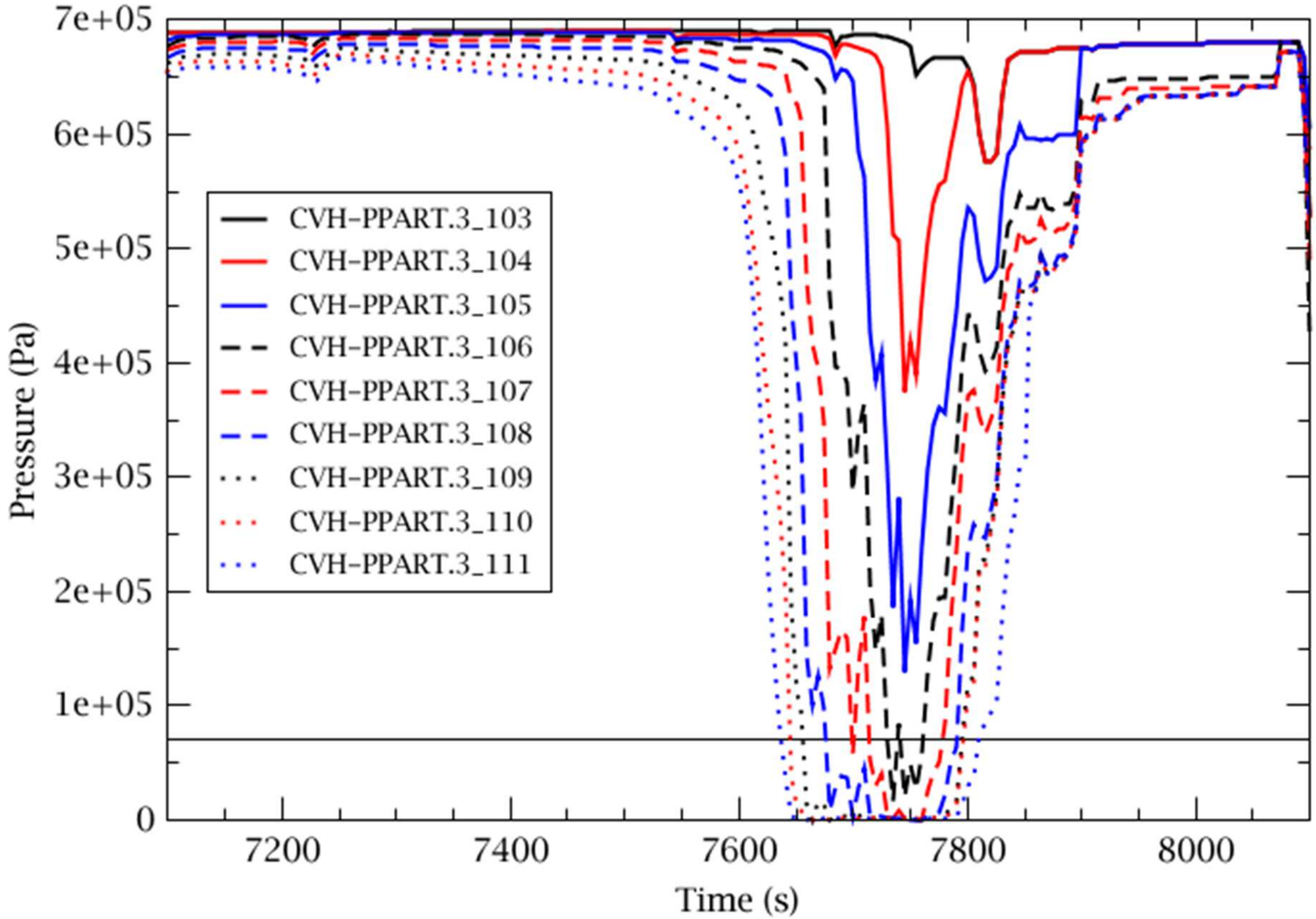
CONTROL VOLUME NODALIZATION



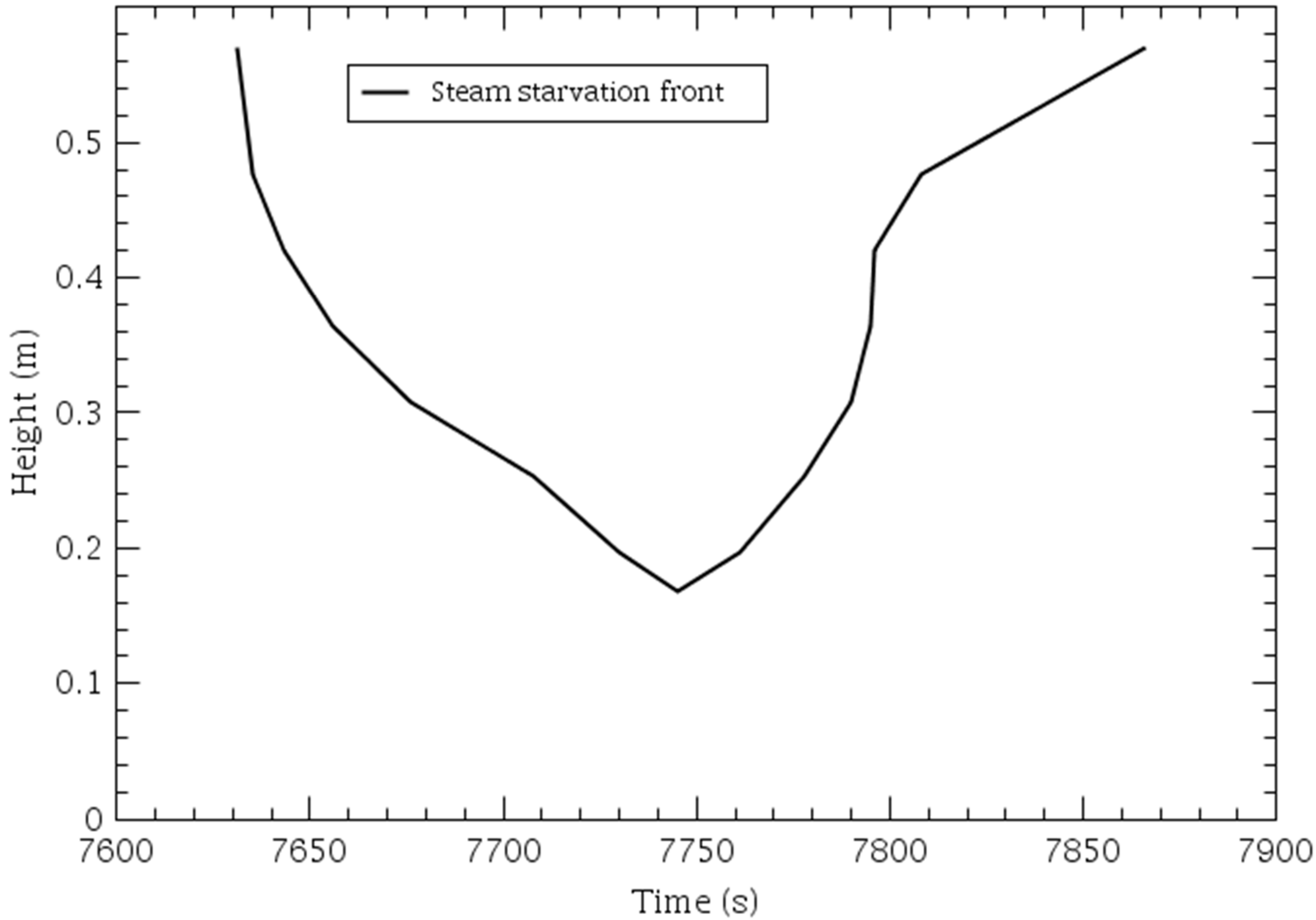
CONTROL VOLUME NODALIZATION



CONTROL VOLUME NODALIZATION - 12 CV



Control volume nodalization - 12 CV



MELCOR CODE VERSIONS

Using different code versions of MELCOR

1.8.5 RD, 1.8.6 YT, 1.8.6 YV, 2.1_668, 2.1_1576 (Two optimization levels)

PREPARATION AND CONVERSION

Input deck preparation for the conversion to more recent MELCOR code versions

- For all following calculations:
- Changing B_4C modelling from OS to NS
- Switching off the eutectic model

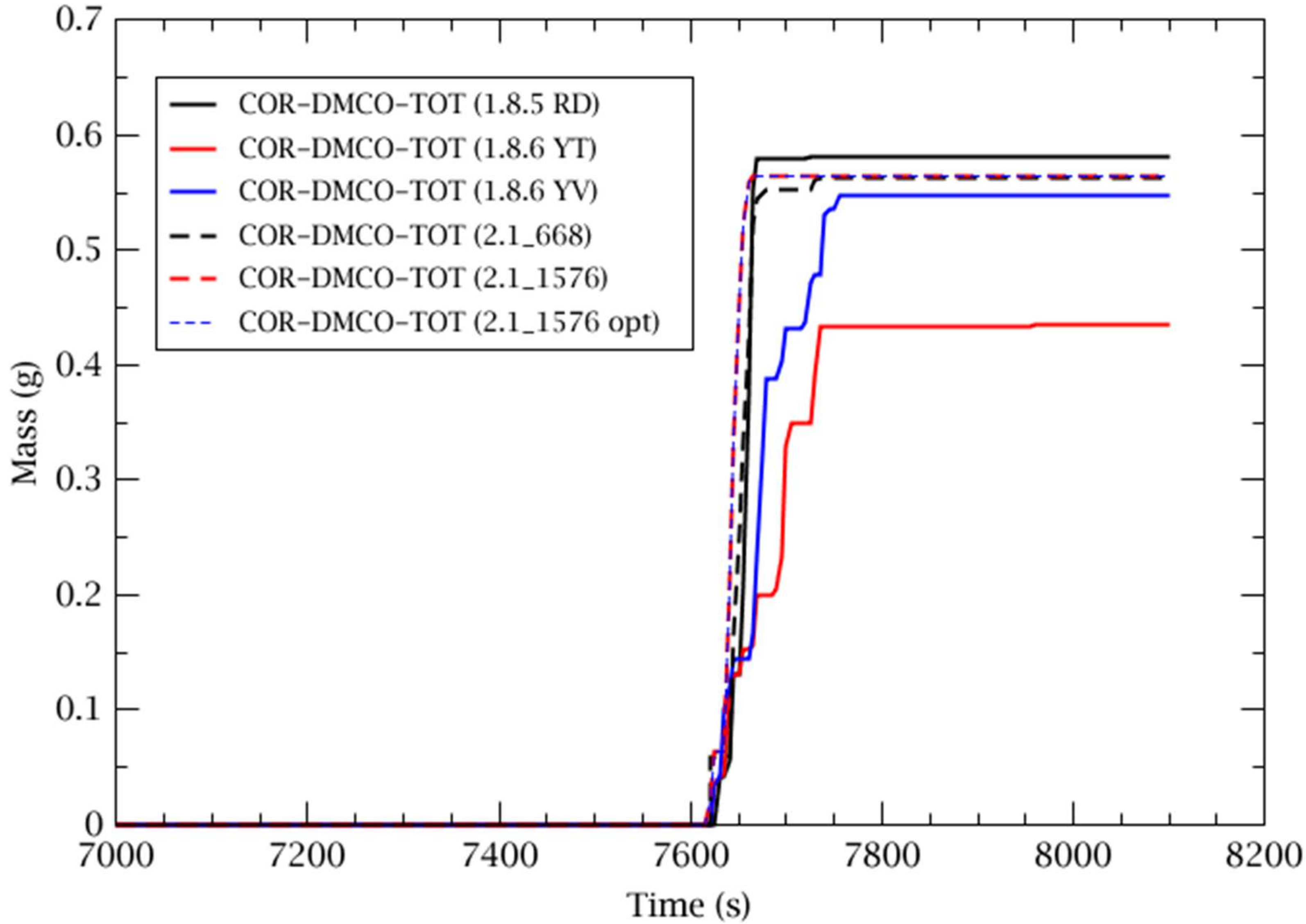
Conversion of input deck for MELCOR 1.8.6

Converter failed → Changing input deck by hand

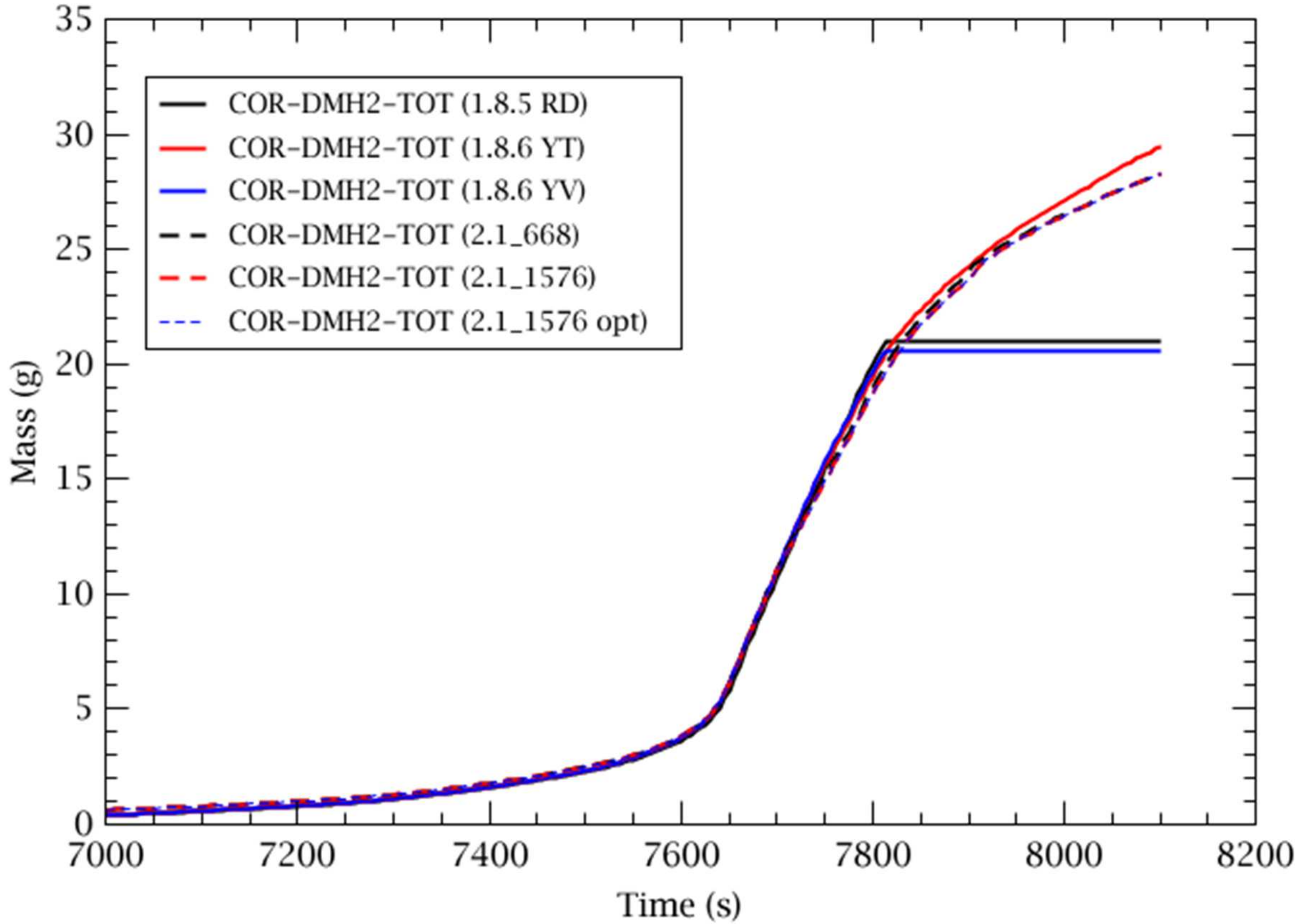
Conversion of input deck for MELCOR 2.1

Only minor changes by hand neccessary

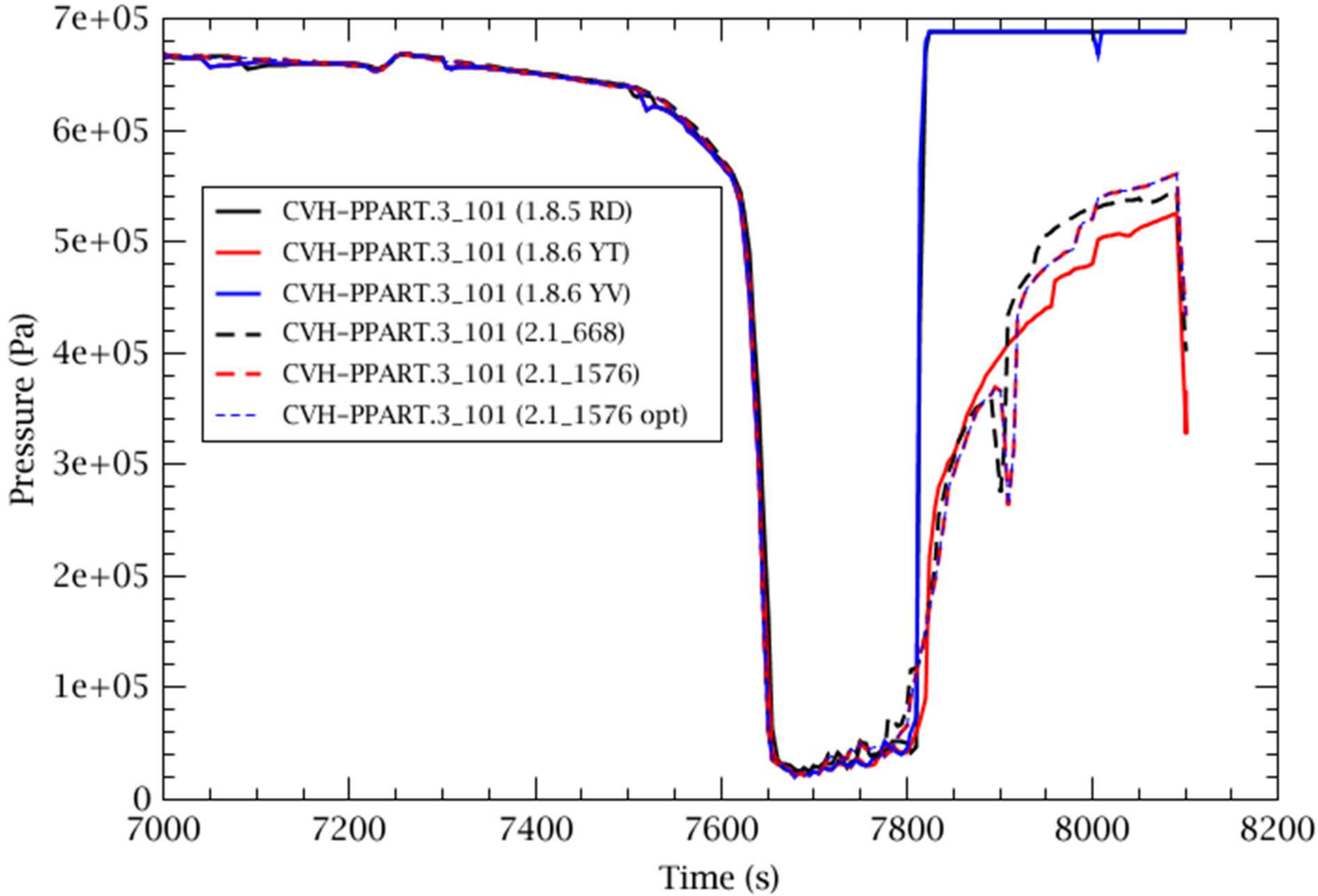
CODE VERSION COMPARISON - CO MASS



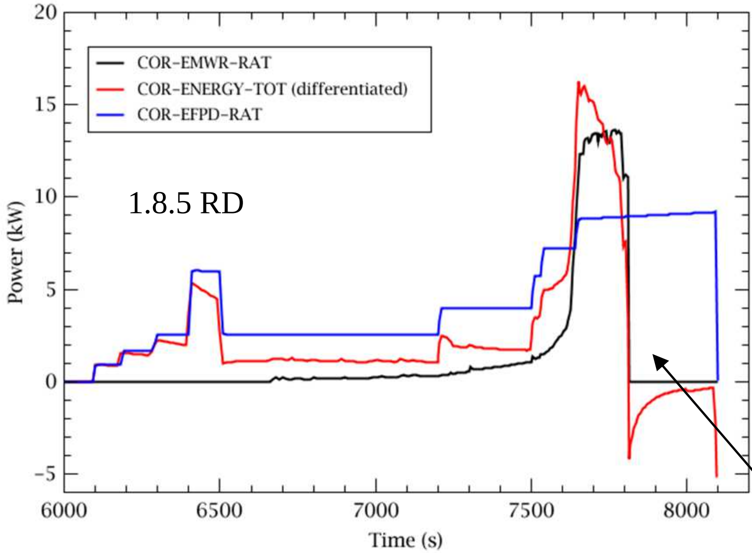
CODE VERSION COMPARISON - H_2 MASS

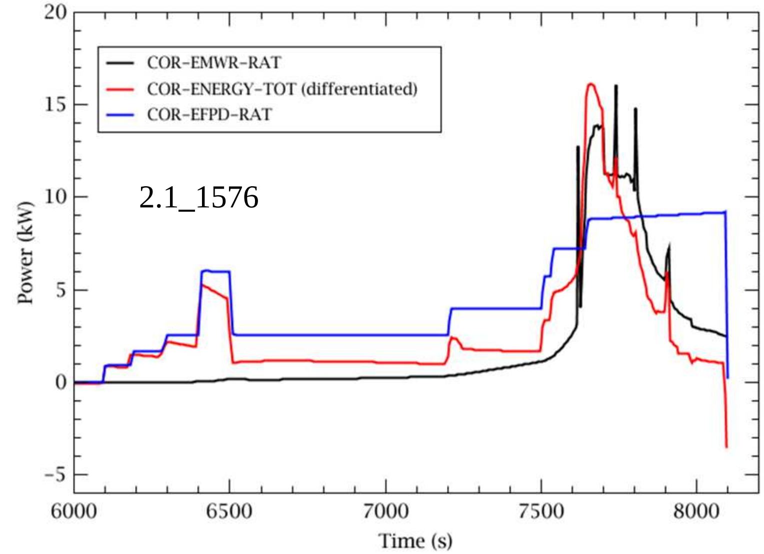


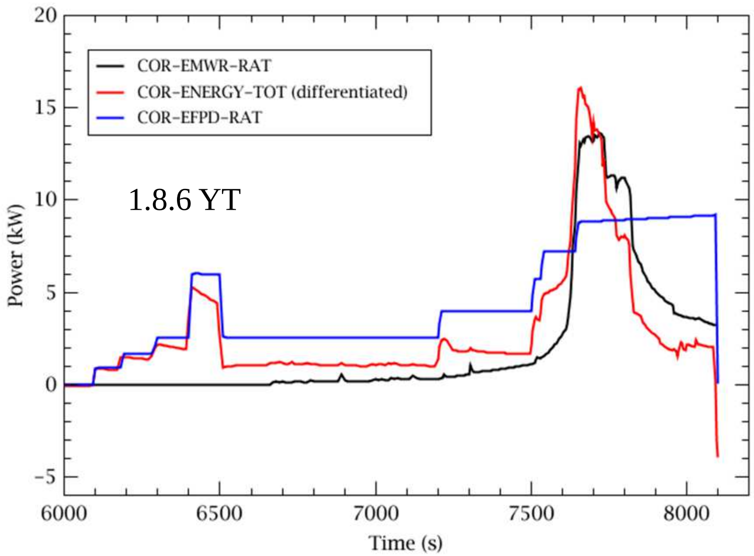
CODE VERSION COMPARISON - STEAM PRESSURE



HEAT GENERATION





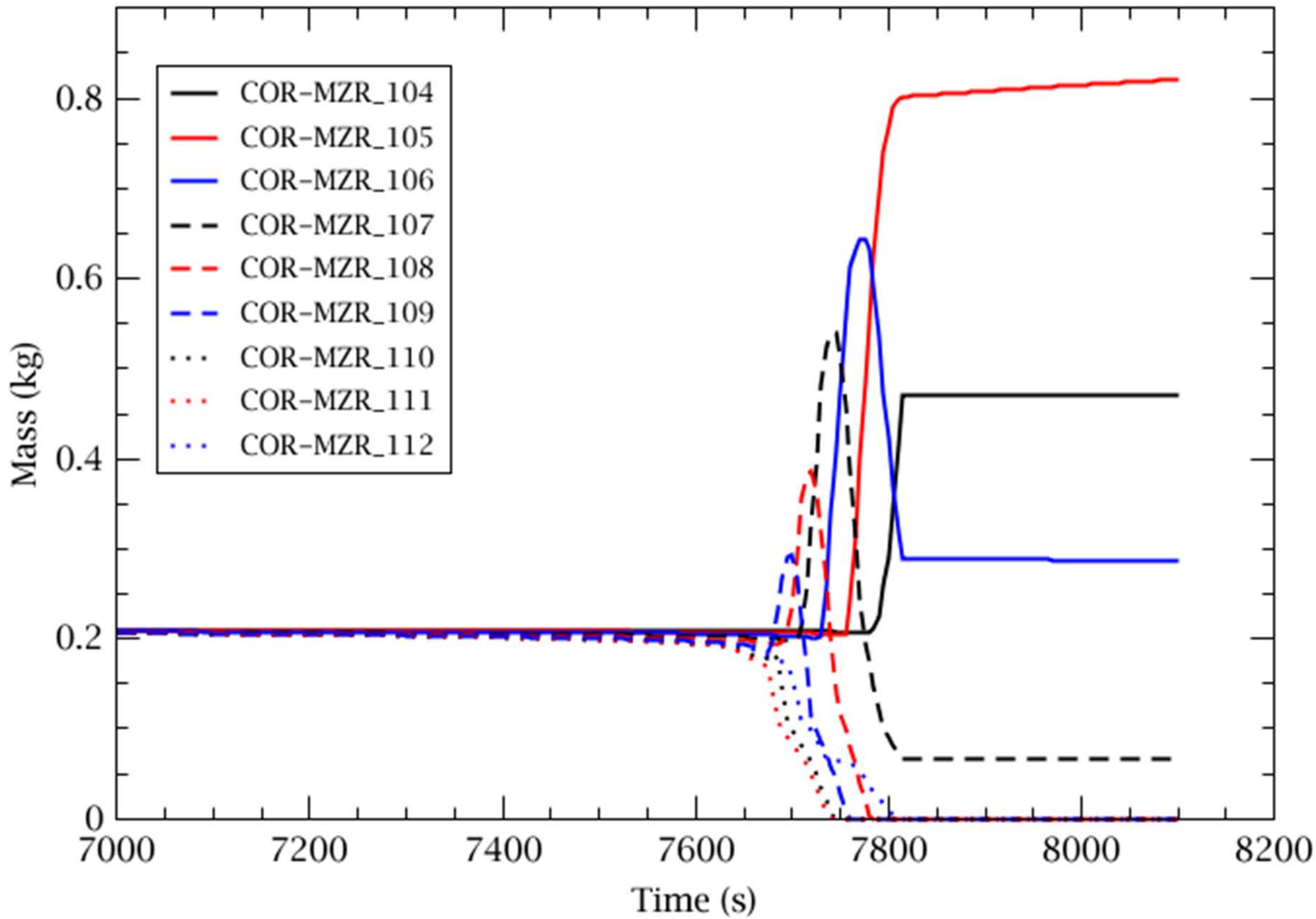


Comparison of different code versions:

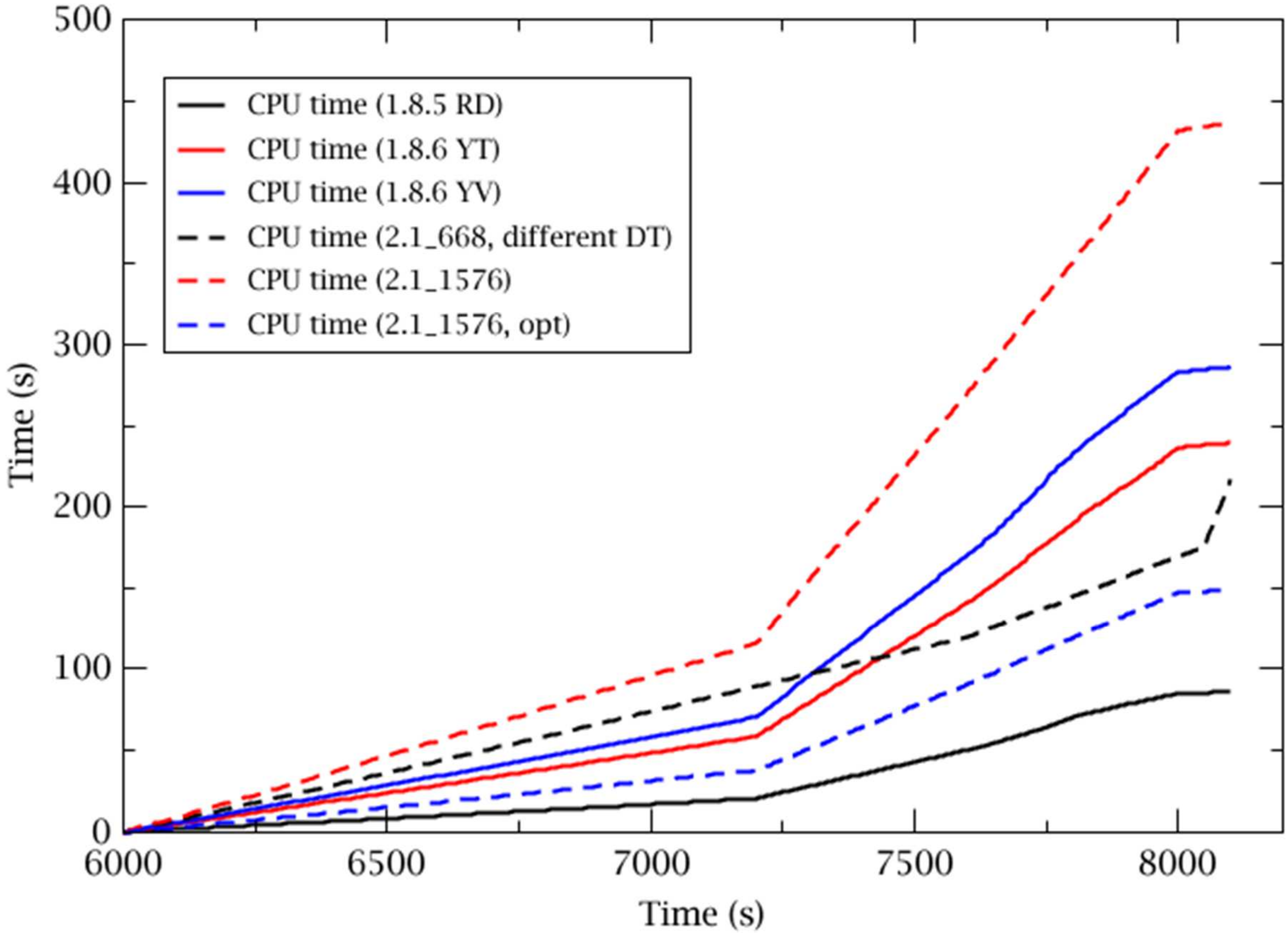
MELCOR 1.8.5 switches off oxidation heat

(Problem was not seen with eutectic model)

MASS RELOCATION WITH 1.8.5 RD



CPU TIME CONSUMPTION (0.1s, 0.025s, 0.2s)



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CONCLUSIONS AND RECOMMENDATIONS -I

Calculations of ACRR DF-4 performed with several MELCOR 1.8.5, 1.8.6 and 2.1 versions

Comparison for temperatures not possible because of thermocouple limitations

Fairly good agreement for hydrogen generation

- - moderate dependence on timestep and noding for this case
- - B_4C contributes only slightly to calculated oxidation during ACRR DF-4, several different factors limits B_4C oxidation
- - B_4C sensitivity studies; threshold temperature for B_4C oxidation and interaction with steel, oxidisable fraction, oxidation kinetics
- - interaction with steel inhibits B_4C oxidation
- - significant dependence on oxidation kinetic coefficient (if pellets instead of powder)

CONCLUSIONS AND RECOMMENDATIONS - II

Calculations ran successfully in most cases

- code problems in mid-transient concerning Zry oxidation (V1.8.5RD and V1.8.6YV)
- Version 2.1_668 shows run time problems
- V 2.1_1576 more stable than V2.1_668
  – no problems with time steps and compiler optimization
- The eutectic reaction would seem an important process to model, not only for B_4C-steel

- recommendation to reactivate
- recommendation also to include oxidation of B_4C-steel mixtures

OUTLOOK

- Assessment of MELCOR 1.8.6 and MELCOR 2.1 continues
  – feedback being provided to USNRC and Sandia Labs

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Thank you for your attention