Recent experience with MELCOR

Juraj Jančovič

MELCOR – main tool for severe accident analyses at VUJE

- Almost exclusively VVER440 models
  VVER440 (6-loop, PWR, with BWR like fuel assemblies (fuel canisters),
  after reactor trip configuration with fuel and also fuel bypass in the lower plenum),

- MELCOR 1.8.3 – two-loop model (single and fivefold loop), up to 2004,

- MELCOR 1.8.5 RK – (2004 – 2020), "happy times", three-loop model, many successful projects,
  hundreds of analyses, (6/2004 MELCOR 1.8.5 RK version and model still kept as a life boat),

- MELCOR 2.x (2010 -) – new reactor model developed and "welded" onto 3-loop model
  translated into 2.x format.

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MELCOR – main tool for severe accident analyses at VUJE

- Presently:

- 15254 (10/2019) regularly used with various success,
  (safety report analyses, using all my faculties and cunning, ultimately successful),

- 18019 (12/2020), 21402 (12/2021) and recent r2023 (3/2023) used sparsely and usually in the mode "we shall watch and pray",

- MELCOR 2.2 VVER440 model translated by Robert Sanders into MELCOR 1.8.6 to be used in the full scope simulator of Bohunice V2 NPP.

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Four crashes of MELCOR (1)

- Nr. 1 – in fact not a real crash. Just a stop of calculation.

- Information is provided that calculation requires some activity that cannot be physicaly done. Such as a pump wants to take water out of volume where there is no more pool mass.

- Very helpfull – leads to computational model repair/upgrade.

Four crashes of MELCOR (2)

- Nr. 2 – there is information where there is instability, hinting a solution.

- In shown case usually helps:

- pool/atmosphere heat transfer fraction change,
- time step change,
- turning off of mass transfer at the HS.

```
<Diagnostic Message> Time= 4.5607E+04 Dt= 2.5269E-05 Cycle= 696904 (HS ) L,C= 2,447146
 Attempted cycle advancement was unsuccessful / DT reduced to = 1.2634E-05
<Diagnostic Message> Time= 4.5607E+04 Dt= 1.2634E-05 Cycle= 696904 (HS ) L,C= 3,447147
 ERROR IN TEMPERATURE ALGORITHM EXCEEDS DESIRED TOLERANCE
 FOR HEAT STRUCTURE HS00051          :
 TEMPERATURE ERROR =  3.219E-03,  TOLERANCE =  5.000E-04
<Diagnostic Message> Time= 4.5607E+04 Dt= 1.2634E-05 Cycle= 696904 (MEX) L,C= 3,447148
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 ALL FUTURE REQUEST DURING THIS EXECUTION IGNORED.
<Diagnostic Message> Time= 4.5607E+04 Dt= 2.0023E-05 Cycle= 696905 (MEX) L,C= 3,447149
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 ALL FUTURE REQUEST DURING THIS EXECUTION IGNORED.
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 HS PACKAGE TIME STEP CUT
 TEMPERATURE CONVERGENCE FAILURE FOR HEAT STRUCTURE HS00051          :
 TEMPERATURE ERROR =  1.031E-02
<Diagnostic Message> Time= 4.5607E+04 Dt= 5.0295E-05 Cycle= 696907 (HS ) L,C= 3,447152
 HS PACKAGE CUT TIME STEP
 FATAL ERROR FOR HEAT STRUCTURE HS00051
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  HS  package requested repeating cycle 696907 with halved timestep
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 TEMPERATURE ERROR =  1.034E-02
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<Diagnostic Message> Time= 4.5607E+04 Dt= 1.9927E-05 Cycle= 696908 (HS ) L,C= 3,447160
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 DT LESS THAN DTMIN - LAST DT ATTEMPTED =  1.99270E-05
<Diagnostic Message> Time= 4.5607E+04 Dt= 1.9927E-05 Cycle= 696908 (HS ) L,C= 0,447164
 TRACE TURNED ON AND CYCLE REPEATED BEFORE ABORT
<Diagnostic Message> Time= 4.5607E+04 Dt= 1.9927E-05 Cycle= 696908 (HS ) L,C= 2,447165
 Attempted cycle advancement was unsuccessful / DT reduced to = 1.0000E-05
<Diagnostic Message> Time= 4.5607E+04 Dt= 1.0000E-05 Cycle= 696908 (HS ) L,C= 0,447166
 MEXLOP fatal error pass - Initialization
 DT= 1.00000E-05  IERR=      1 MEXTRC=      1
<Diagnostic Message> Time= 4.5607E+04 Dt= 1.0000E-05 Cycle= 696908 (MEX) L,C= 0,447167
 MEXLOP fatal error pass - Communication
 DT= 1.00000E-05  IERR=      1 MEXTRC=      1
<Diagnostic Message> Time= 4.5607E+04 Dt= 1.0000E-05 Cycle= 696908 (MEX) L,C= 0,447168
 MEXLOP fatal error pass - Advancement
 DT= 1.00000E-05  IERR=      1 MEXTRC=      1
```

Four crashes of MELCOR (3)

Four crashes of MELCOR (3)

- Nr. 3 – there is a hint where there can be a problem,
  no concrete information provided but helpful. (MES, extdiag and MELCOR DIA files) (15254)
  Another example in the right picture.

Four crashes of MELCOR (4)

- Nr. 4 – crash from full time step, no report, all files as if electricity switch turned off.

- OUT file (21402)

- Hoping that such a crash is/will be eliminated.

```
CYCLE= 521880 T= 4.626274E+04 DT(MAX)= 1.000000E-01 CPU= 1.642541E+05
CYCLE= 521881 T= 4.626284E+04 DT(MAX)= 1.000000E-01 CPU= 1.642542E+05
CYCLE= 521882 T= 4.626294E+04 DT(MAX)= 1.000000E-01 CPU= 1.642543E+05
CYCLE= 521883 T= 4.626304E+04 DT(MAX)= 1.000000E-01 CPU= 1.642544E+05
CYCLE= 521884 T= 4.626314E+04 DT(MAX)= 1.000000E-01 CPU= 1.642545E+05
CYCLE= 521885 T= 4.626324E+04 DT(MAX)= 1.000000E-01 CPU= 1.642546E+05
CYCLE= 521886 T= 4.626334E+04 DT(MAX)= 1.000000E-01 CPU= 1.642547E+05
CYCLE= 521887 T= 4.626344E+04 DT(MAX)= 1.000000E-01 CPU= 1.642548E+05
CYCLE= 521888 T= 4.626354E+04 DT(MAX)= 1.000000E-01 CPU= 1.642549E+05
CYCLE= 521889 T= 4.626364E+04 DT(MAX)= 1.000000E-01 CPU= 1.642550E+05
CYCLE= 521890 T= 4.626374E+04 DT(MAX)= 1.000000E-01 CPU= 1.642551E+05
CYCLE= 521891 T= 4.626384E+04 DT(MAX)= 1.000000E-01 CPU= 1.642552E+05
CYCLE= 521892 T= 4.626394E+04 DT(MAX)= 1.000000E-01 CPU= 1.642552E+05
CYCLE= 521893 T= 4.626404E+04 DT(MAX)= 1.000000E-01 CPU= 1.642553E+05
CYCLE= 521894 T= 4.626414E+04 DT(MAX)= 1.000000E-01 CPU= 1.642554E+05
CYCLE= 521895 T= 4.626424E+04 DT(MAX)= 1.000000E-01 CPU= 1.642555E+05
CYCLE= 521896 T= 4.626434E+04 DT(MAX)= 1.000000E-01 CPU= 1.642556E+05
CYCLE= 521897 T= 4.626444E+04 DT(MAX)= 1.000000E-01 CPU= 1.642557E+05
CYCLE= 521898 T= 4.626454E+04 DT(MAX)= 1.000000E-01 CPU= 1.642558E+05
CYCLE= 521899 T= 4.626464E+04 DT(MAX)= 1.000000E-01 CPU= 1.642559E+05
CYCLE= 521900 T= 4.626474E+04 DT(MAX)= 1.000000E-01 CPU= 1.642560E+05
CYCLE= 521901 T= 4.626484E+04 DT(MAX)= 1.000000E-01 CPU= 1.642562E+05
CYCLE= 521902 T= 4.626494E+04 DT(MAX)= 1.000000E-01 CPU= 1.642563E+05
CYCLE= 521903 T= 4.626504E+04 DT(MAX)= 1.000000E-01 CPU= 1.642564E+05
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CYCLE= 521905 T= 4.626524E+04 DT(MAX)= 1.000000E-01 CPU= 1.642566E+05
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CYCLE= 521921 T= 4.626684E+04 DT(MAX)= 1.000000E-01 CPU= 1.642581E+05
```

The ultimate crash report

- load on a non-existing support structure ...

MELCOR lower plenum molten pool

- MP2 temperature increase up to crash…
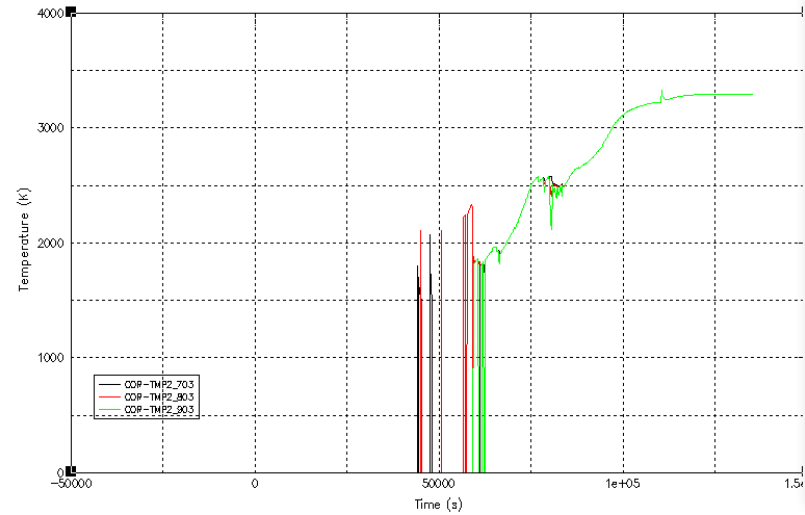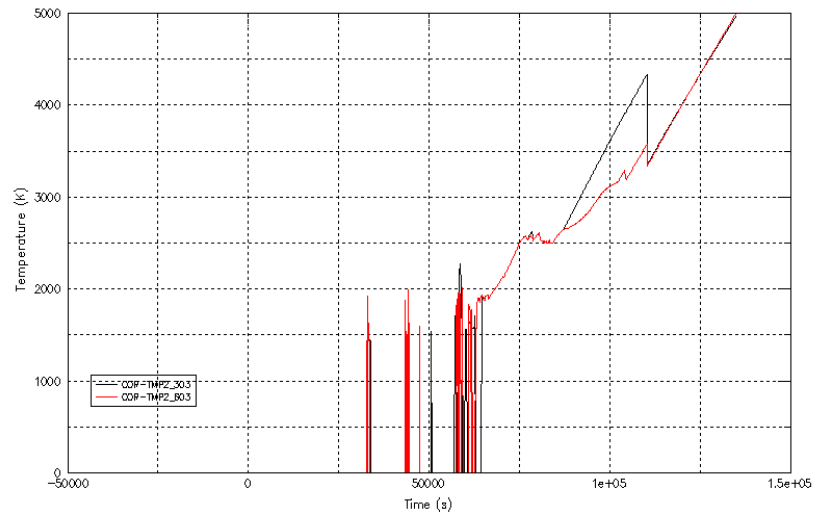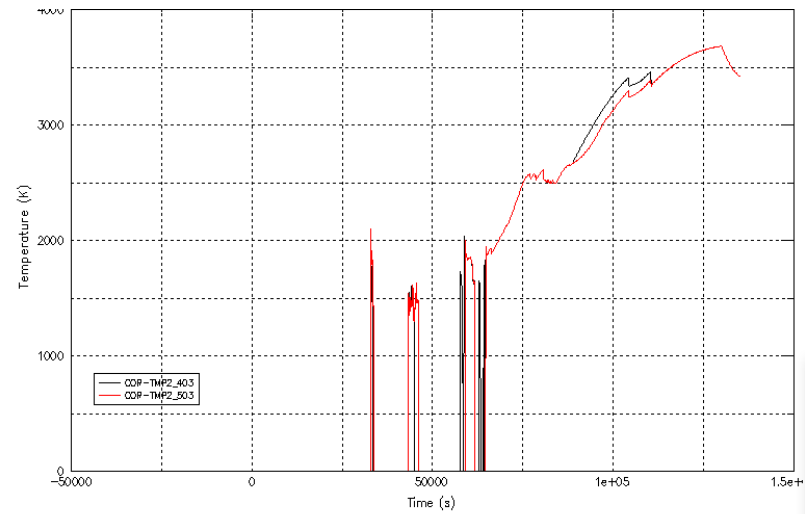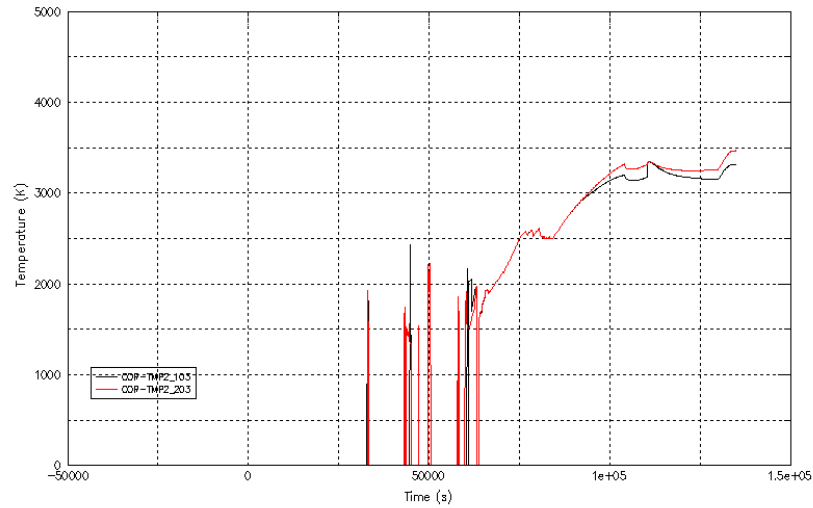
MELCOR lower plenum molten pool

- MP2 temperature increase up to crash...

- Axial level 03 contains no fuel, no cladding but does contain canister mass (also supporting and non-supporting structure mass),
- Molten pool consists of steel and zirconium (mostly steel),
- Will be analysed...

- For the time being heat transfer from the component used.

MELCOR lower plenum molten pool

- MP2 temperature increase up to crash...

```
COR_QHS   13
        1   3   9   MP2   CF00605   !jja toto je z kraja do vody v sachte reaktora
        2   3   3   MP2   CF00615
        3   3   4   MP2   CF00616
        4   3   6   MP2   CF00625
        5   3   7   MP2   CF00626
        6   3   4   MP2   CF00635
        7   3   5   MP2   CF00636
        8   3   5   MP2   CF00645
        9   3   6   MP2   CF00646
       10   3   7   MP2   CF00655
       11   3   8   MP2   CF00656
       12   3   8   MP2   CF00665
       13   3   9   MP2   CF00666
!
```

```
COR_QHS   9
        1   3   9   MP2   CF00695   !jja do vody v sachte reaktora z kazdeho MP2
        2   3   8   MP2   CF00685
        3   3   7   MP2   CF00675
        4   3   6   MP2   CF00665
        5   3   5   MP2   CF00655
        6   3   4   MP2   CF00645
        7   3   3   MP2   CF00635
        8   3   2   MP2   CF00625
        9   3   1   MP2   CF00615
!
```

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MELCOR molybdenum surge

- EXVES scenario (STC11) experienced significant increase of Mo group release
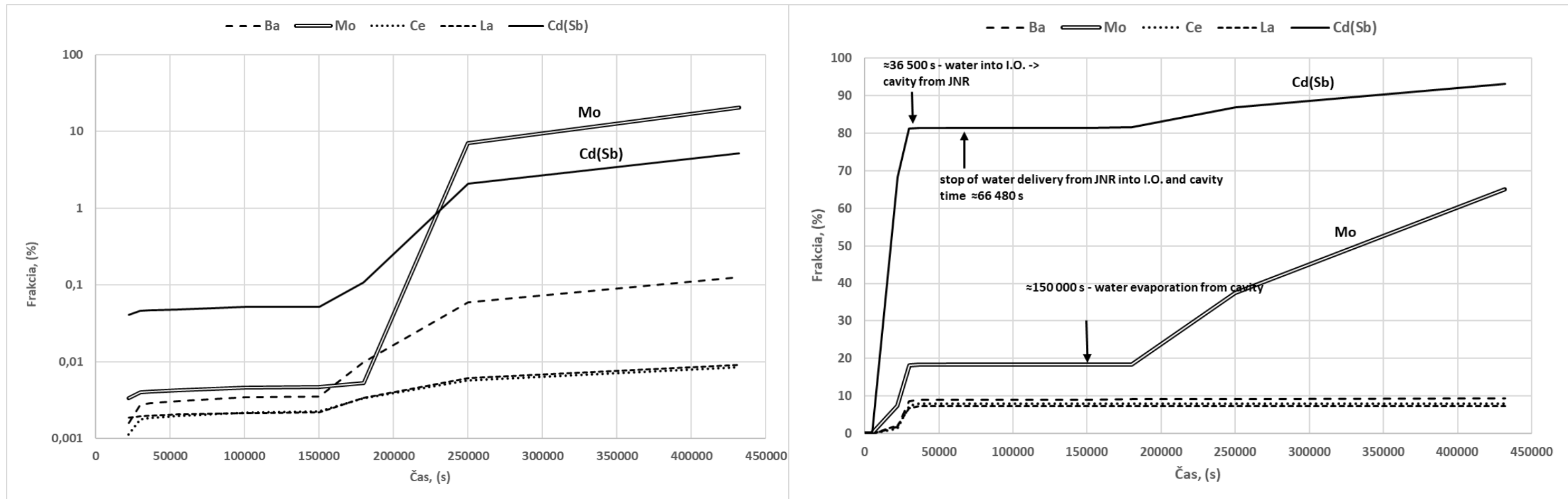
MELCOR RN retention and resuspension

- STC11 vs. STC9 – only different time of containment failure

Zdrojový člen (STC)	Popis STC	Frekven-cia [1/rok]	Príspevok k celkovej frekvencii [1/rok]	Únik do okolia, [%]		
				Xe	I	Cs
Režim 1 - Plný výkon reaktora						
STC1	Celistvosť HZ zachovaná, sprchovanie HZ, neporušená tlaková nádoba	**1,12E-06**	50,99	0,04	0,02	0,02
STC2	Celistvosť HZ zachovaná, bez sprchovania HZ, neporušená tlaková nádoba	**7,26E-07**	33,05	2,09	0,06	0,07
STC11	Neskoré porušenie HZ po porušení tlakovej nádoby, neobnovenie chladenia poškodenej AZ mimo tlakovej nádoby (bez sprchovania HZ)	**1,31E-07**	5,96	65,77	0,36	0,26
STC9	Veľmi skoré porušenie HZ s porušením tlakovej nádoby, neobnovenie chladenia poškodenej AZ mimo tlakovej nádoby (bez sprchovania HZ)	7,18E-08	3,27	97,25	33,21	32,66
STC12S	Neskoré porušenie HZ bez porušenia tlakovej nádoby (so sprchovaním HZ)	3,92E-08	1,78	42,84	0,28	0,02

STC9-MLOCA100HL-EXVES-DEPR-BS-FAILED-EARLY (4 800 s)

STC11-MLOCA100HL-EXVES-DEPR-BS-FAILED-LATE (90 000 s)

Two orders of magnitude difference.
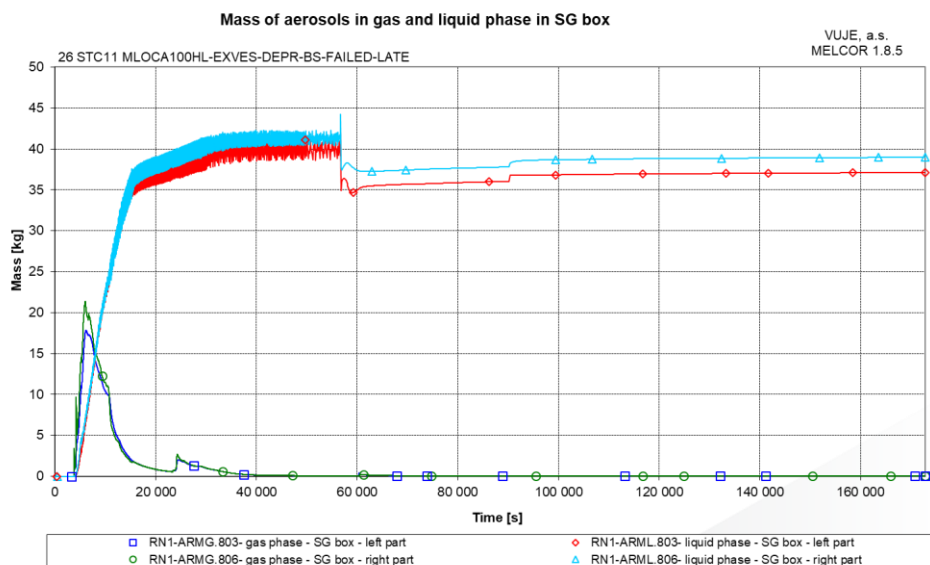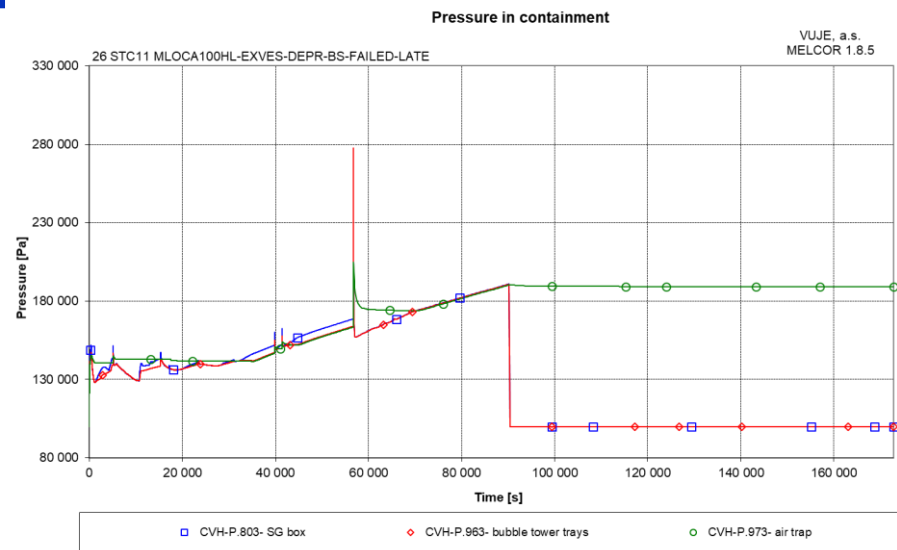
MELCOR RN retention and resuspension

■ STC11 – MELCOR 2.2 (15254)

Mass of aerosols in gas and liquid phase in SG box

Integral production of gasses in reactor cavity

Water level in reactor cavity
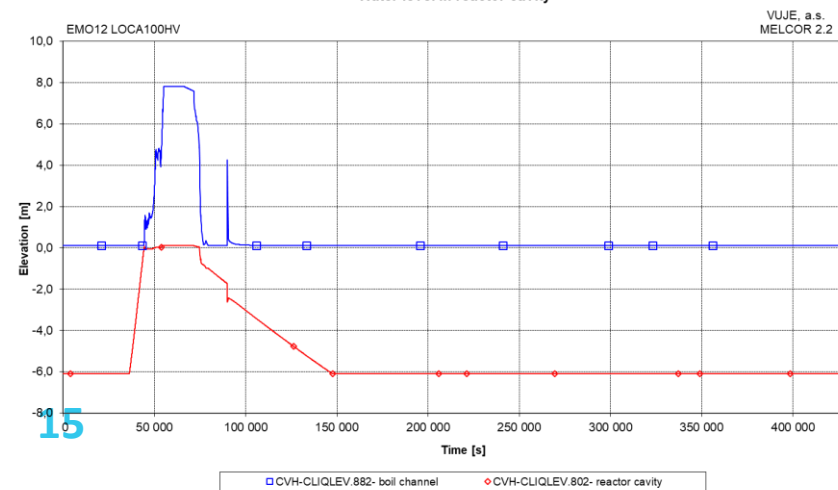
MELCOR RN retention and resuspension

■ LOCA 2x496 – IMVES – MELCOR 2.2 (15254)
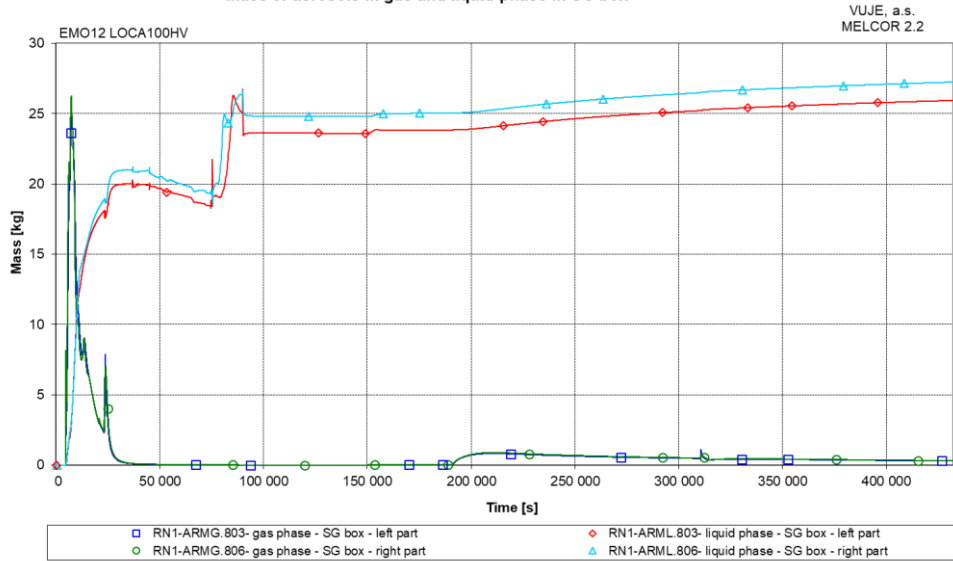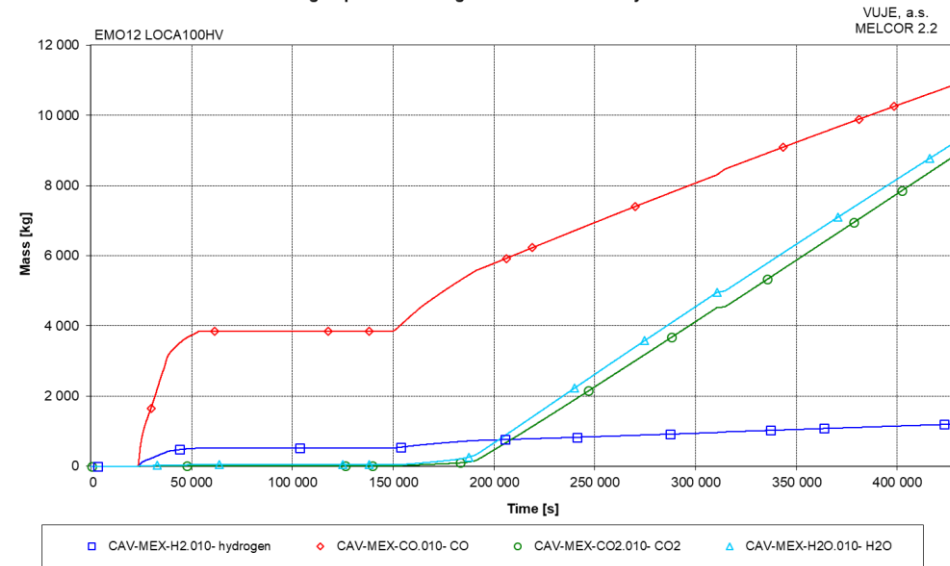
Mass of aerosols in gas and liquid phase in SG box

VUJE, a.s.
MELCOR 2.2

EMO12 LOCA

Legend:
- □ RN1-ARMG.803- gas phase - SG box - left part
- ◇ RN1-ARML.803- liquid phase - SG box - left part
- ○ RN1-ARMG.806- gas phase - SG box - right part
- △ RN1-ARML.806- liquid phase - SG box - right part

Water level in reactor cavity

VUJE, a.s.
MELCOR 2.2

EMO12 LOCA
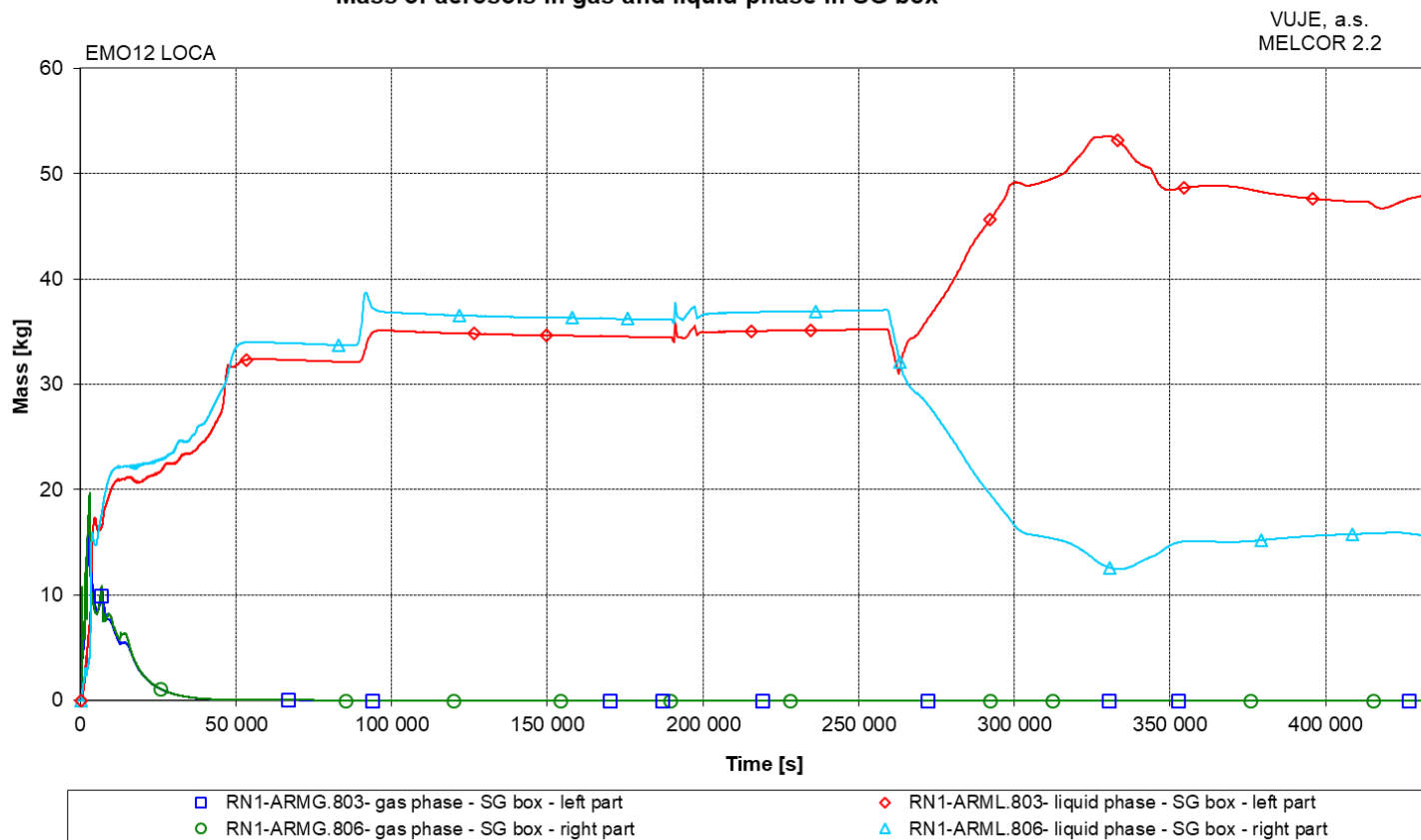
- □ CVH-CLIQLEV.882- boil channel
- ◇ CVH-CLIQLEV.802- reactor cavity
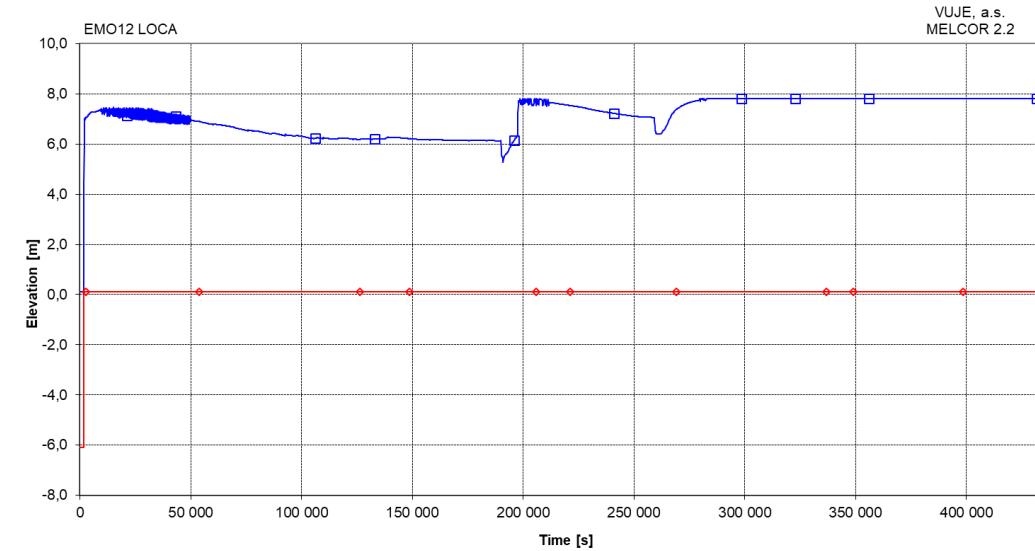
Spray water temperature

VUJE, a.s.
MELCOR 2.2

EMO12 LOCA

- □ SPR-TP.2- containment sprays
- ◇ SPR-TP.2- containment sprays
- ○ SPR-TP.3- dedicated system
- × SPR-TP.4- dedicated system

16
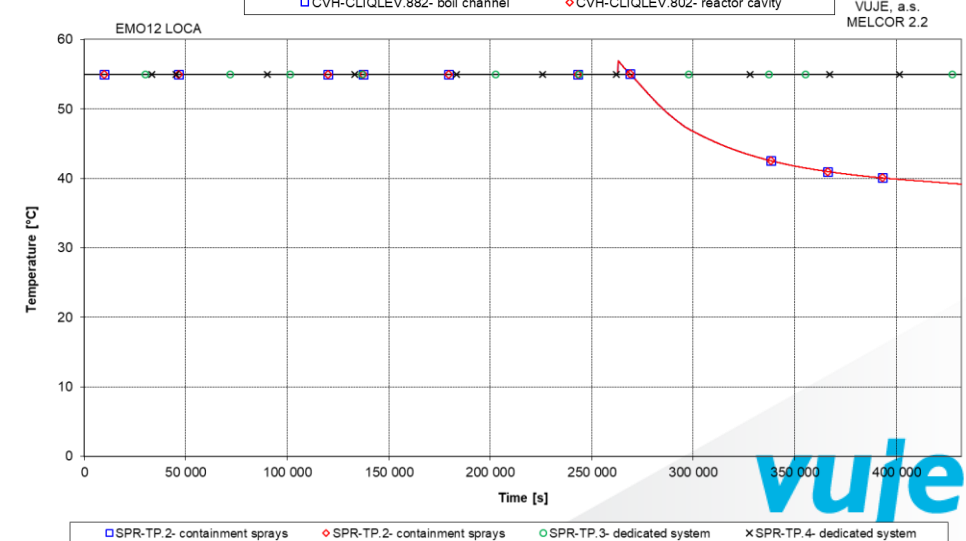
MCCI temperatures and components

The CAV package variables that may be used for plot variables are listed and described below. Note that control function arguments (some that are identical in definition to these plot variables but different in format) are described in the following section. In the following list, n refers to the cavity index, lay refers to the desired 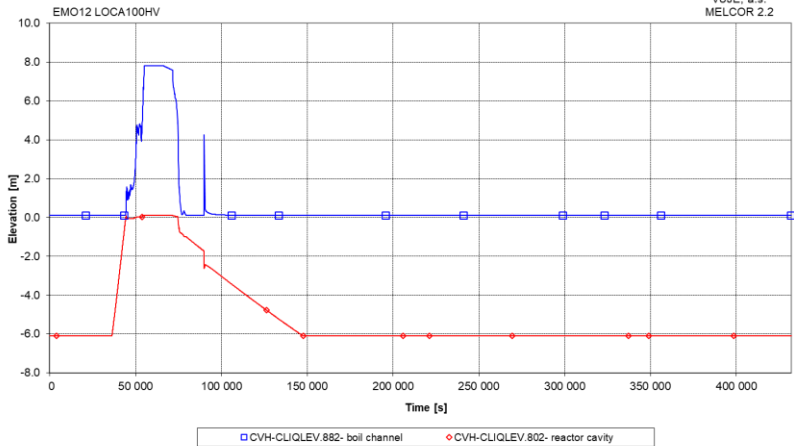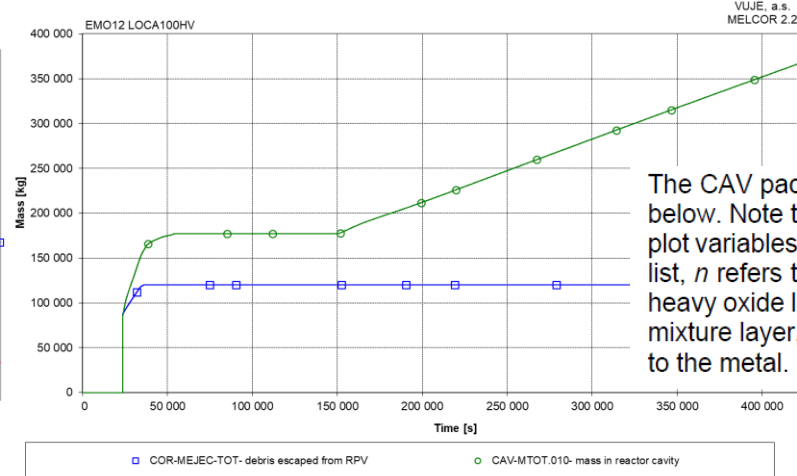layer, with HOX referring to the heavy oxide layer, LOX to the light oxide layer, MET to the metal layer, HMX to the heavy mixture layer, and LMX to the light mixture layer. Here heavy and light are in comparison to the metal. Finally, gas refers to one of the four gases (H_2, H_2O, CO, or CO_2).

The CAV package variables that may be used for plot variables are listed and described below. Note that control function arguments (some that are identical in definition to these plot variables but different in format) are described in the following section. In the following list, n refers to the cavity index, lay refers to the desired layer, with HOX referring to the heavy oxide layer, LOX to the light oxide layer, MET to the metal layer, HMX to the heavy mixture layer, and LMX to the light mixture layer. Here heavy and light are in comparison to the metal. Finally, gas refers to one of the four gases (H_2, H_2O, CO, or CO_2).
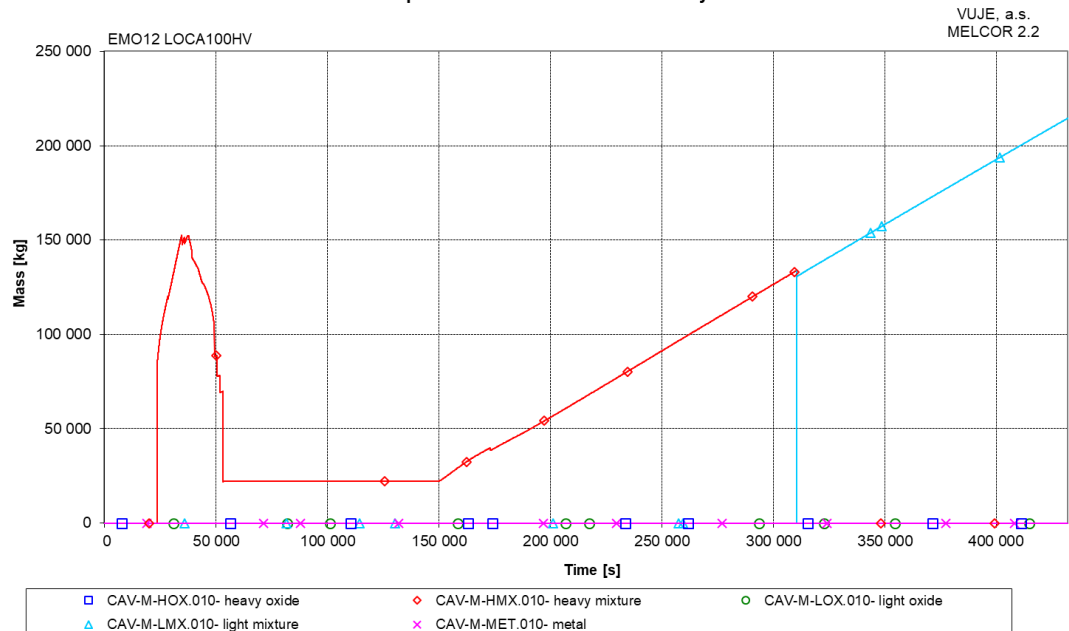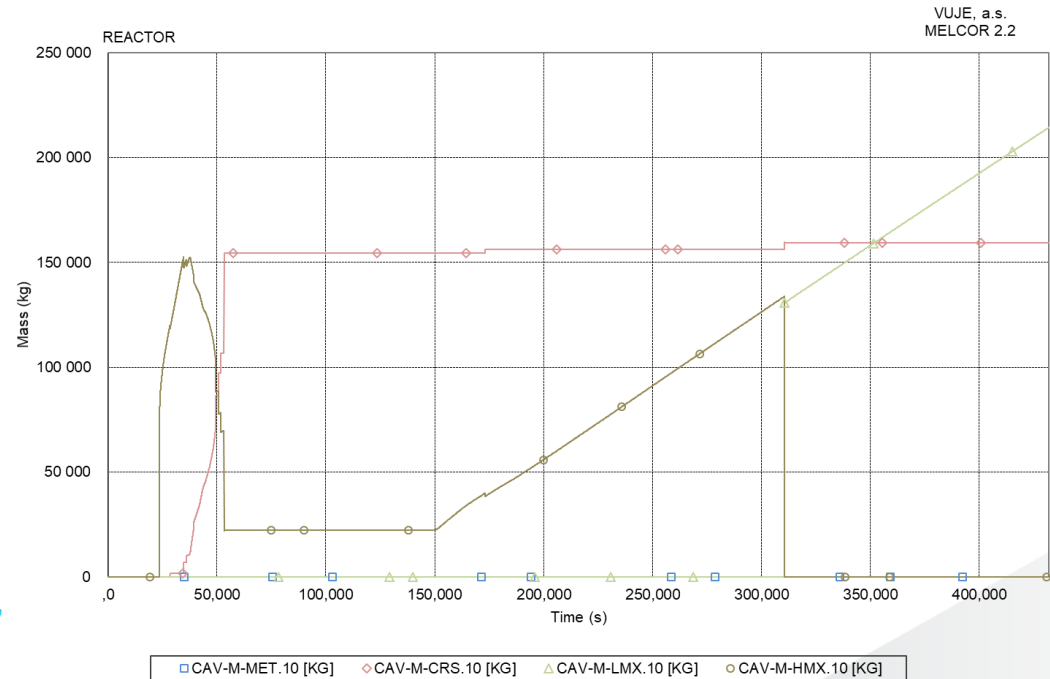
MCCI temperatures and components

Code usage overview – STC11, LOCA100-EXVES

- Calculated up to 5 days (432 000 s), using 15254,

- Crashed at 697 s, no report, using 18019,

- Crashed at 20 313 s, ERROR IN CORE LOWER HEAD MODEL, ONE-DIMENSIONAL MECHANICAL MODEL FAILED TO CONVERGE,
  time step changing and different restart times did not help, using 21402

- Crashed at 7 091 s, POOL VOID NOT CONVERGED,
  TOO LARGE A MASS OR ENERGY SINK GENERATED FOR CVH,
  TIME STEP REDUCED TO 0.0000E+00, using r2023.0

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Code usage overview – PRISE scenario, crash even before core damage (15254)
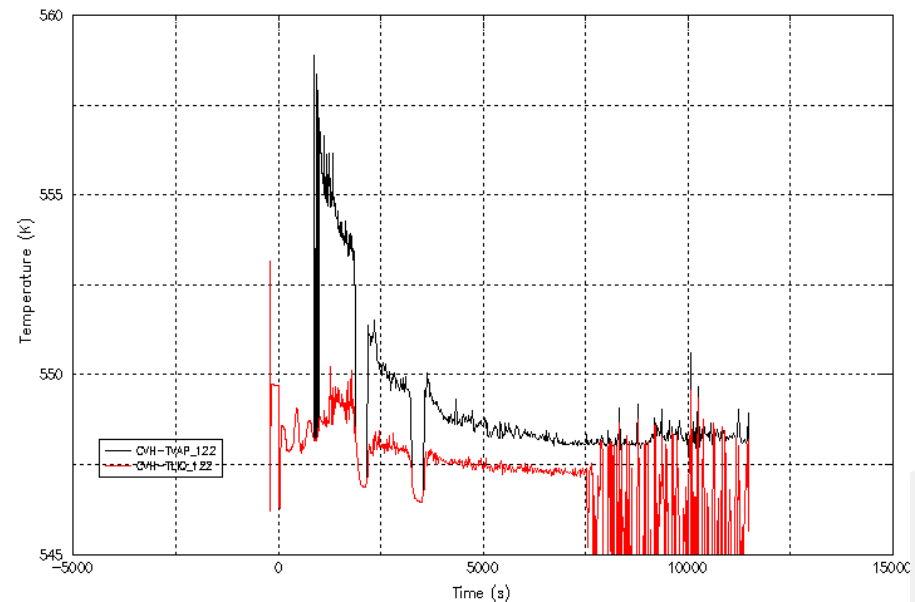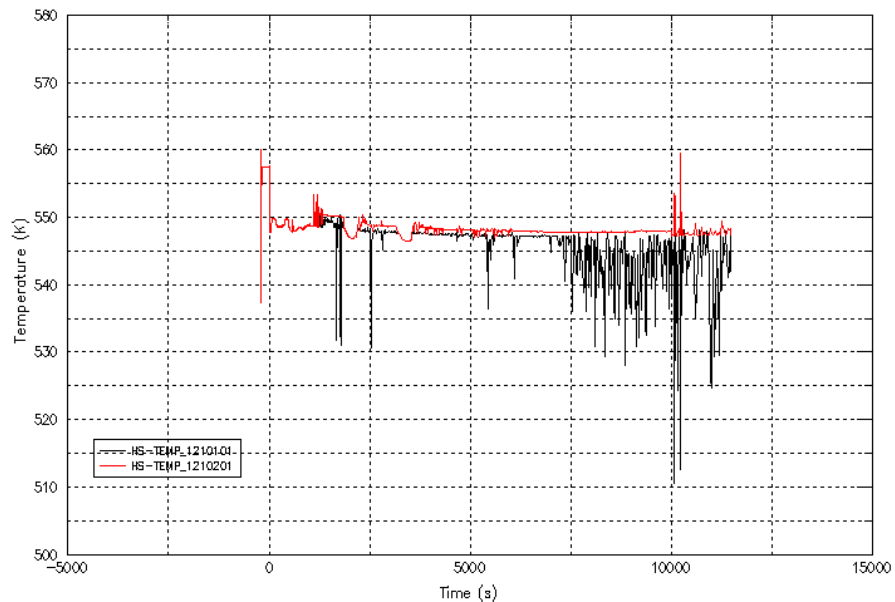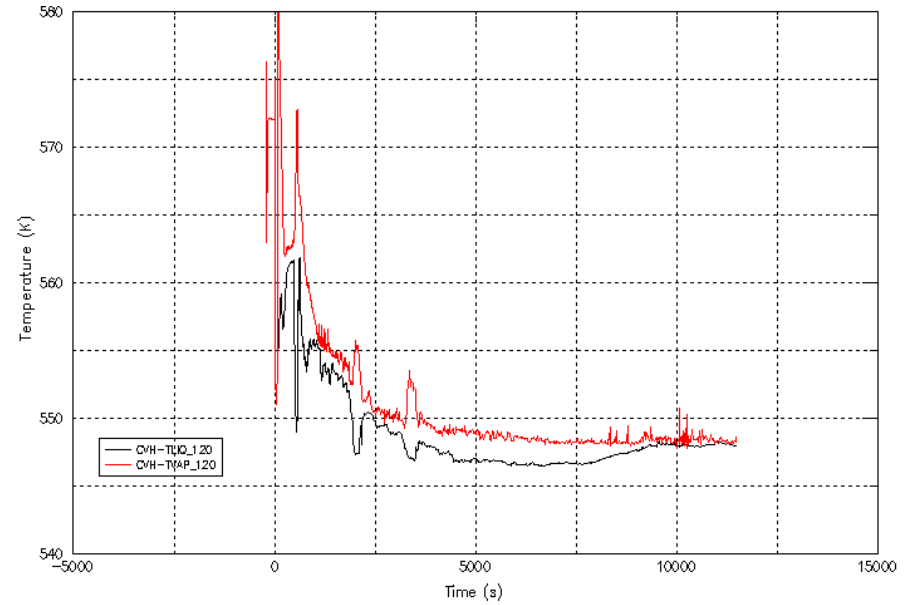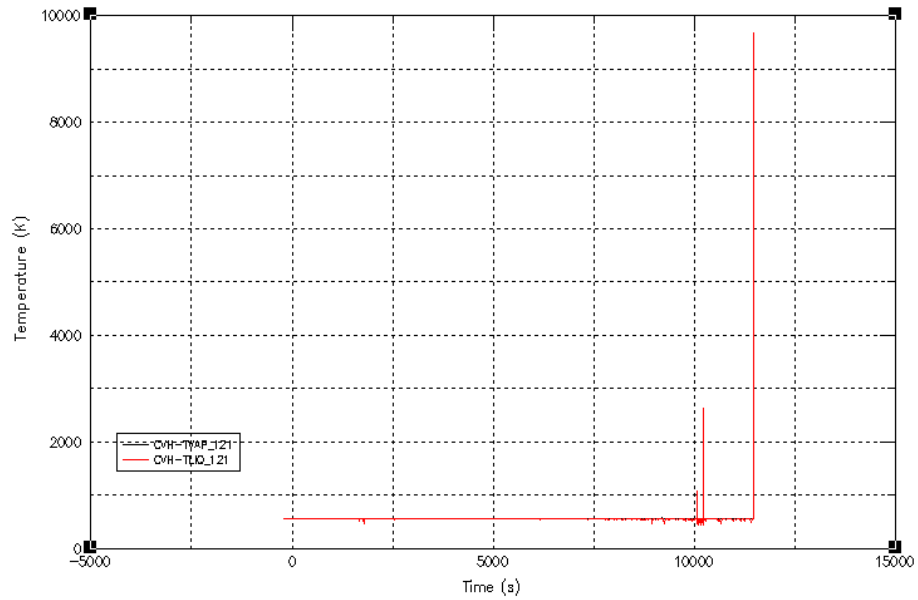
Conclusion

- MELCOR is nowadays exclusively used for severe accident analyses as capacity and capability (both financial and personal) for other codes in severe accident area are diminishing.

- "The first step of avoiding a trap is knowing of its existence." Thufir Hawat

- The first step of finding the cause of a crash is knowing where the instability happened.

- The most important area of MELCOR 2.2 code upgrade is in crash reporting.

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Thank you for your attention.

Feel free to ask questions.

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Fax: + 421 33 599 1200

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