Cross-walk study between MELCOR, ASTEC and MAAP: LB LOCA scenario and encountered modeling issues for the MELCOR 2.2.21402

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12th – 14th April 2023

JSI, Ljubljana, Slovenia

14th Meeting of the European MELCOR and MACCS User Group (EMUG)

Skupina ÚJV

LIDÉ | INOVACE | TECHNOLOGIE

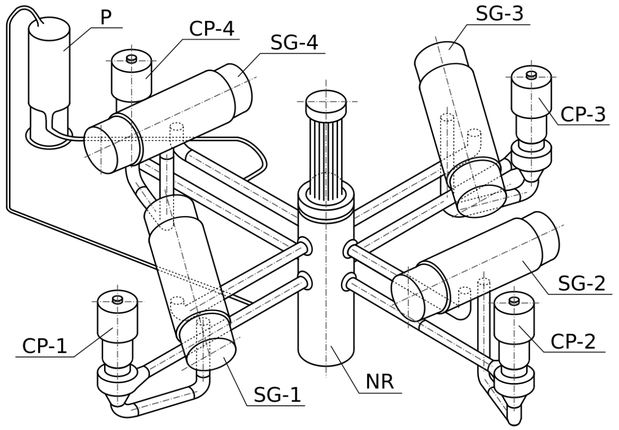
OVERVIEW

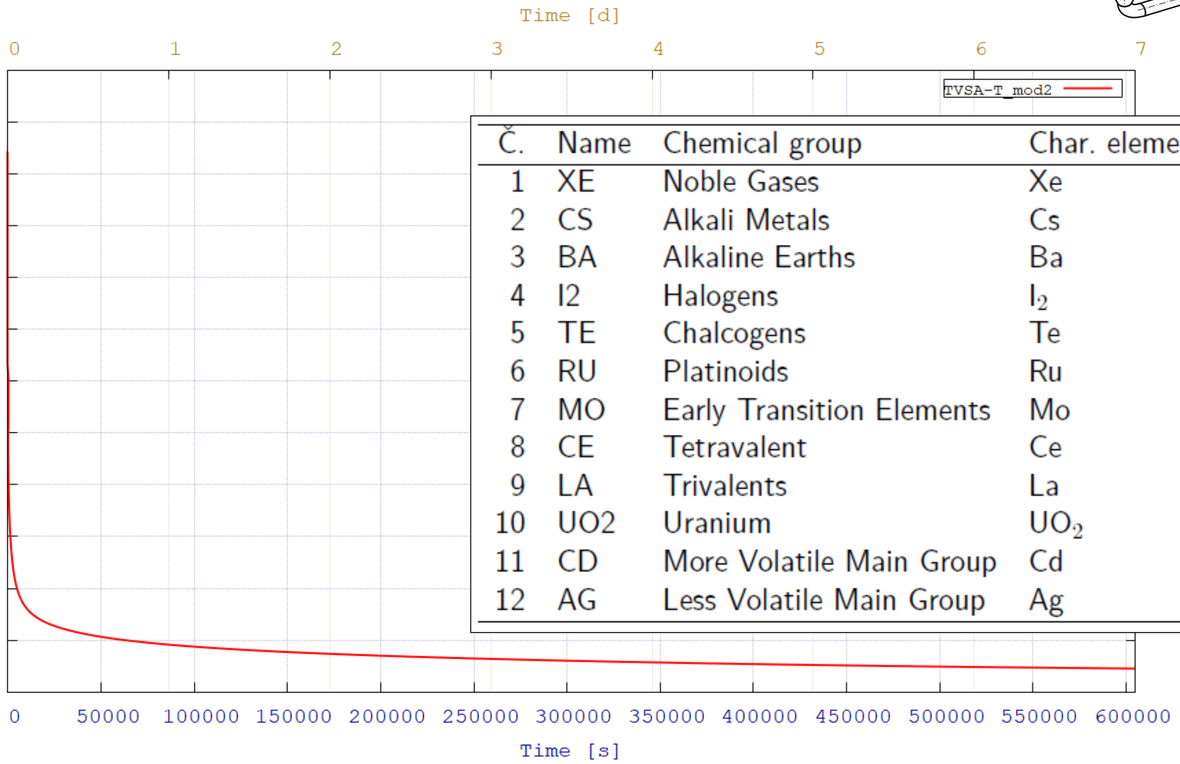
1. New input model of the VVER-1000 core
   - FAs: TVSA-T mod1 => mod2
   - Substantially enhanced oxidation
2. Benchmark analysis of LB LOCA scenario for VVER-1000
   - ASTEC/MELCOR/MAAP
   - Discrepancies in the LP molten mass
3. Encountered MELCOR issues (21402)
   - Unfailed LH even if completely molten
   - SPR package: spray is ON, but no heat/mass transfer

New input model of the VVER-1000 core

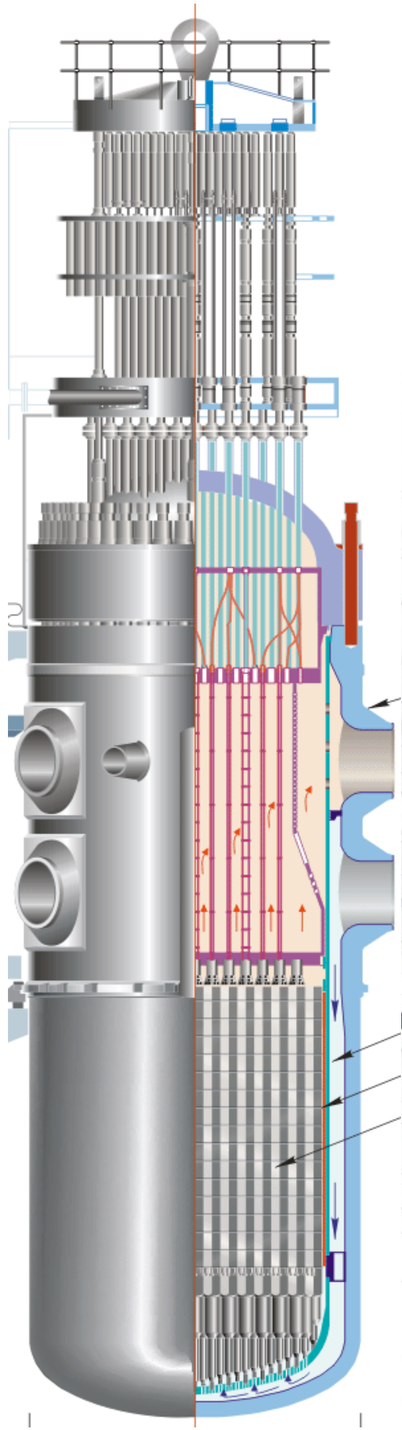
VVER-1000/320 (TEMELIN NPP)

- New FAs (TVEL TVSA-T mod2) modeled (8 => 15 SGs)
- Realistic decay power & FP inventory calculated
  - SCALE/TRITON sequence used

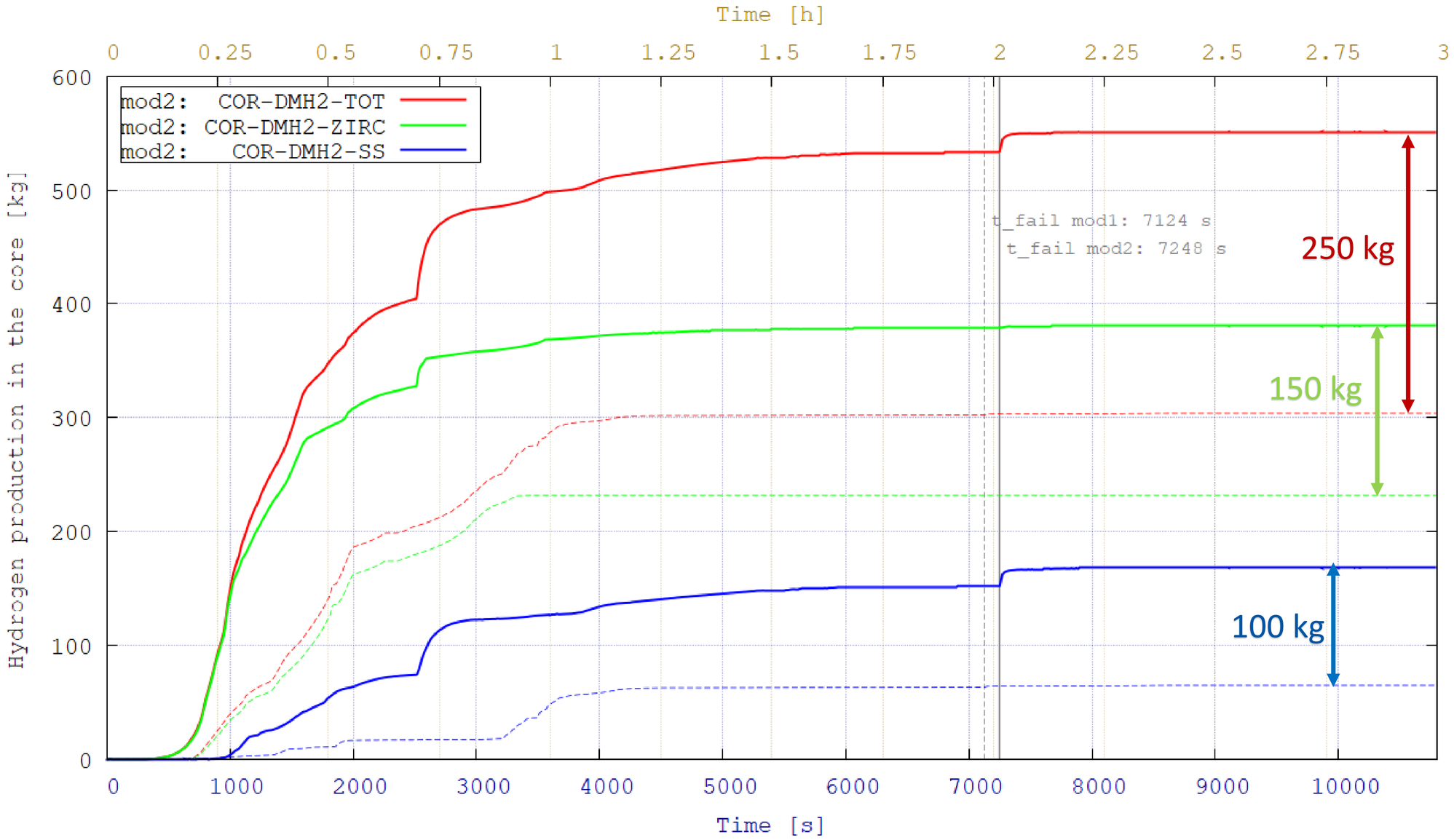




Č.	Name	Chemical group	Char. element	Initial inventory [kg]
1	XE	Noble Gases	Xe	tens of kg
2	CS	Alkali Metals	Cs	hundreds of kg
3	BA	Alkaline Earths	Ba	hundreds of kg
4	I2	Halogens	I_2	tens of kg
5	TE	Chalcogens	Te	tens of kg
6	RU	Platinoids	Ru	hundreds of kg
7	MO	Early Transition Elements	Mo	hundreds of kg
8	CE	Tetravalent	Ce	thousands of kg
9	LA	Trivalents	La	hundreds of kg
10	UO2	Uranium	UO_2	tens of thousands of kg
11	CD	More Volatile Main Group	Cd	units of kg
12	AG	Less Volatile Main Group	Ag	tens of kg



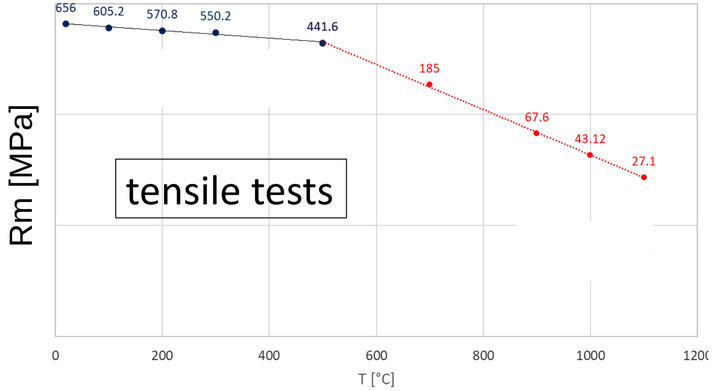
TVSA-T MOD1 VS. MOD2: HYDROGEN PRODUCTION



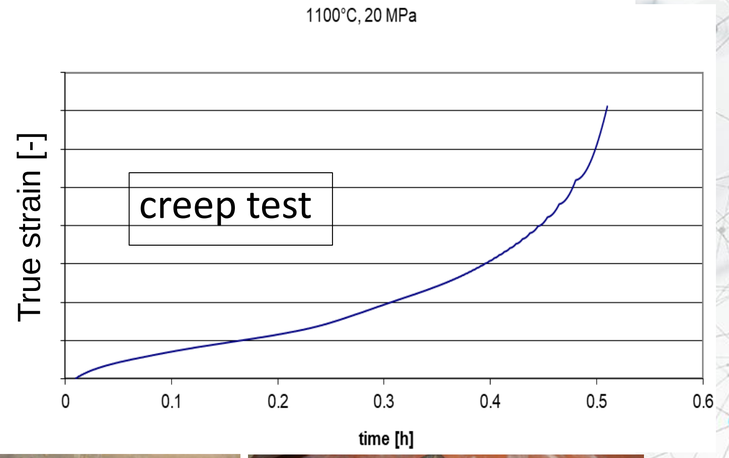
TVSA-T MOD1 VS. MOD2: SURFACE AREA ETC.

- 8 vs. 15 SGs
  - SA of all SGs in the core: 1269 vs. 2141 m^2

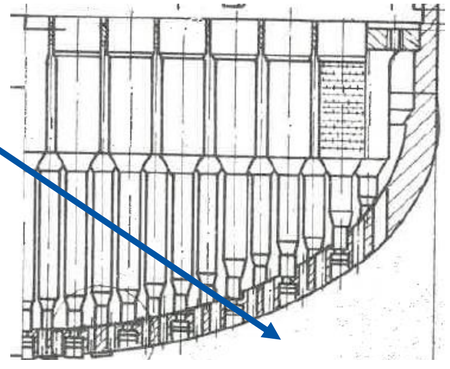
piece	*SA_unit [m^2]*	*# units in FA*	*SA_FA [m^2]*	*ratio*
cladding	0.1066	312	33.26	**2.53**
SG	0.9733	13.5	13.14	



- Accelerated degradation of steel SS-component supporting capabilities
  - Updated failure & collapse temperatures (lowered): investigation of σ_{UTS} and creep properties
  - PD more prone to oxidation than MP?

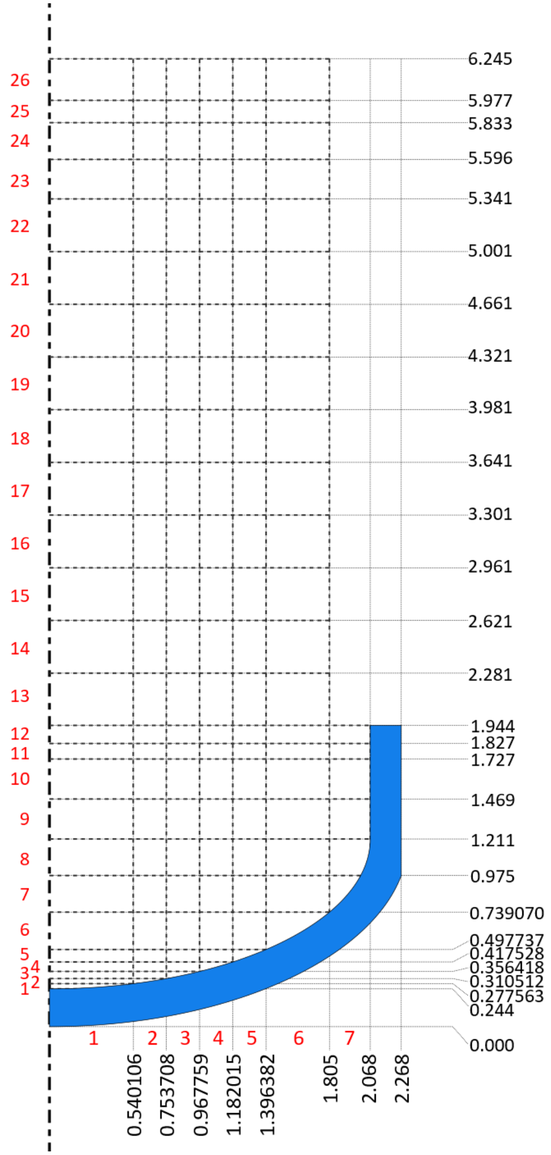


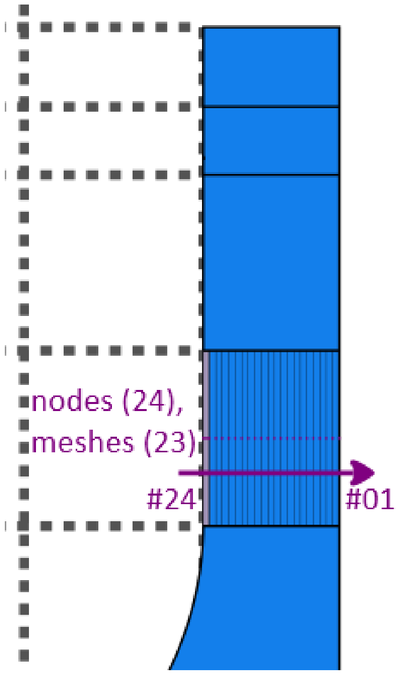
- PD retention within the perforated core barrel LH
  - Experimental investigation
  - Water access into the gap barrel ⇔ RPV
  - => prolonged oxidation

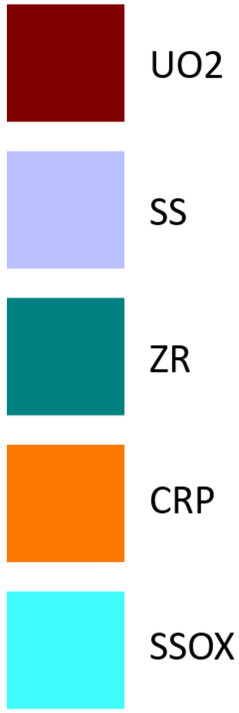


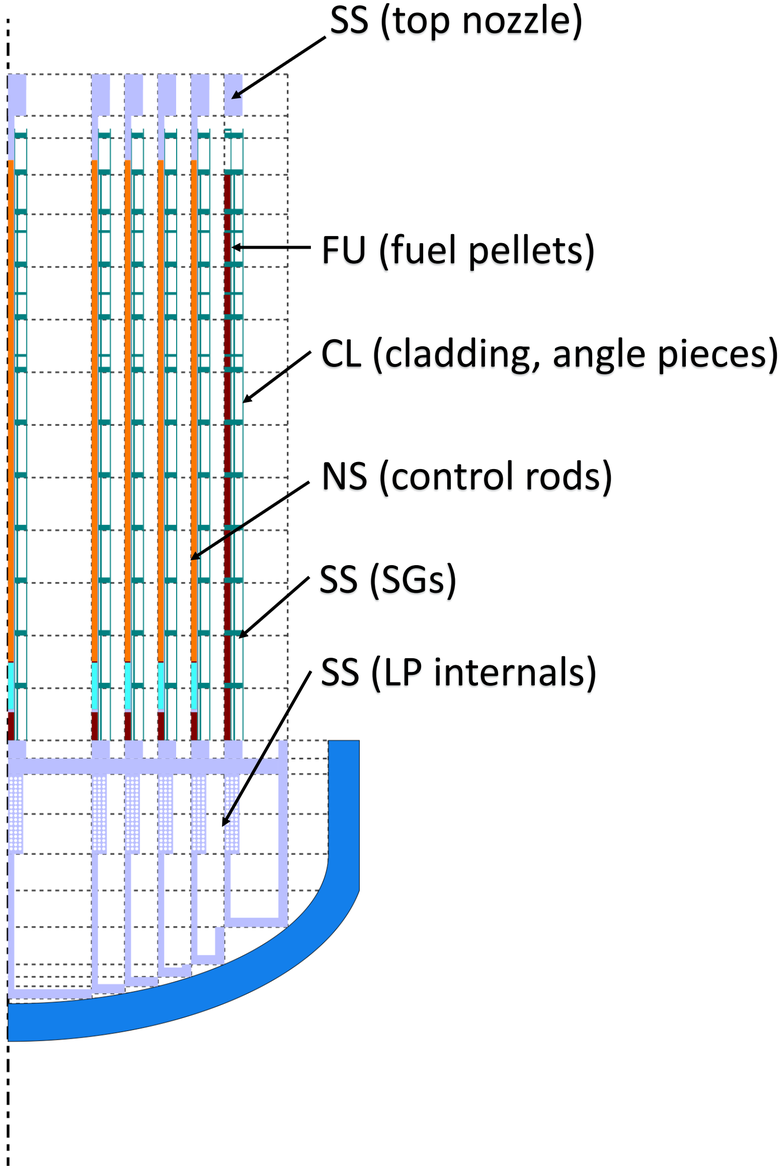
Benchmark analysis of LB LOCA scenario for VVER-1000

MELCOR NODALIZATION: COR

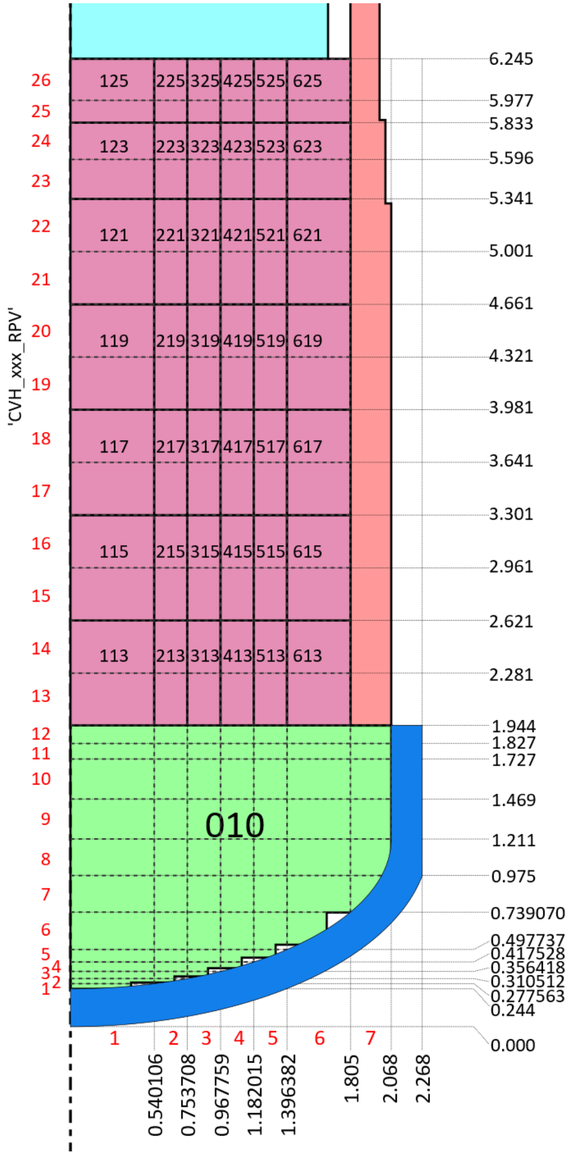






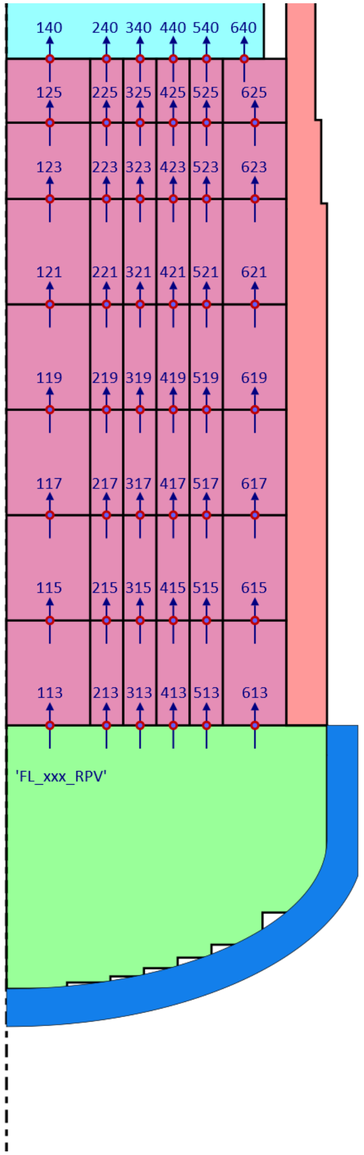


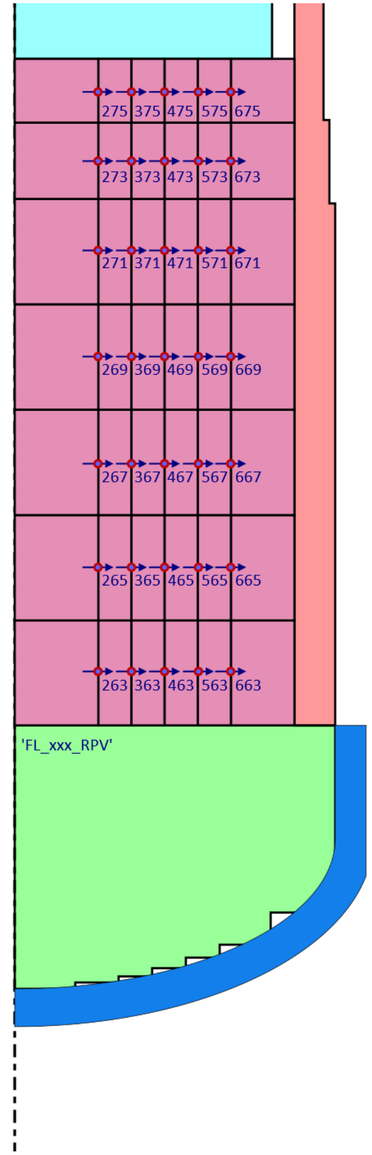
MELCOR NODALIZATION: CV, FL



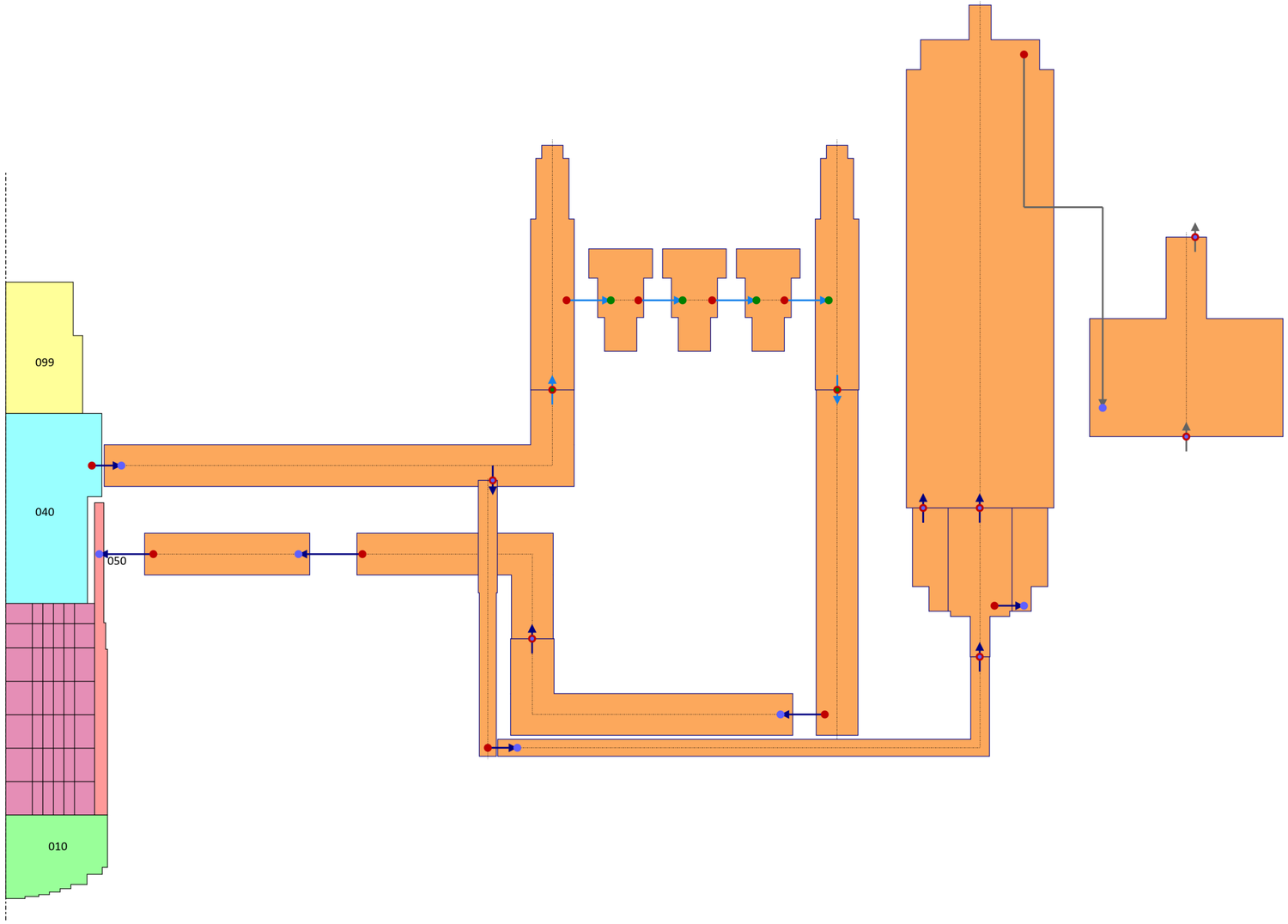
2 COR cells per 1 CV

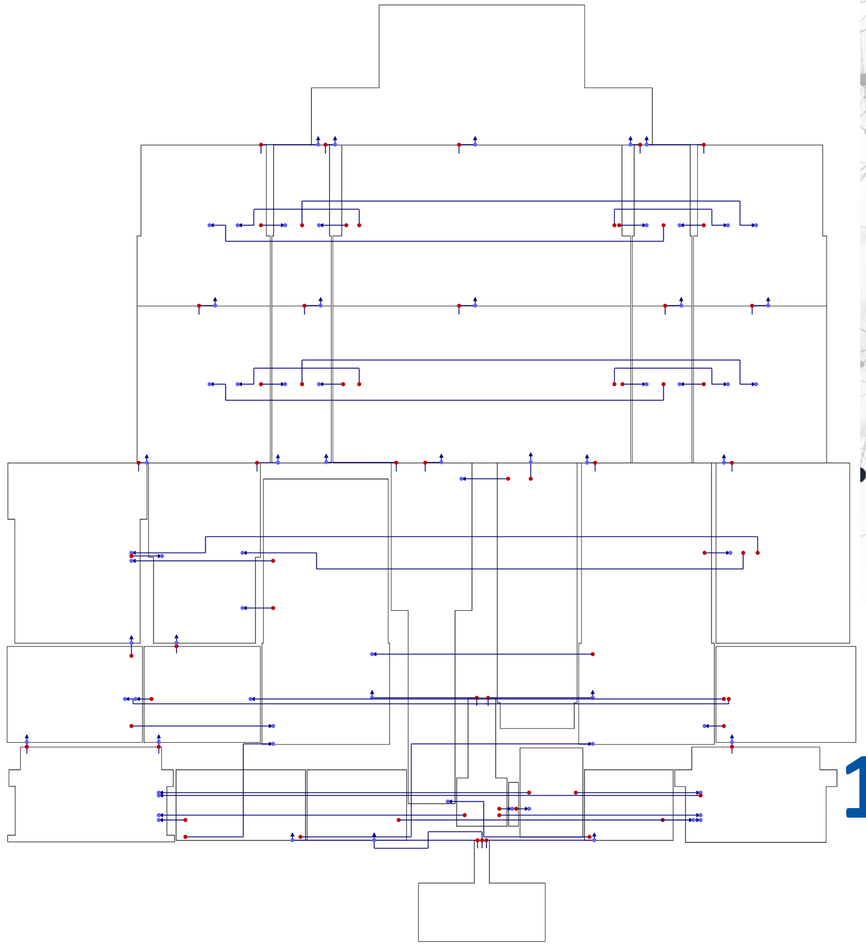
A. l. #/r. r. #	1	2	3	4	5	6	7
	40	40	40	40	40	40	50
26	125	225	325	425	525	625	50
25	125	225	325	425	525	625	50
24	123	223	323	423	523	623	50
23	123	223	323	423	523	623	50
22	121	221	321	421	521	621	50
21	121	221	321	421	521	621	50
20	119	219	319	419	519	619	50
19	119	219	319	419	519	619	50
18	117	217	317	417	517	617	50
17	117	217	317	417	517	617	50
16	115	215	315	415	515	615	50
15	115	215	315	415	515	615	50
14	113	213	313	413	513	613	50
13	113	213	313	413	513	613	50
12	10	10	10	10	10	10	10
11	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
9	10	10	10	10	10	10	10
8	10	10	10	10	10	10	10
7	10	10	10	10	10	10	10
6	10	10	10	10	10	10	'NULL'
5	10	10	10	10	10	'NULL'	'NULL'
4	10	10	10	10	'NULL'	'NULL'	'NULL'
3	10	10	10	'NULL'	'NULL'	'NULL'	'NULL'
2	10	10	'NULL'	'NULL'	'NULL'	'NULL'	'NULL'
1	10	'NULL'	'NULL'	'NULL'	'NULL'	'NULL'	'NULL'





MELCOR NODALIZATION: PC, CTMT

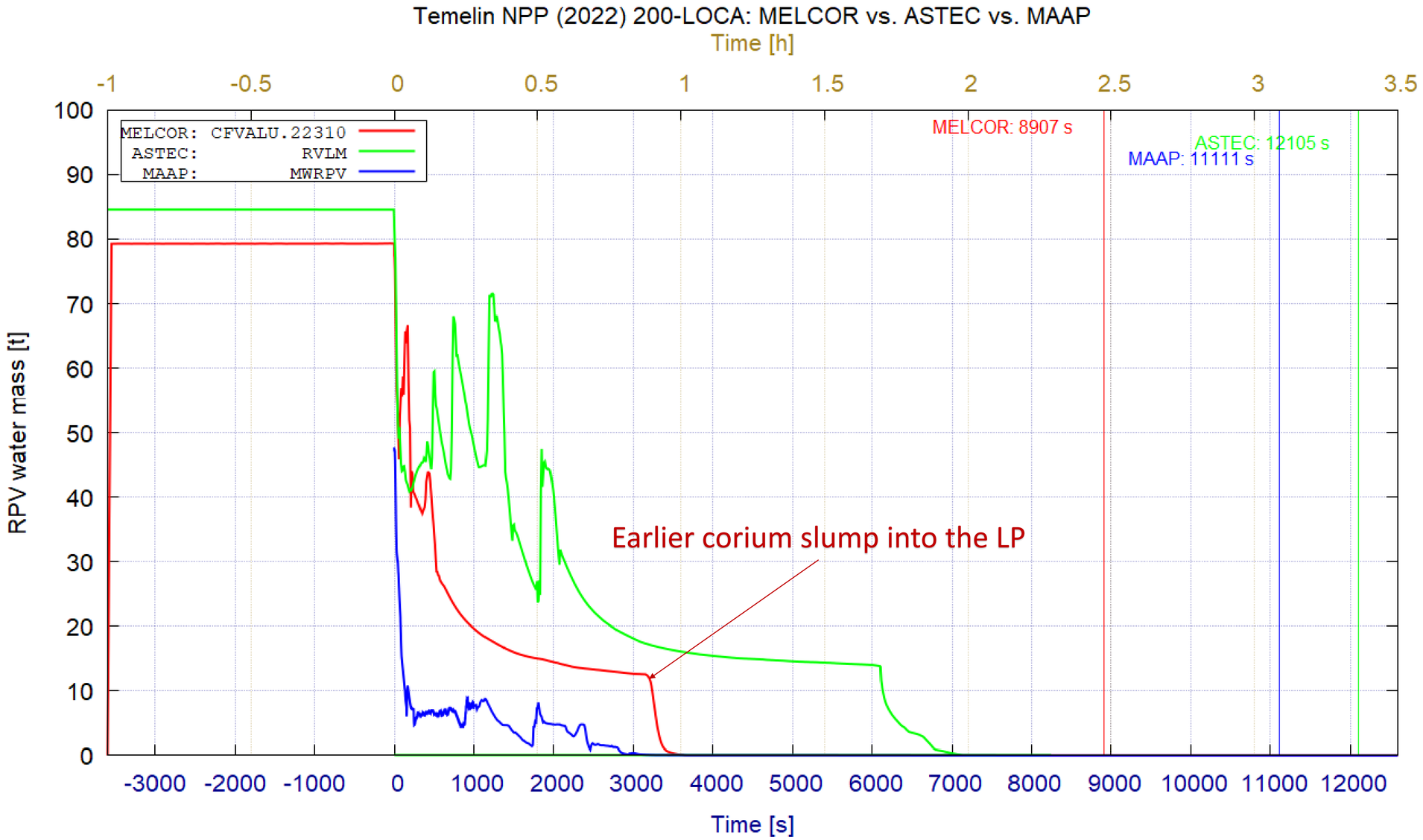




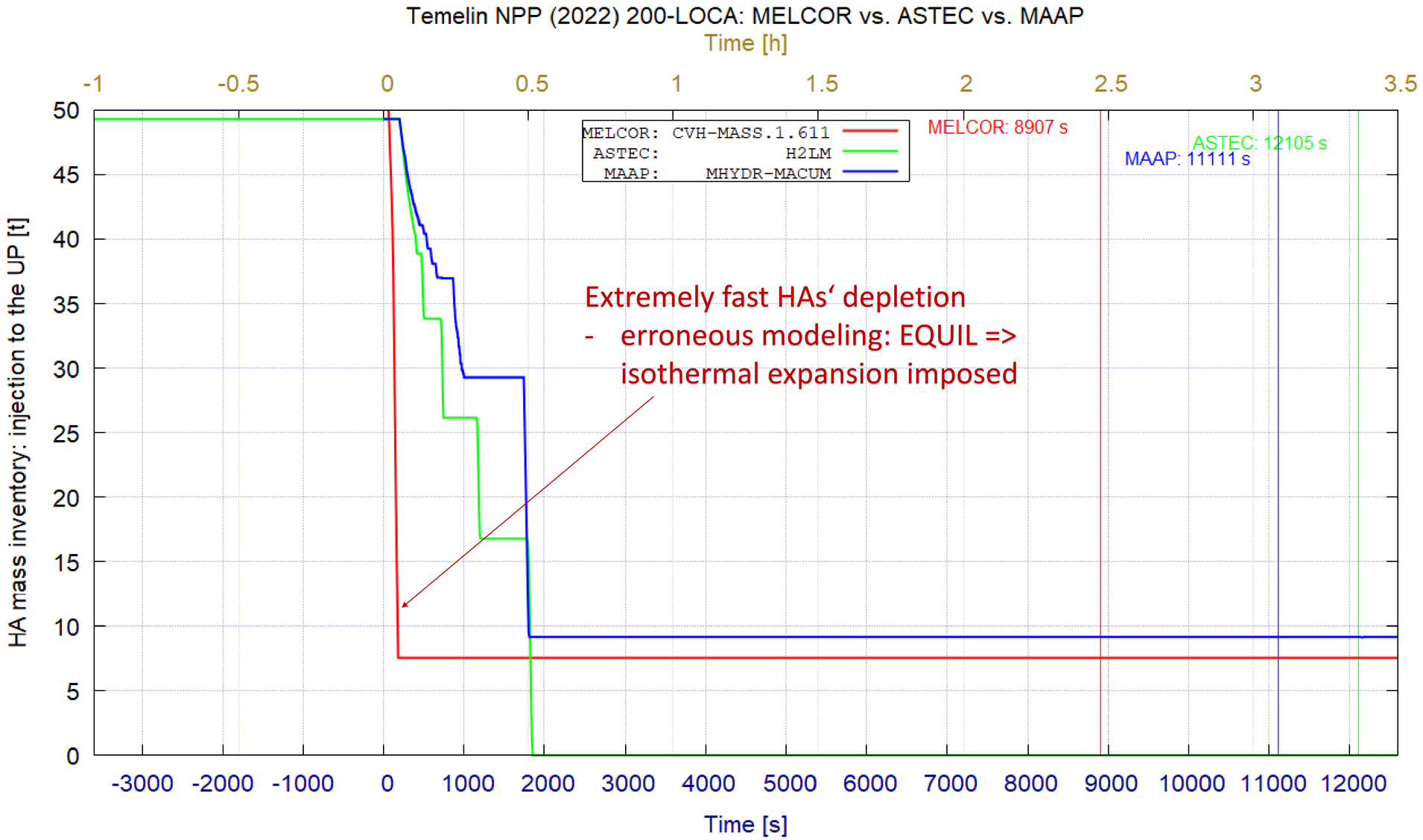
SCENARIO DEFINITON, CODES USED

- LB LOCA (equivalent Ø200 mm) @ CL of 4th loop (single, with connected PRZ)
- SBO => no active systems
- Without IVMR => RPV failure
- Codes used:
  - *MELCOR 2.2.21402*
  - *ASTEC V3.1*
  - *MAAP 5.03-VVER*
- Results:
  - Red- MELCOR: $t_{RPV\text{-}failure}$ = 8907 s (2.47 h)
  - Green-ASTEC: $t_{RPV\text{-}failure}$ = 12105 s (3.36 h)
  - Blue- MAAP: $t_{RPV\text{-}failure}$ = 11111 s (3.09 h)

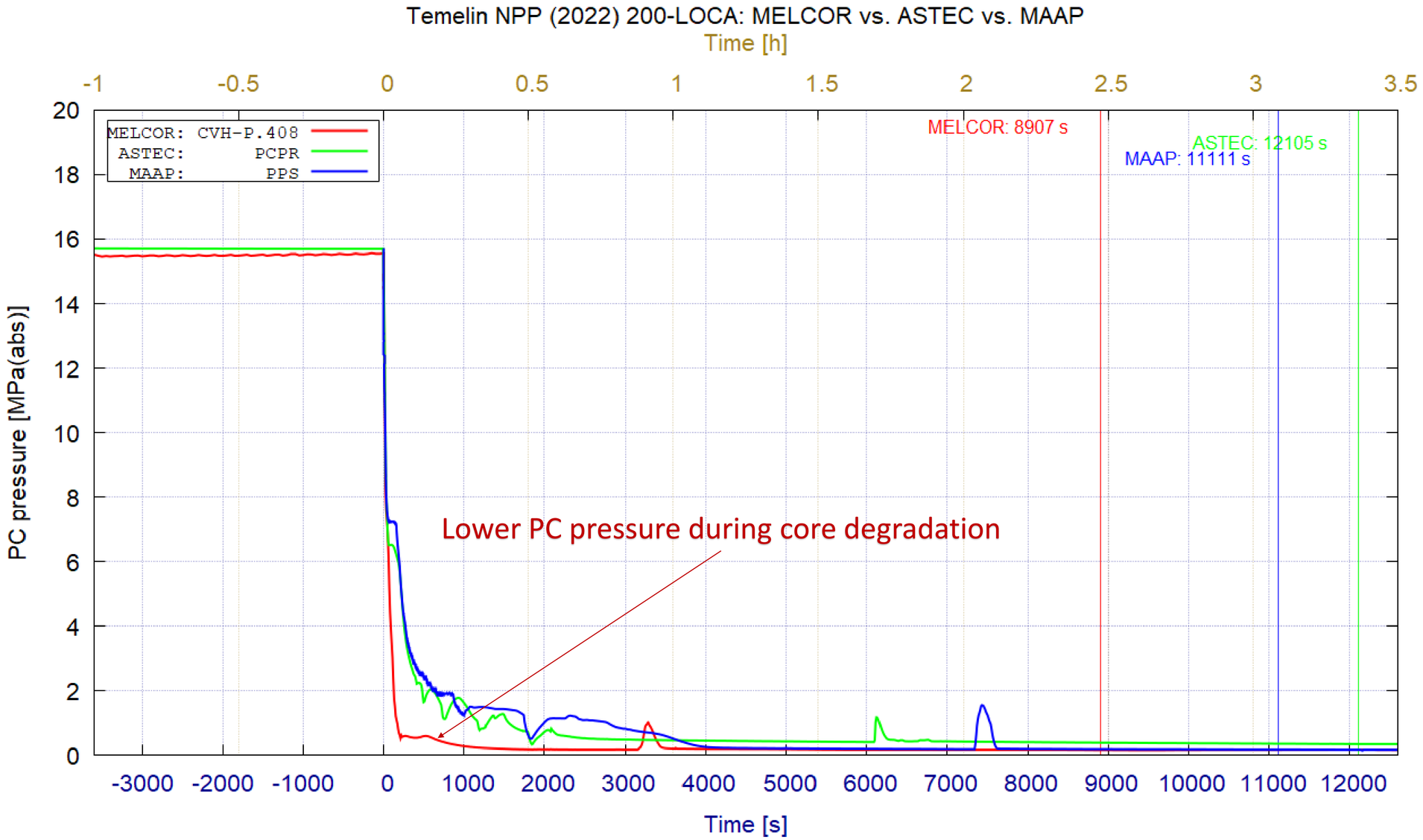
RPV WATER INVENTORY



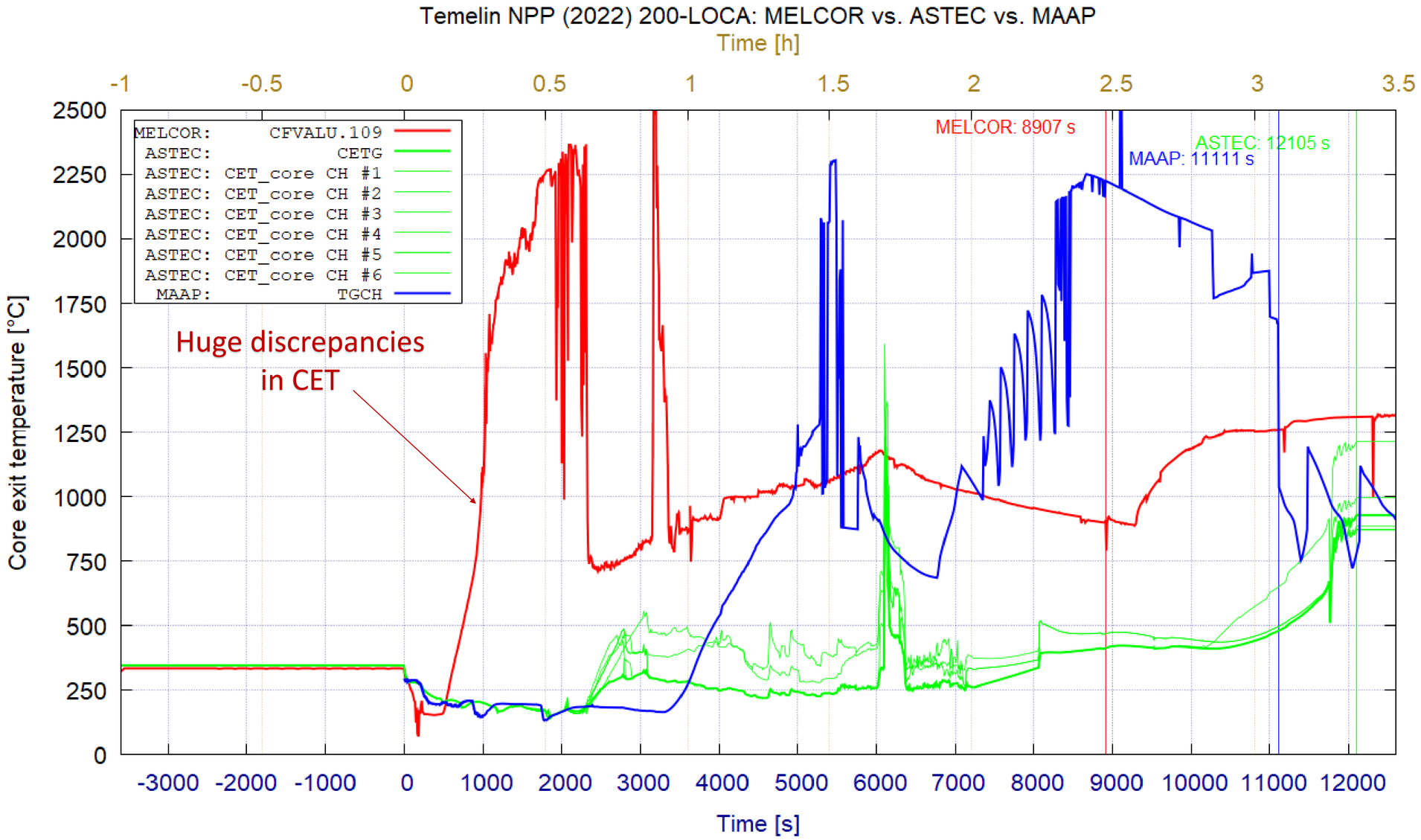
HA INJECTION



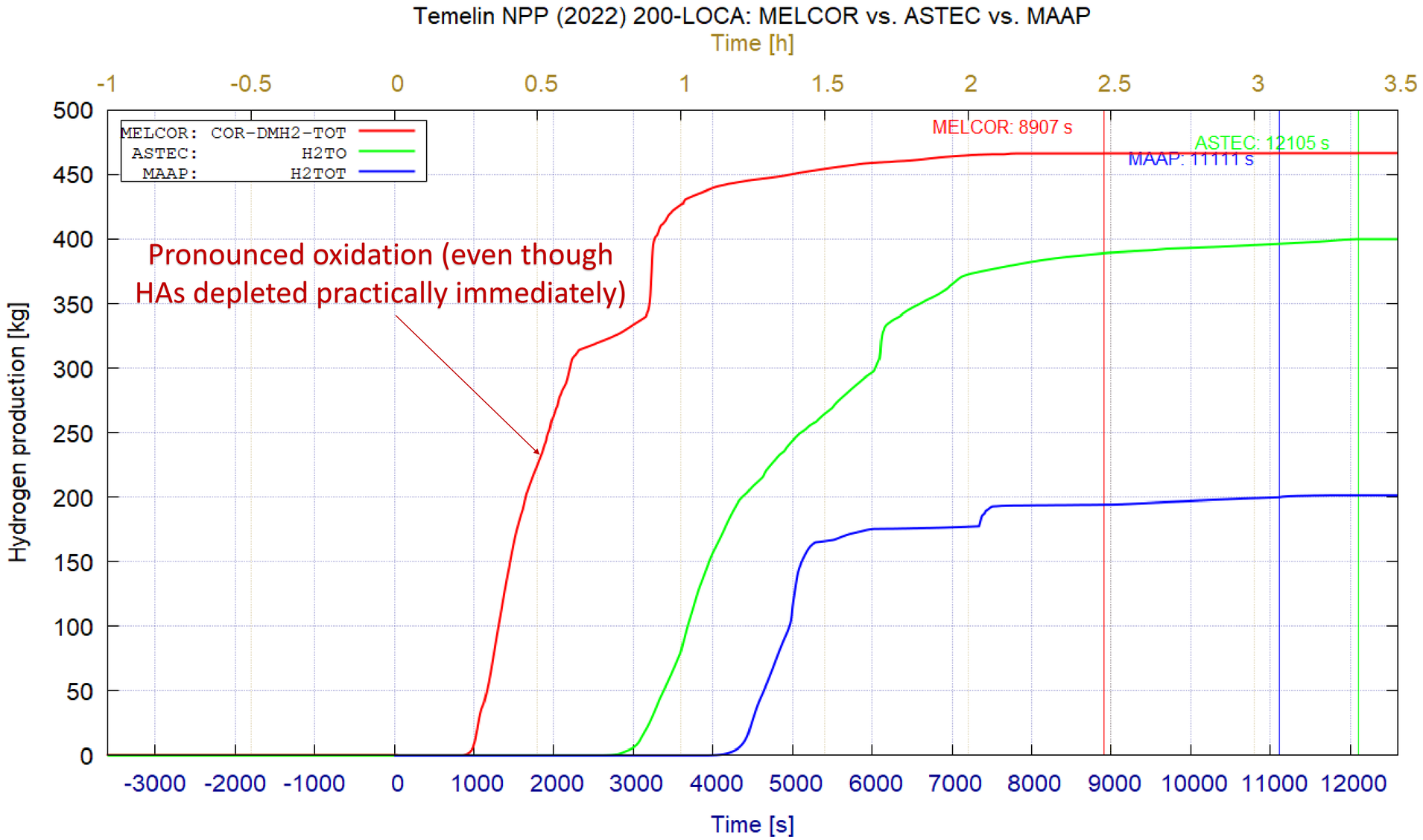
PRIMARY PRESSURE



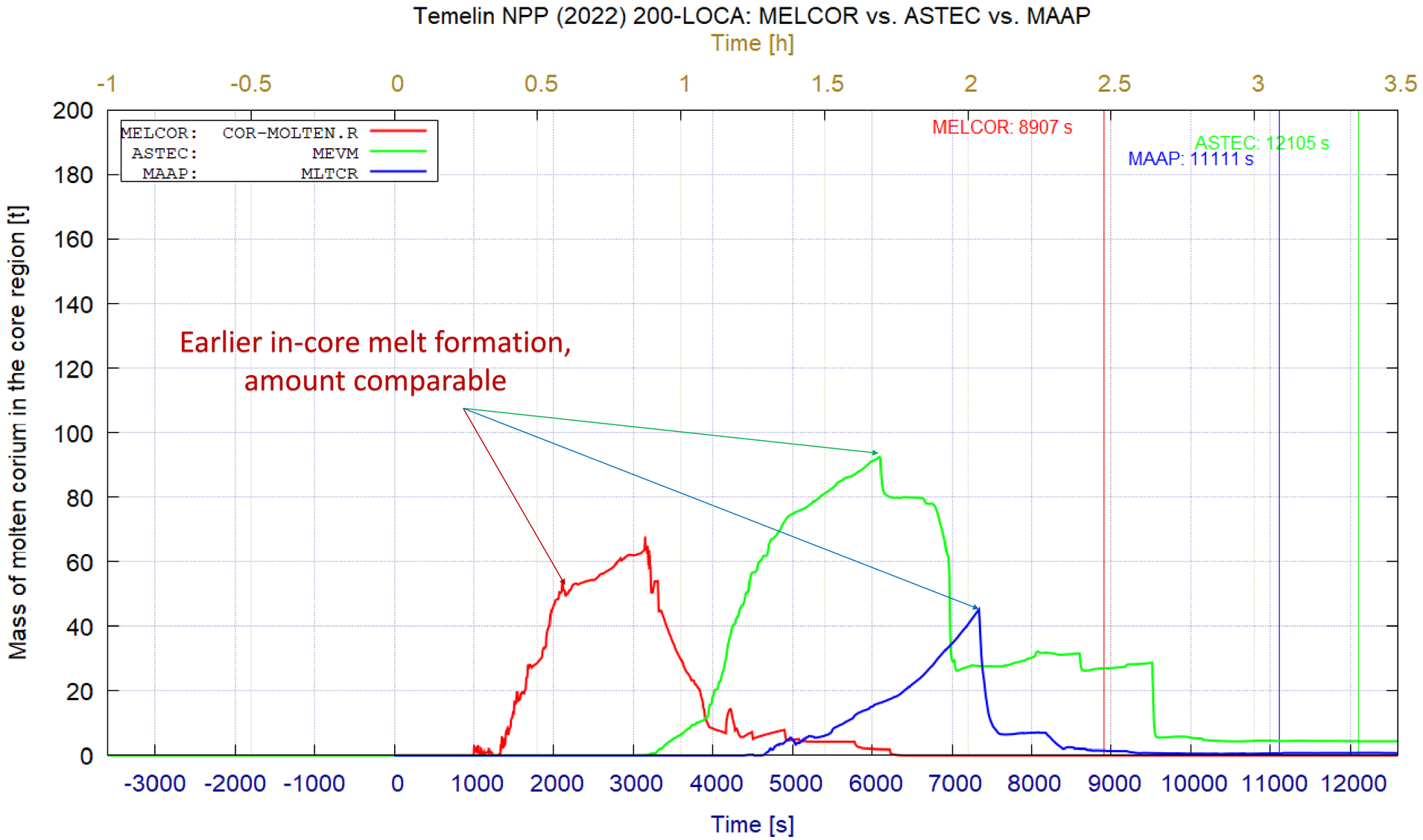
CORE EXIT TEMPERATURE



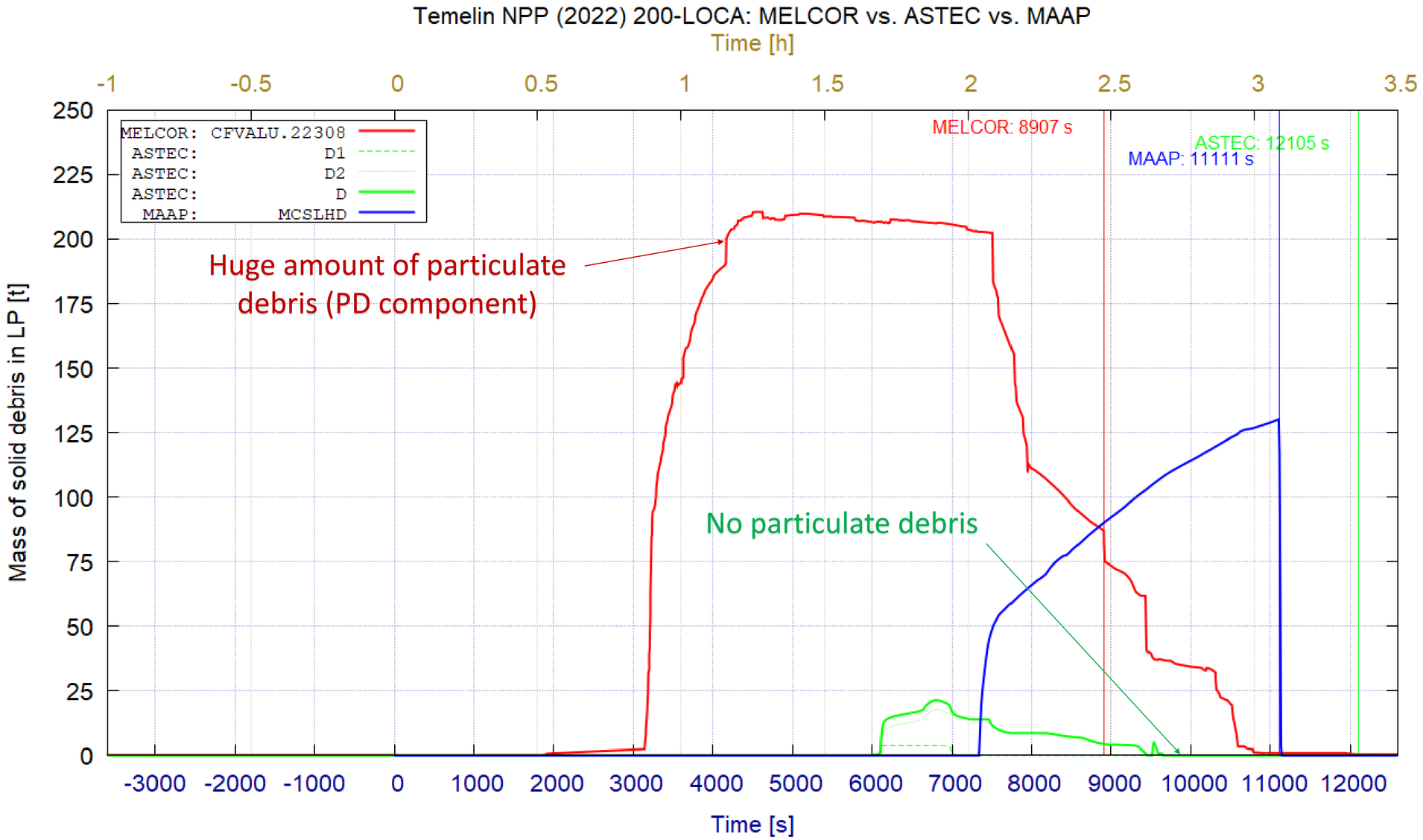
H2 PRODUCTION



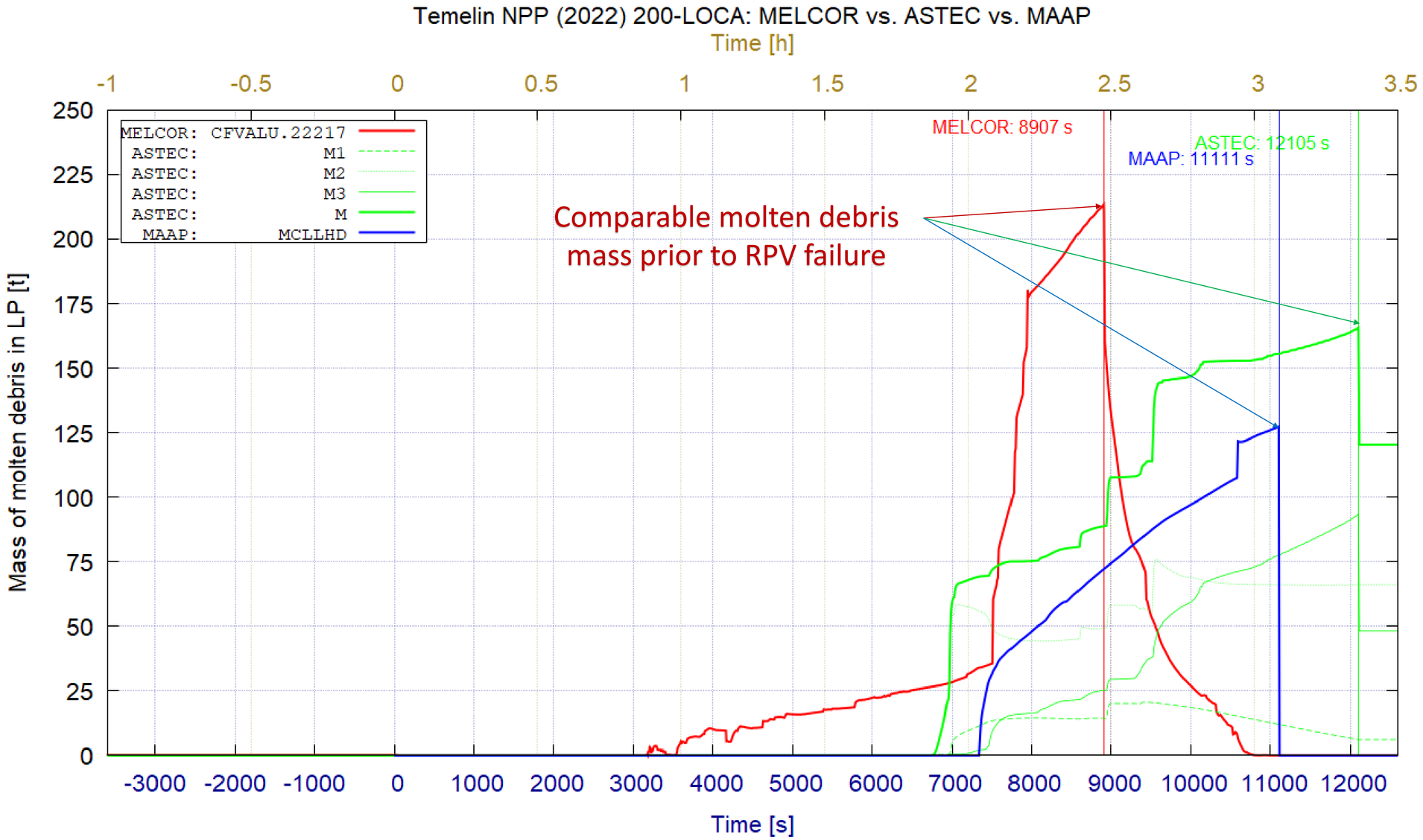
MOLTEN MASS IN THE CORE



SOLID DEBRIS IN LP



MOLTEN DEBRIS IN LP



STATE OF CORIUM AT TIME OF LH FAILURE

- „Liquidity“ of corium influences its spread-ability after RPV failure

Code	*t_RPV-fail [h]*	*Solid debris [t]*	*"Molten" pool [t]*	*Total corium [t]*	*Solid/"Molten" fraction [%]*
MELCOR	2.47	88	213	**301**	29.2
ASTEC	3.36	0	164	**164**	0.0
MAAP	3.09	128	127	**255**	50.2

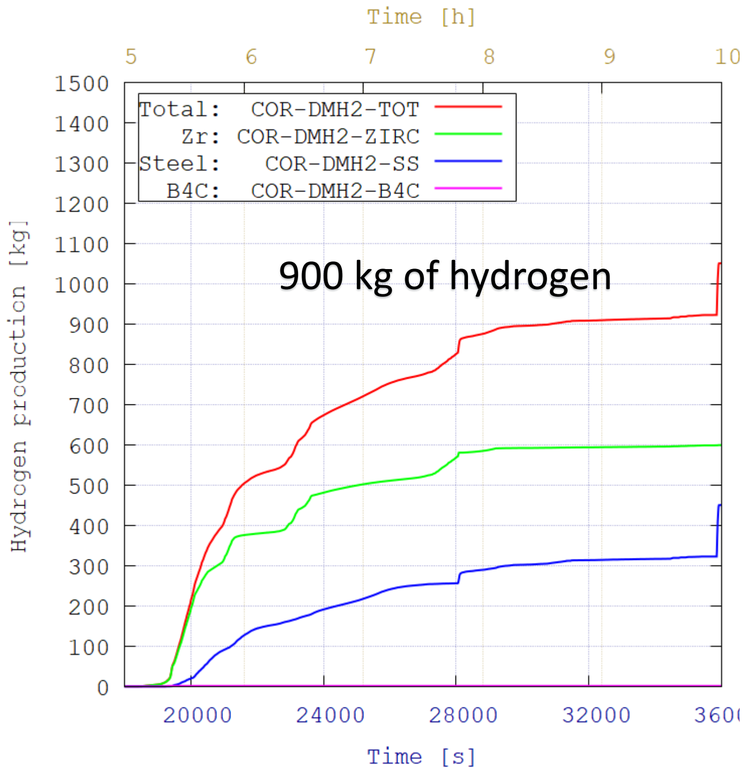
MELCOR: shortest time to failure, largest amount of molten corium & overall debris

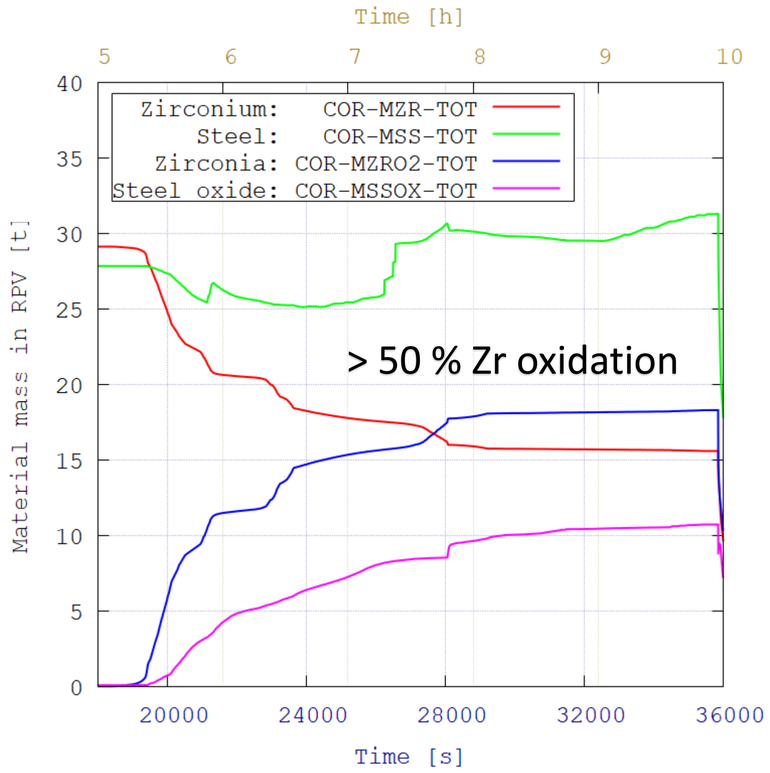
ASTEC: longest time to failure, no solid debris

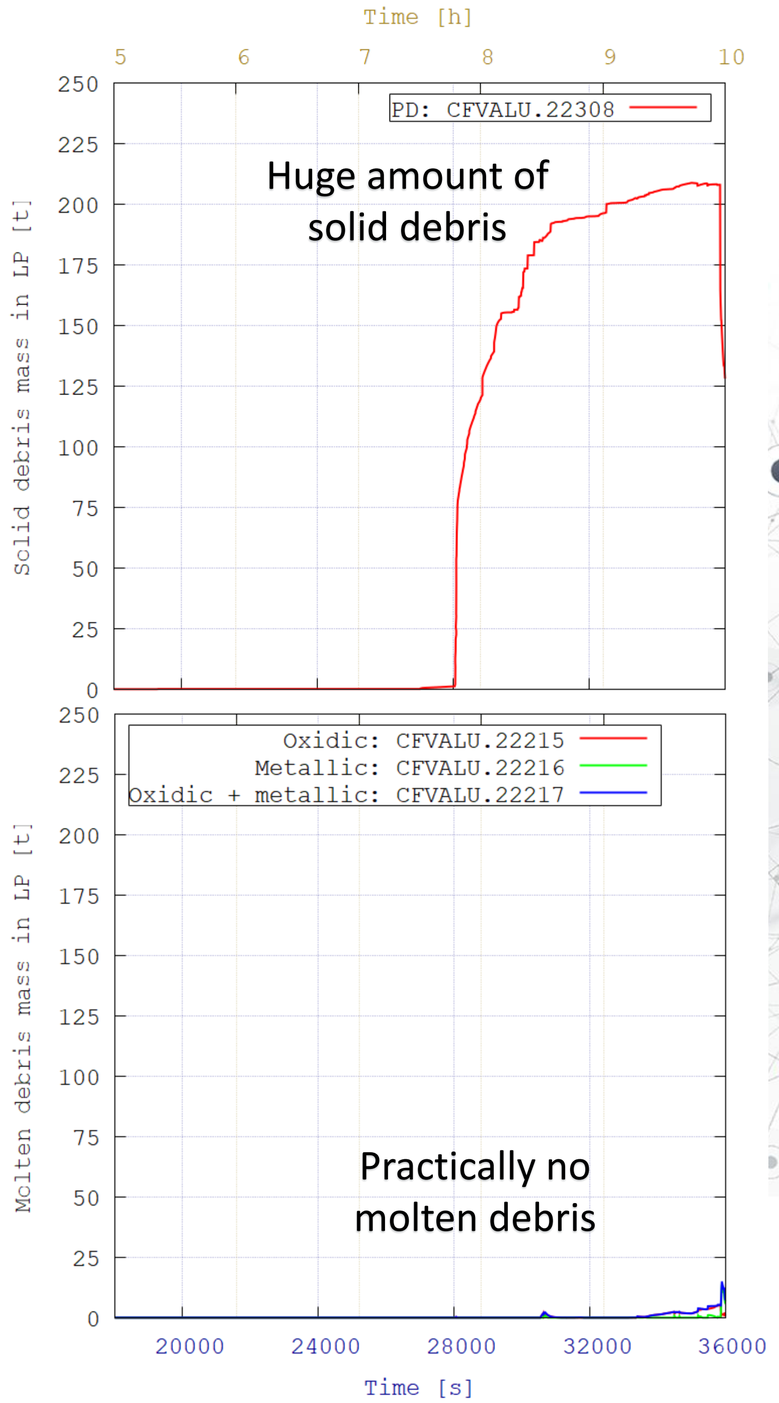
MAAP: rather long time to failure & large amount of debris, 0.5/0.5 of solid/molten debris

RECENT UPDATE: SBO SCENARIO

- The same input model
- Evaluated until RPV failure (~10 h)





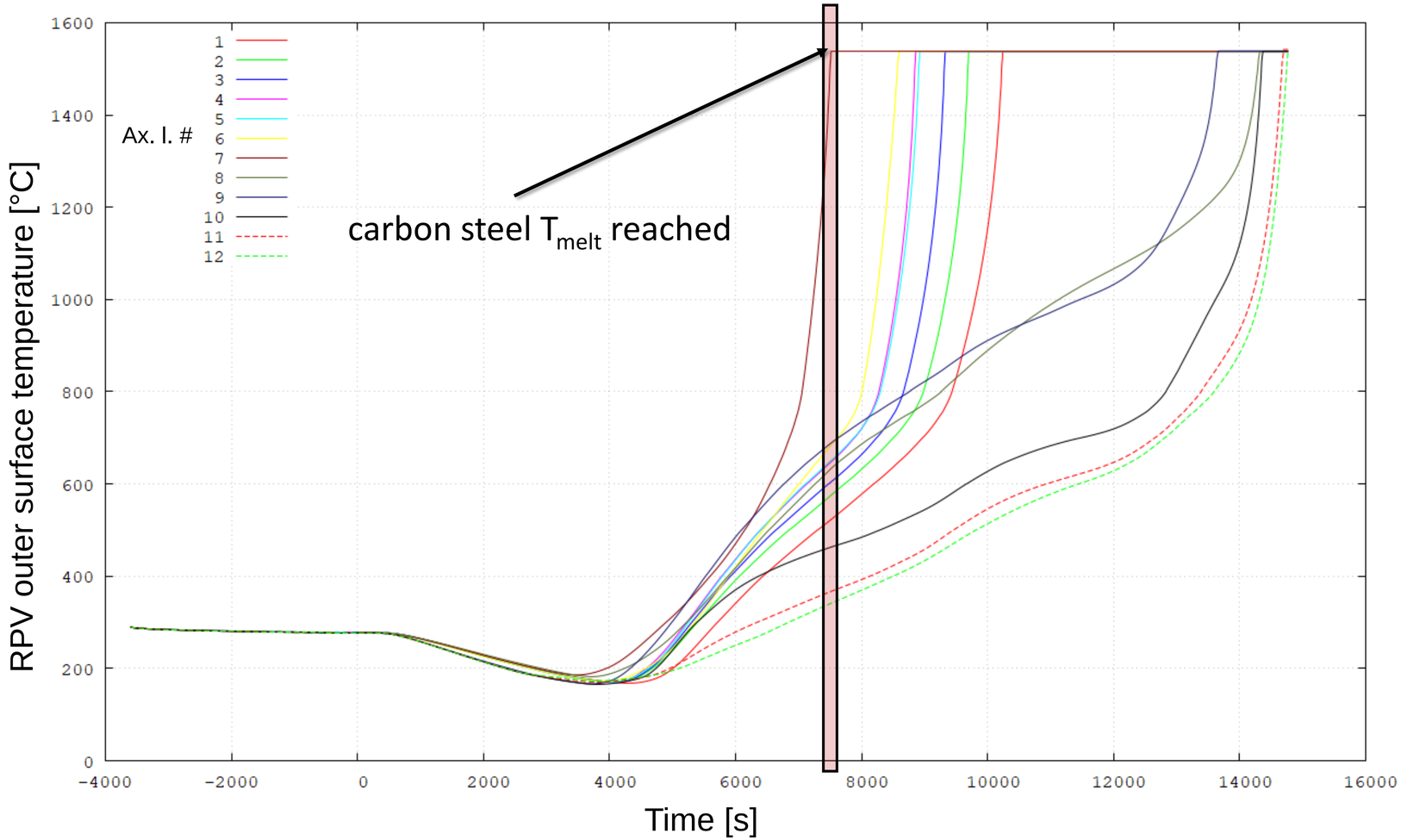


Encountered MELCOR issues (21402)

ABSENCE OF LH FAILURE

- Complete RPV wall melt-through, but no LHF or corium ejection!!!

```
…
  *** LH MELTING HAS STARTED AT MESH 17 OF SEGMENT  3
/SMESSAGE/  TIME= 7.53137E+03 CYCLE= 1001784
  *** LH MELTING COMPLETE AT MESH  1 OF SEGMENT  7
/SMESSAGE/  TIME= 7.57136E+03 CYCLE= 1005783
  *** LH MELTING HAS STARTED AT MESH 15 OF SEGMENT  5
/SMESSAGE/  TIME= 7.57160E+03 CYCLE= 1005807
  *** LH MELTING HAS STARTED AT MESH 21 OF SEGMENT  1
…
```

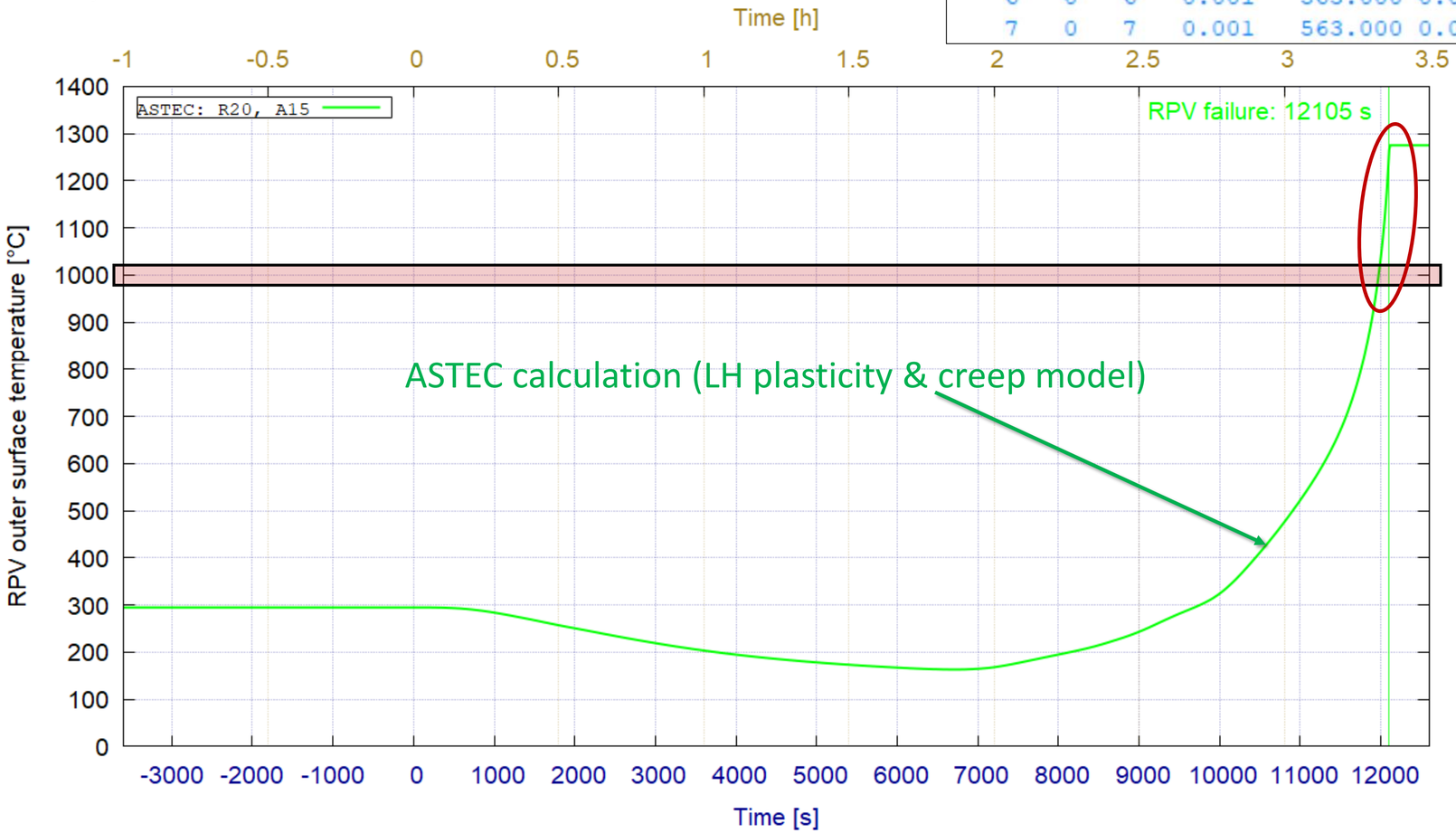


ALTERNATIVE LH FAILURE CRITERION

- Virtual „penetrations“ defined
- Failure: T=1000 °C at outer RPV surface
  - „Verified“ by ASTEC simulation

„Tiny“ penetrations defined

```
COR_PEN 7
!    NP   IPNREF   IRP XMPN     TPN ASPN     AXPN     DFLPN    ICFLHF
     1    0    1    0.001    563.000 0.001 0.001 0.5 'CF_3012'
     2    0    2    0.001    563.000 0.001 0.001 0.5 'CF_3022'
     3    0    3    0.001    563.000 0.001 0.001 0.5 'CF_3032'
     4    0    4    0.001    563.000 0.001 0.001 0.5 'CF_3042'
     5    0    5    0.001    563.000 0.001 0.001 0.5 'CF_3052'
     6    0    6    0.001    563.000 0.001 0.001 0.5 'CF_3062'
     7    0    7    0.001    563.000 0.001 0.001 0.5 'CF_3072'
```



SPR PACKAGE 2.2.21402

CONTAINMENT SPRAY SOURCES

SRC	C.V.	CONTROL C.F.	TEMP C.F.	DROPLET TEMP (K)	FLOW C.F.	FL-RATE (M**3/S)	HS RAIN T.P.	NO. DROP SIZES	STAT
SPR_1	CVH_899	CF_604	CF_699	3.145E+02	CF_607	1.7444E-01	---	1	ON
SPR_2	CVH_899	CF_200604	CF_200699	3.196E+02	CF_200607	0.0000E+00	---	1	OFF

Though spray number 1 is ON and has non zero flow rate, there are zero mass transfer data.

DROPLET DISTRIBUTIONS FOR SOURCE SPR_1

GROUP NO.	DIAMETER M	REL. FREQ.	FLOW RATE DROPS/SEC	DROPLET MASS KG
1	8.0000E-04	1.0000E+00	6.5070E+08	2.6594E-07

SPRAY JUNCTION DATA FOR SOURCE SPR_1

JUNCTION NO.	FROM VOLUME	TO VOLUME	TRANSMISSION FACTOR
1	CVH_899	CVH_881	1.00000E+00
2	CVH_881	CVH_861	1.00000E+00
3	CVH_861	CVH_852	5.00000E-02
4	CVH_861	CVH_833	1.50000E-01
5	CVH_861	CVH_832	2.00000E-02
6	CVH_861	CVH_831	2.00000E-02

This anomaly occurs only if spray system is using a junction data SPR_JUN

SPRAY HEAT AND MASS TRANSFER DATA

CONTROL VOL	HEAT TRAN RATE W	MASS TRAN RATE KG/S
CVH_810	0.00000E+00	0.00000E+00
CVH_824	0.00000E+00	0.00000E+00
CVH_831	0.00000E+00	0.00000E+00
CVH_832	0.00000E+00	0.00000E+00
CVH_833	0.00000E+00	0.00000E+00
CVH_852	0.00000E+00	0.00000E+00
CVH_861	0.00000E+00	0.00000E+00
CVH_881	0.00000E+00	0.00000E+00
CVH_899	0.00000E+00	0.00000E+00

OBSERVATIONS

- Rather pronounced core oxidation
  - Due to:
    - Larger surface of Zr SGs (for new FAs)
    - Earlier supporting structure components slumping?...
    - Water accessibility into in the gap between *barrel LH <=> RPV wall*?...
- Large amount of solid debris prior to RPV failure observed
  - Due to higher T_{melt} of oxides (in agreement with large H_2 production)
  - Completely different to ASTEC results (which predicts no solid debris)
- Some bugs/issues encountered
  - r2023 to be tested!

Thank you for the attention!

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