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CENTER FOR NUCLEAR AND
RADIATION SAFETY

Validation of WWER-1000 MELCOR model

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Contents

Unit description

- Investigated unit – VVER-1000/320:
  - Reactor
  - 4 circulating loops with horizontal SGs, MCP
  - 163 fuel assemblies (61 with control rods)

Main thermal-hydraulic characteristics of the reactor

Parameter	Value
Reactor power, MWt	3000
Reactor pressure, abs., kgf/cm^2 (MPa)	160±3 (15.7±0.3)
Reactor outlet temperature, °C	320
Reactor heat-up, °C	30.3
Reactor flow, m^3/h	84800+4000-4800
SG pressure, abs., kgf/cm^2 (MPa)	64±2 (6.28±0.2)
SG level, mm	2550±50

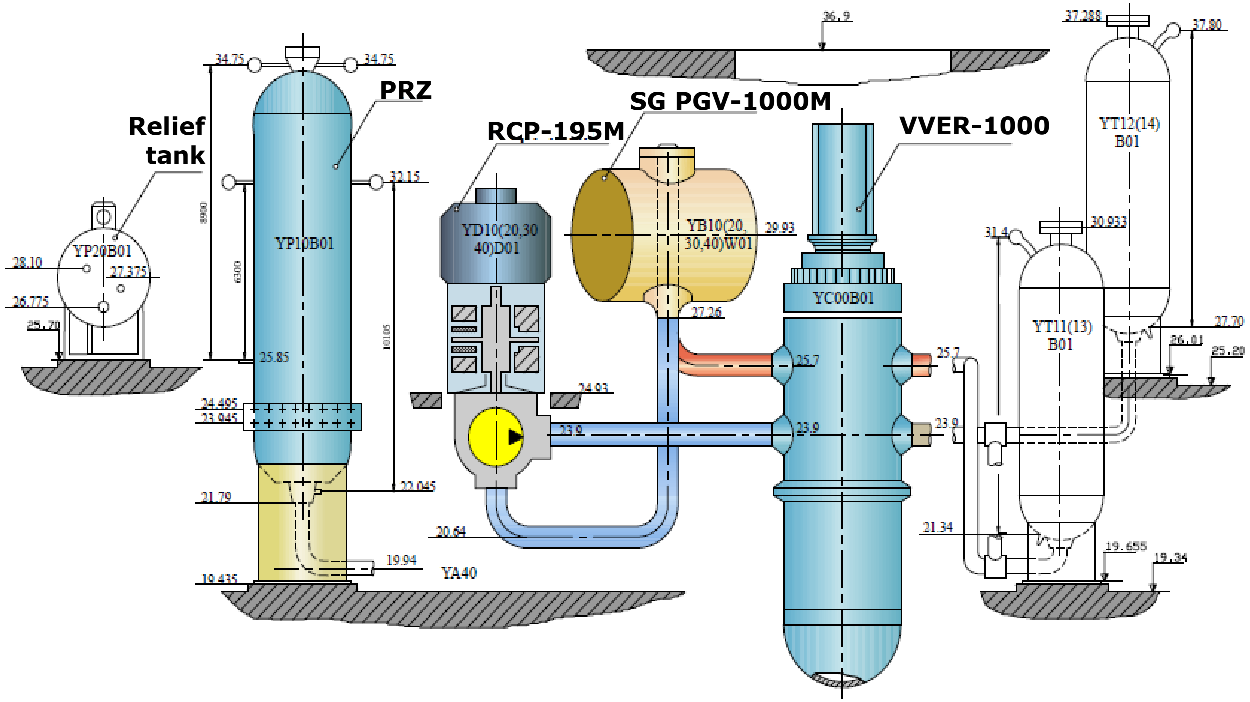


Figure 1. VVER-1000 primary system configuration

Unit description

- Containment compartments:
  - reinforced concrete containment structures, including pre-stressed tendons system and hermetic steel liner
  - locks, hatches and components installed in the concrete containment
  - various types of penetrations
  - parts of pipelines, which serve as containment components
  - isolation devices
- Containment is designed to withstand the internal pressure of 4.9 bar (abs.) and temperature of 150ºC;
- Design containment leakage is 0.3% vol./day

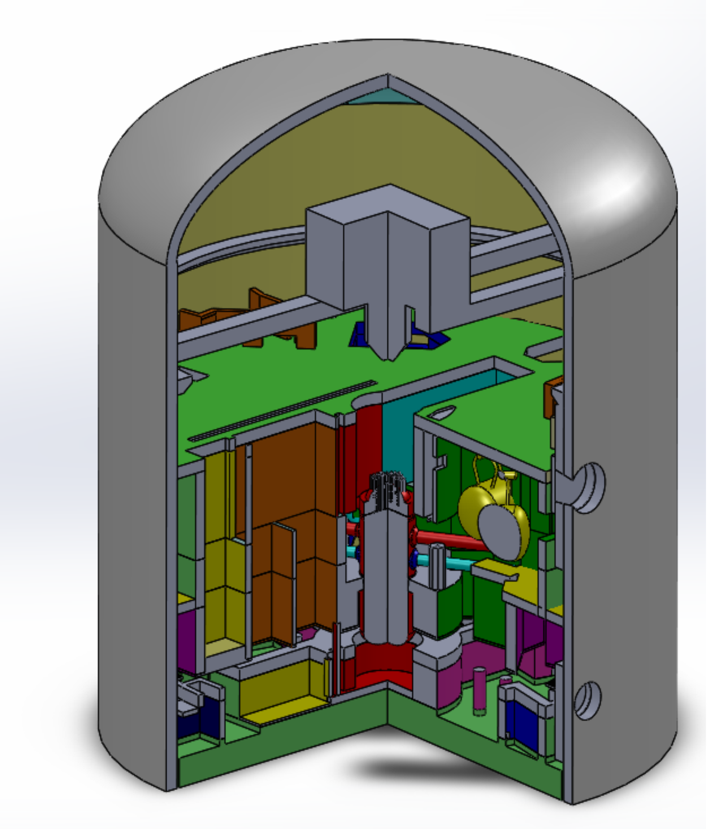


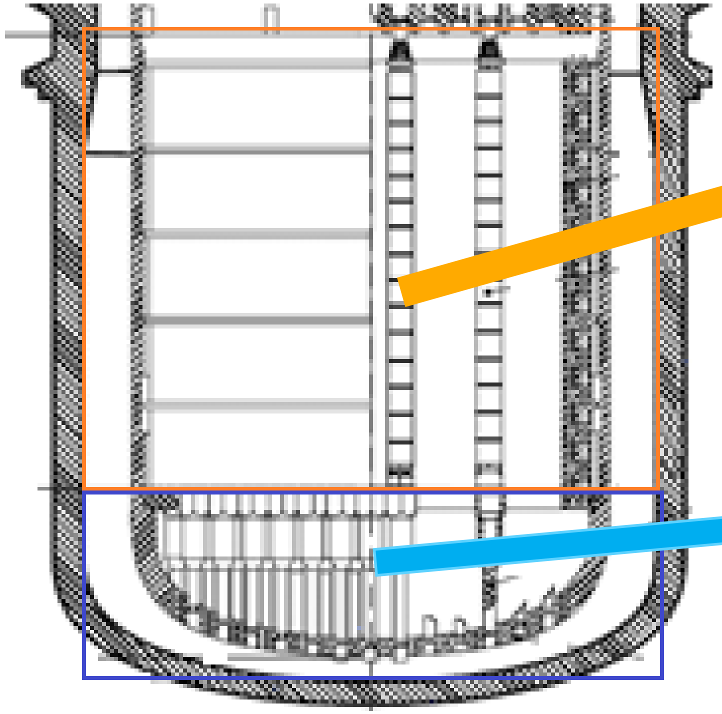
Figure 2. VVER-1000 containment

MELCOR Model description

- VVER-1000/320 MELCOR model consists:
  - core model
  - primary circuit model
  - secondary circuit model
  - containment
  - hydrogen recombiners
  - filtered containment venting system
  - safety systems

MELCOR Model description

Reactor core model



Bottom elevation, m	Top elevation, m	Section height, m	HS10201	HS10203	HS10205	HS10205		
22.301	23.018	0.717	125	225	325	425	HS10224	Upper unheated part of the reactor core
21.946	22.301	0.355	124	224	324	424	HS10222	Fuel part of the reactor core
21.591	21.946	0.355	123	223	323	423	HS10220	
21.236	21.591	0.355	122	222	322	422	HS10218	
20.881	21.236	0.355	121	221	321	421	HS10216	
20.526	20.881	0.355	120	[illegible]	320	420	HS10214	
20.171	20.526	[illegible]	[illegible]	[illegible]	319	419	HS10212	
19.816	[illegible]	[illegible]	118	218	318	418	HS10210	
19.461	[illegible]	0.355	117	217	317	417	HS10208	
[illegible]	19.461	0.355	116	216	316	416	HS10206	
18.751	19.106	0.355	115	215	315	415	HS10204	
18.525	18.751	0.226	114	214	314	414	HS10202	Bottom unheated part of the reactor core above support structures
18.348	18.525	0.177	113	213	313	413	HS10108	Elements of reactor barrel bottom and support structures
18.219	18.348	0.129	112	212	312	412	-	
18.099	18.219	0.120	111	211	311	411	-	
17.979	18.099	0.120	110	210	310	410	-	
17.878	17.979	0.101000	109	209	309	409	-	
17.787053	17.878	0.090947	108	208	308	408	-	
17.691573	[illegible]	[illegible]	[illegible]	[illegible]	307	407	-	
[illegible]	17.69157	0.095902	106	206	306	406	-	
17.509051	17.59567	0.086620	105	205	305	405	-	
17.417259	17.50905	0.091792	104	204	304	404	-	
17.226125	17.41726	0.191134	103	203	303	403	-	
17.061902	17.22612	0.164222	102	202	302	402	-	
16.899	17.0619	0.162902	101	201	301	401	-	
			1	2 Reactor bottom	3	4		

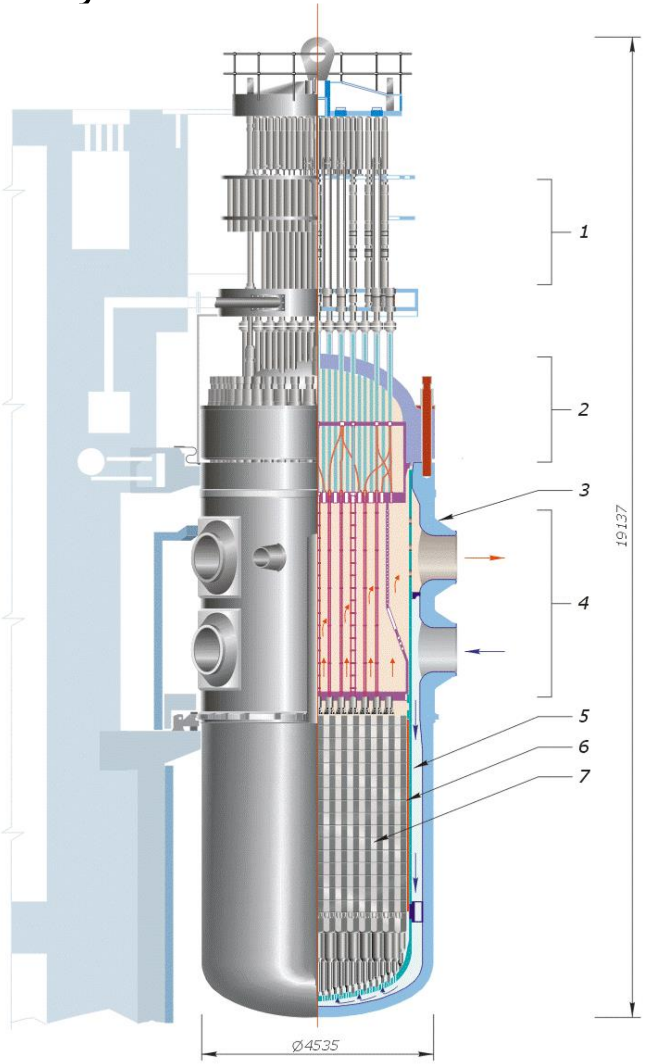
4 radial rings

25 axial sections (10 fuel section)

Figure 3. Reactor core model nodalization

MELCOR Model description

Hydraulic model of reactor



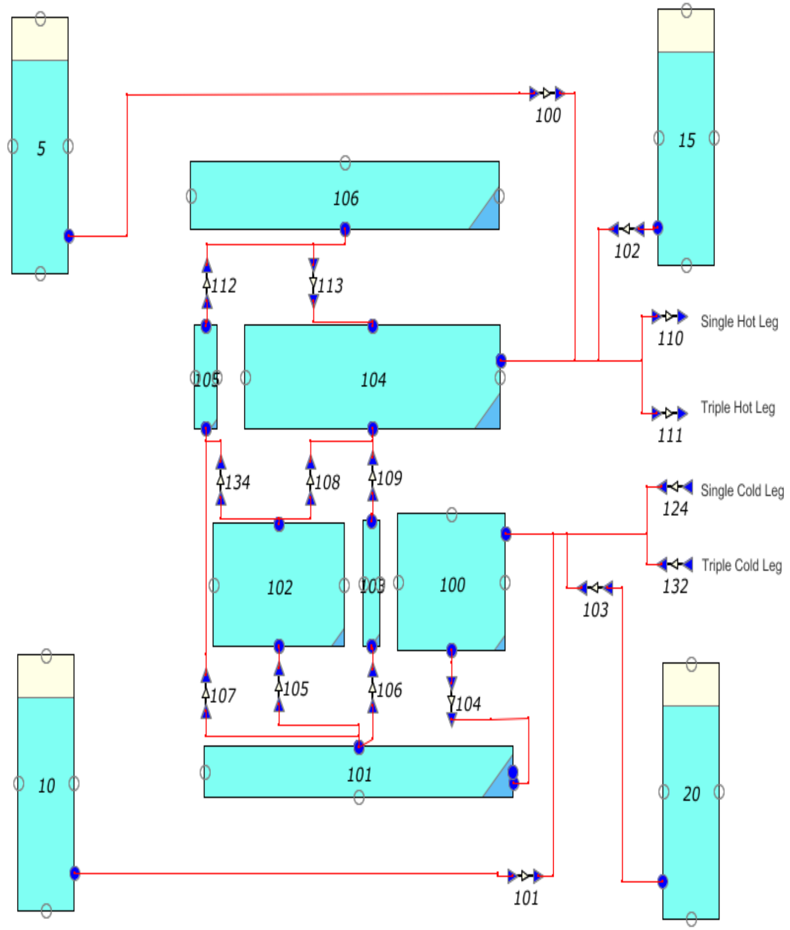
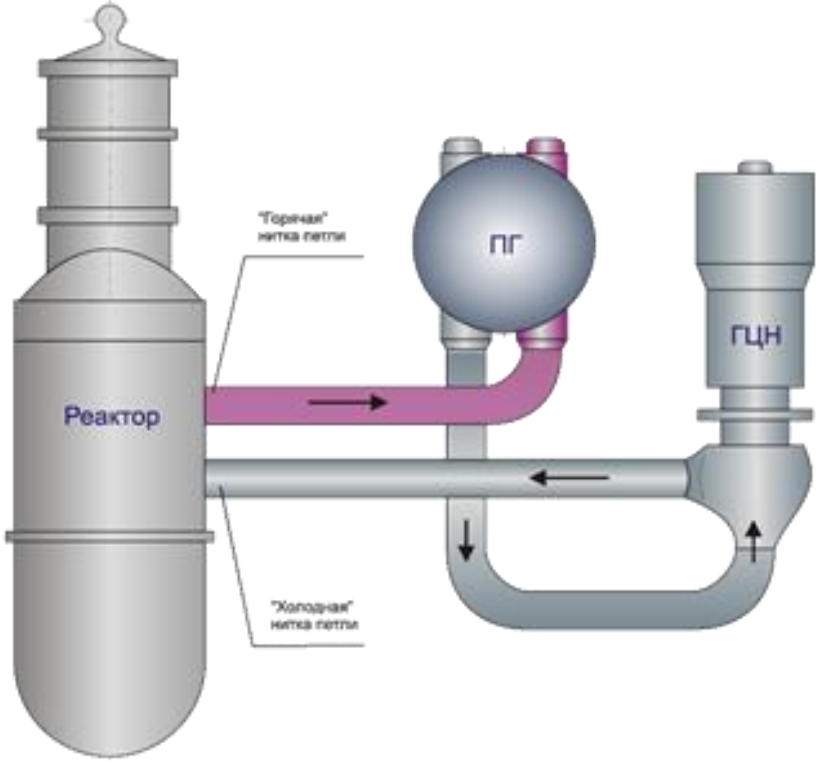


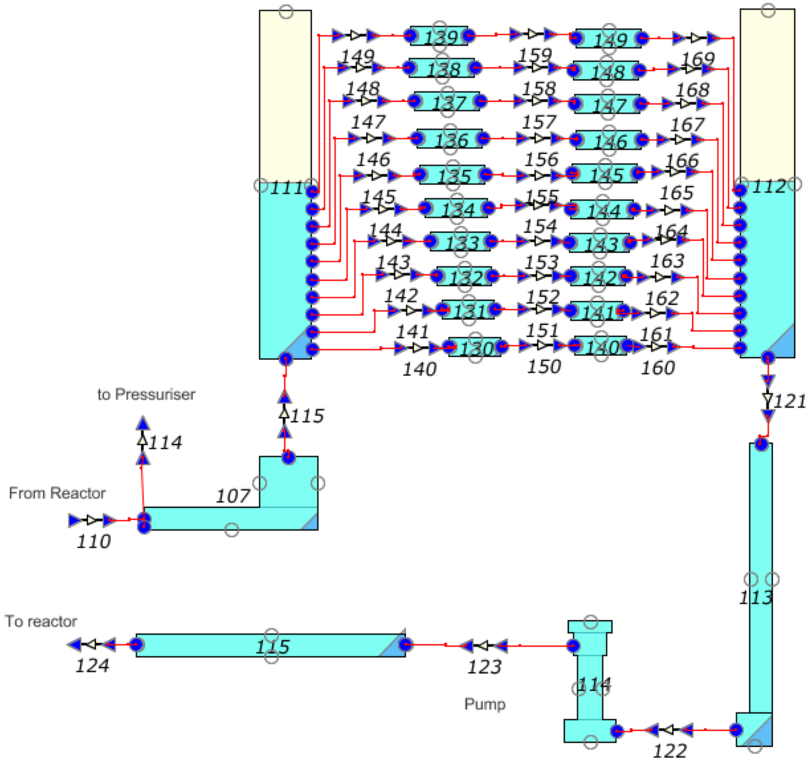
Figure 4. Reactor and hydroaccumulators nodalization diagram

- 7 control volumes for reactor model
- 9 flow paths for reactor model
- 4 flow paths for hydroaccumulators

MELCOR Model description

Primary circuit model





Single/triple RCS loop:

- 4 control volumes
- 6 flow paths

Figure 5. Primary circuit single loop nodalization

MELCOR Model description

Secondary circuit model

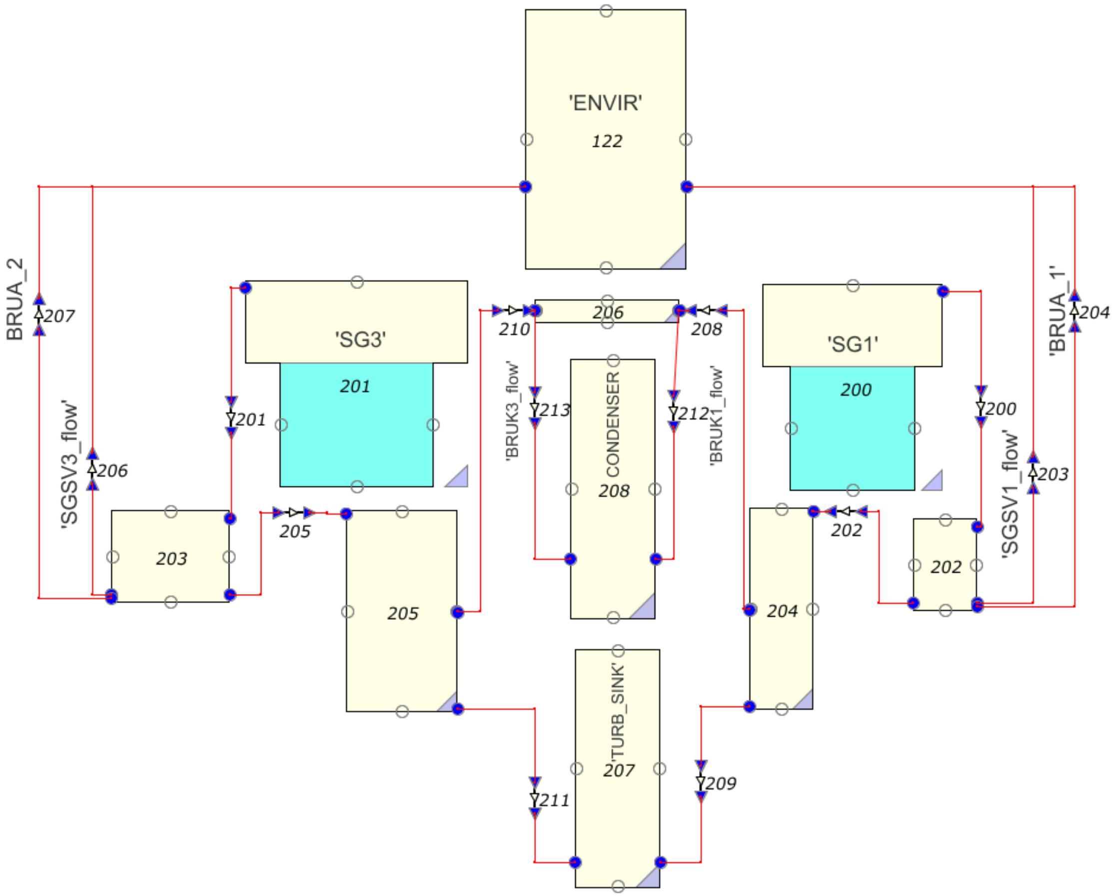


Figure 6. Nodalization of the secondary circuit

- 10 control volumes (include single/triple SG)
- 14 flow paths

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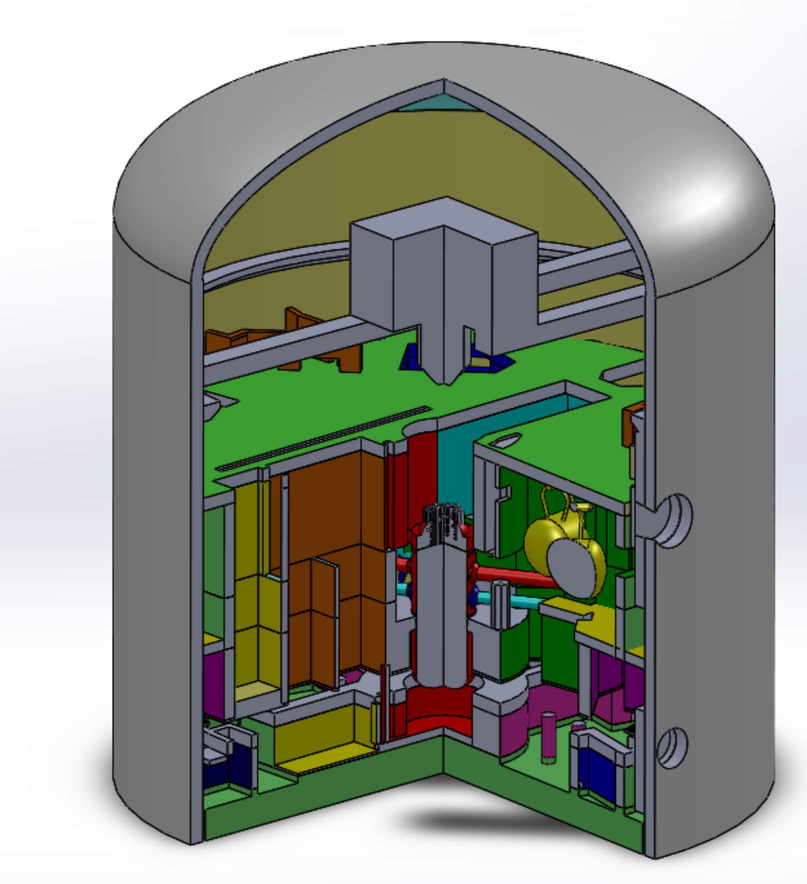
MELCOR Model description

Containment model



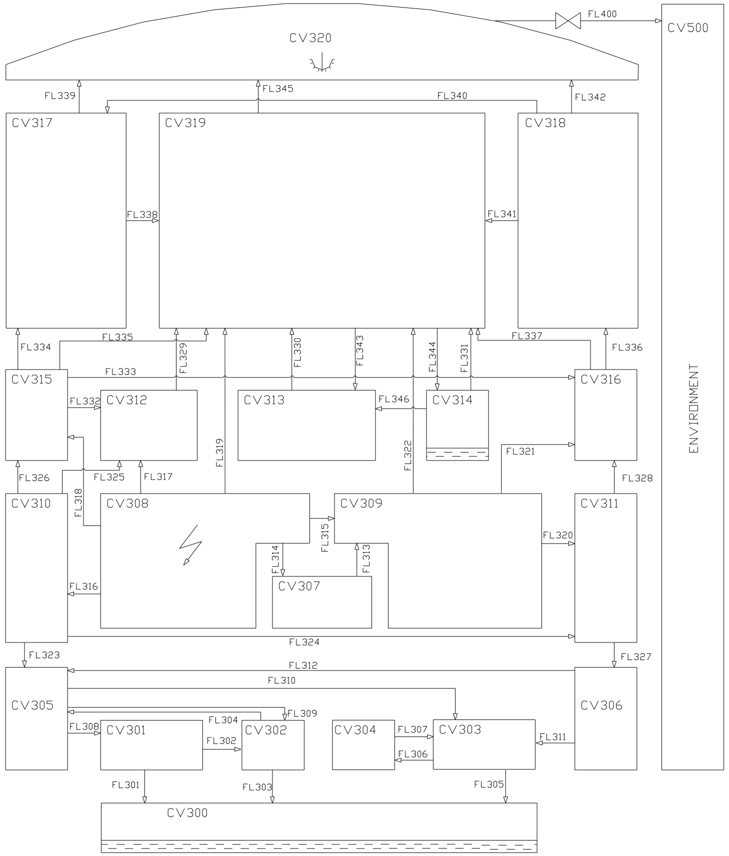


Figure 7. Containment nodalization diagram

- 21 control volume
- 51 flow paths

MELCOR Model description

Recombiners model

In ZNPP the NIS type of PARs are implemented as a measure for hydrogen detonation prevention.
The parameters of built-in MELCOR PAR model are adjusted in accordance with NIS-PAR-44H characteristics and the location of PARs in containment.
Parameters of PAR model are determined iteratively using a simplified calculation model with constant atmosphere parameters.
Capacity for NIS-PAR type 22H was determined in proportion to the number of cartridges compared to the NIS-PAR-44H.
For NIS-PAR types 22KKH and 44KKH with additional exhaust sections 1000mm (KKH), the capacity of each module is increased 1.25 times.

Figure 8. NIS PAR type

MELCOR Model description

FCVS model

FCVS is modeled by connection 777 ('Filtr_tube') between containment control volume 310 ('VENT_TL1') and additional environment control volume 500 ('ENVIR_2')

<u>FCVS characteristics</u>

Retention rate of aerosols > 99.99 %

Retention rate of iodine > 99.0 %

FCVS tube diameter – Dn 300 mm

Tube FCVS level (midpoint) connection to containment – 35.71 m

FCVS design rate – 7.41 kg/sec at P_{CNT}= 5 kgf/cm^2, Steam 86%, Air 14%

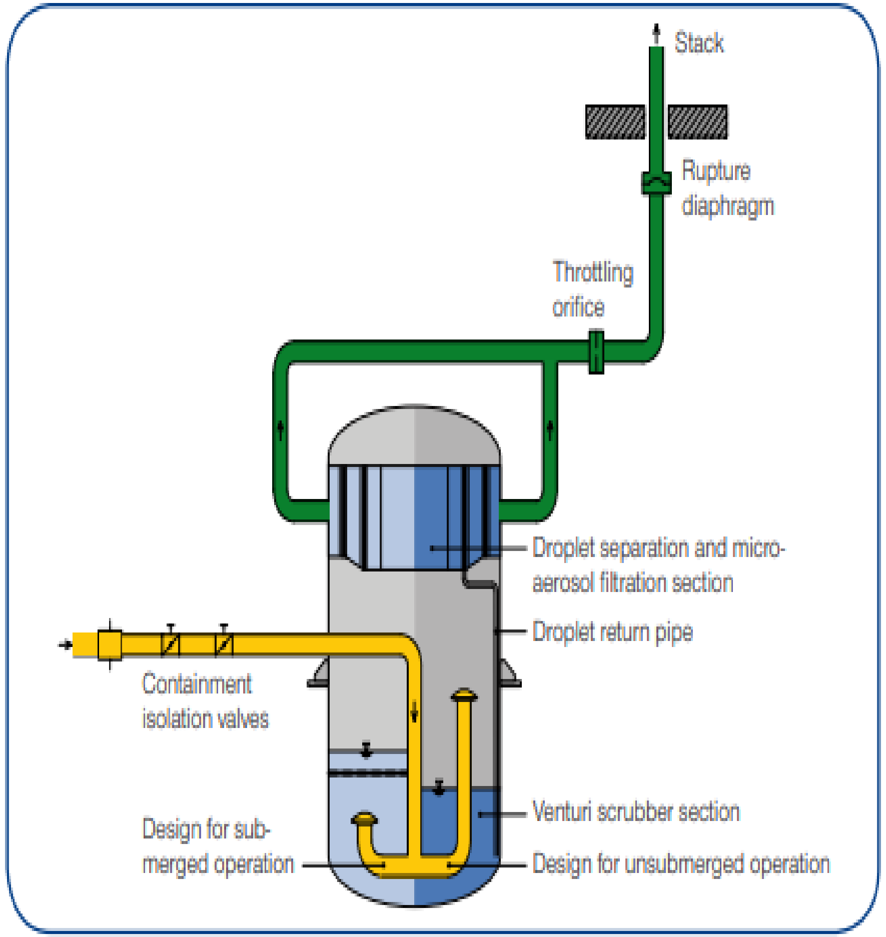


Figure 9. AREVA Wet Filter Method

MELCOR Model validation

Validation scenarios

1. MELCOR 1.8.5-2.1 comparative calculation of the "total station blackout" severe accident scenario
2. Simulation of RNPP Unit 3 incident "Pressurizer Pilot-operated Relief Valve (PORV) Stuck Open during Tests“
3. Simulation of RNPP Unit 3 periodic containment integrity test to confirm correct adjustment of the containment leakage flow rate
4. Scenario 4: Recombines model validation of NIS PAR type 44H model capacity
5. Scenario 5: FCVS model flow rate validation

MELCOR Model validation

Scenario 1: Comparative calculation of the "total station blackout» severe accident scenario

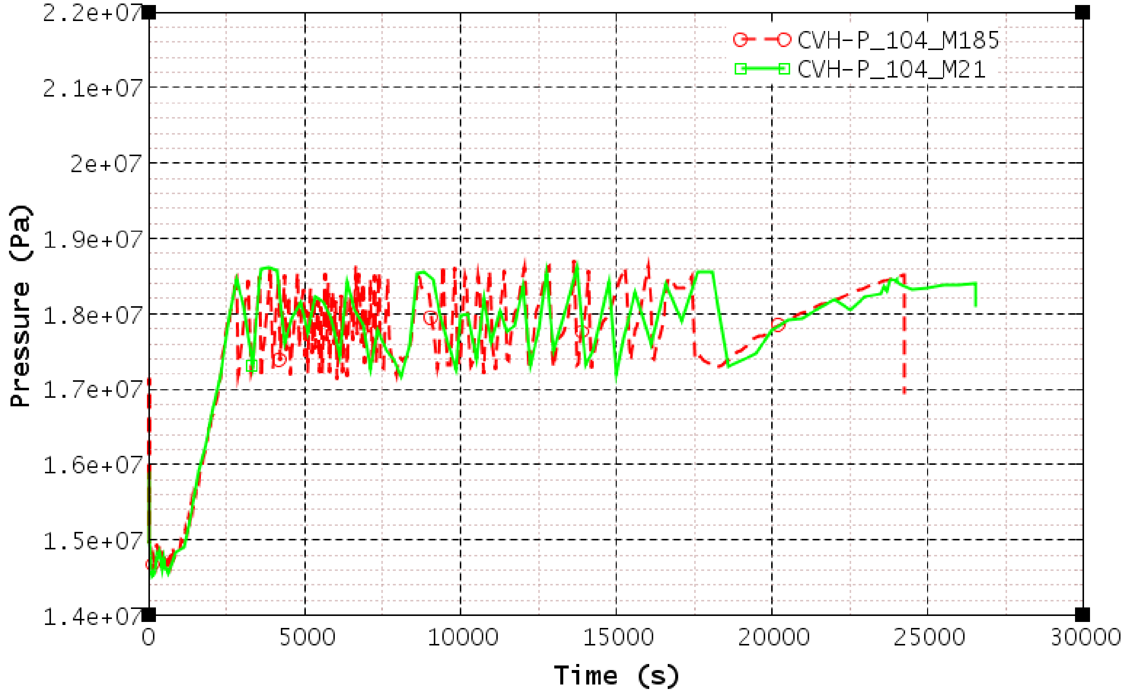


Figure 10. RCS pressure

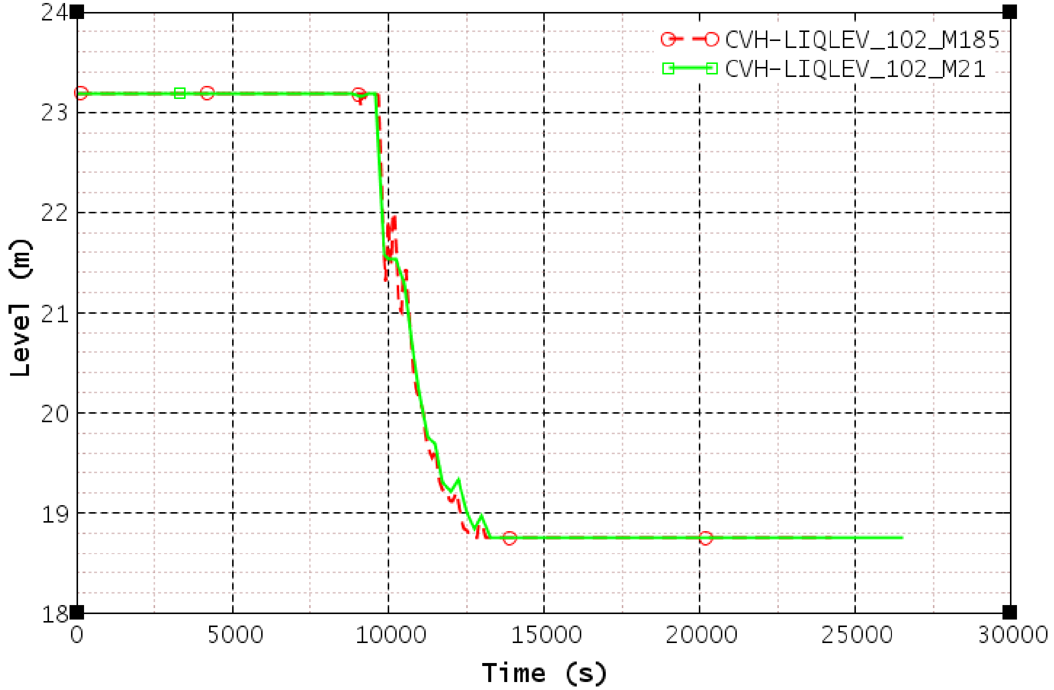


Figure 11. Reactor core water level

MELCOR Model validation

Scenario 1: Comparative calculation of the "total station blackout» severe accident scenario

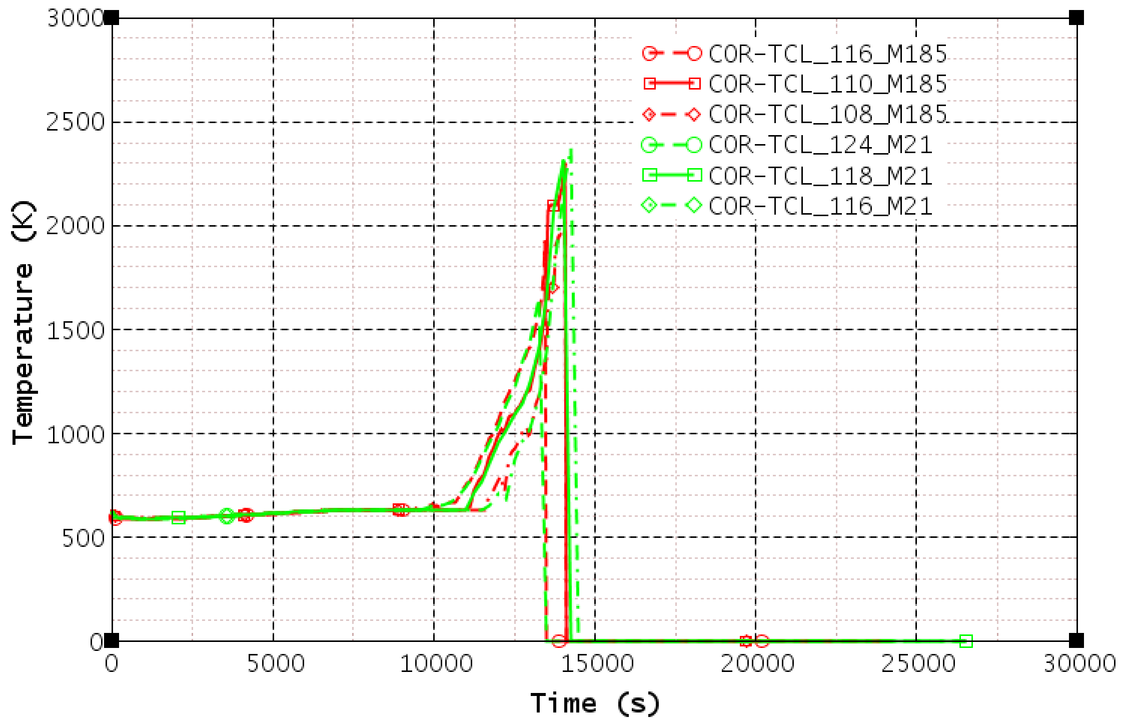


Figure 12. Cladding temperature

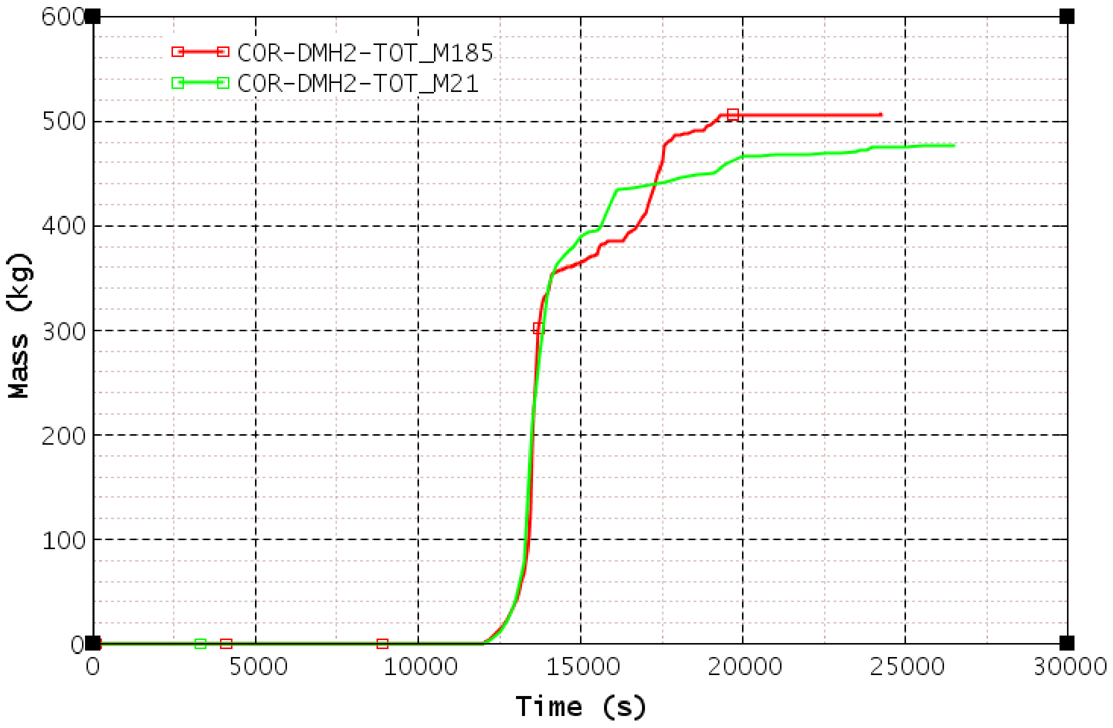


Figure 13. In-vessel hydrogen mass generation

MELCOR Model validation

Scenario 1: Conclusions

Both code versions produce similar results

Differences are observed after core damage and melt relocation explained by more detailed representation of reactor bottom part in WWER-1000/V-320 model for MELCOR 2.1

- subdivision of lower part of reactor core into several axial segments
- modelling of additional ring for downcomer
- RPV bottom detalization

MELCOR Model validation

Scenario 2: RNPP Unit 3 PRZ PORV Stuck Open during Tests

This incident occurred at RNPP Unit 3 in 2009 during routine start-up tests of PRZ PORV operation by primary circuit pressure increase

Malfunction of the pilot valve after PRZ PORV opening resulted in continuous loss of primary circuit coolant with actuation of

- high pressure injection system (HPIS)
- low pressure injection system (LPIS)
- injection from hydroaccumulators

Main operator actions during the incident were aimed in a control of safety injection pumps operation and cooling-down of the secondary circuit.

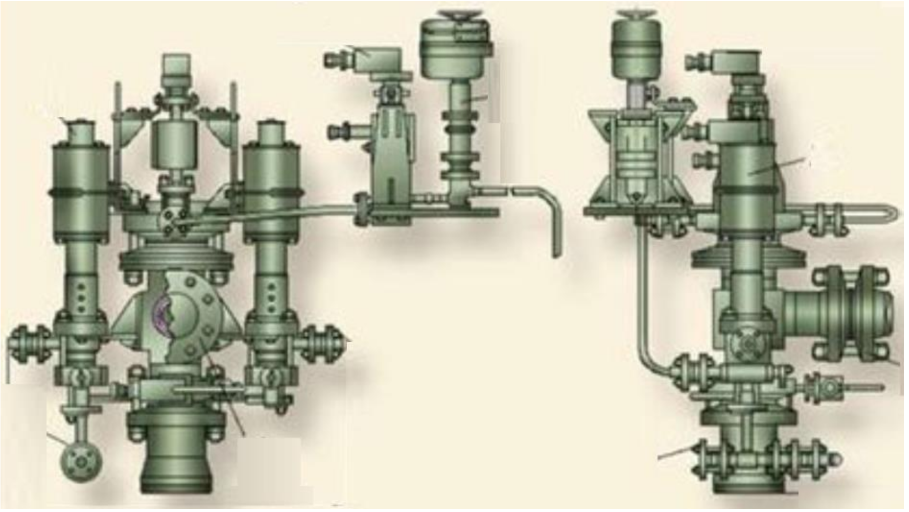


Figure 14. PRZ PORV

MELCOR Model validation

Scenario 2: RNPP Unit 3 PRZ PORV Stuck Open during Tests

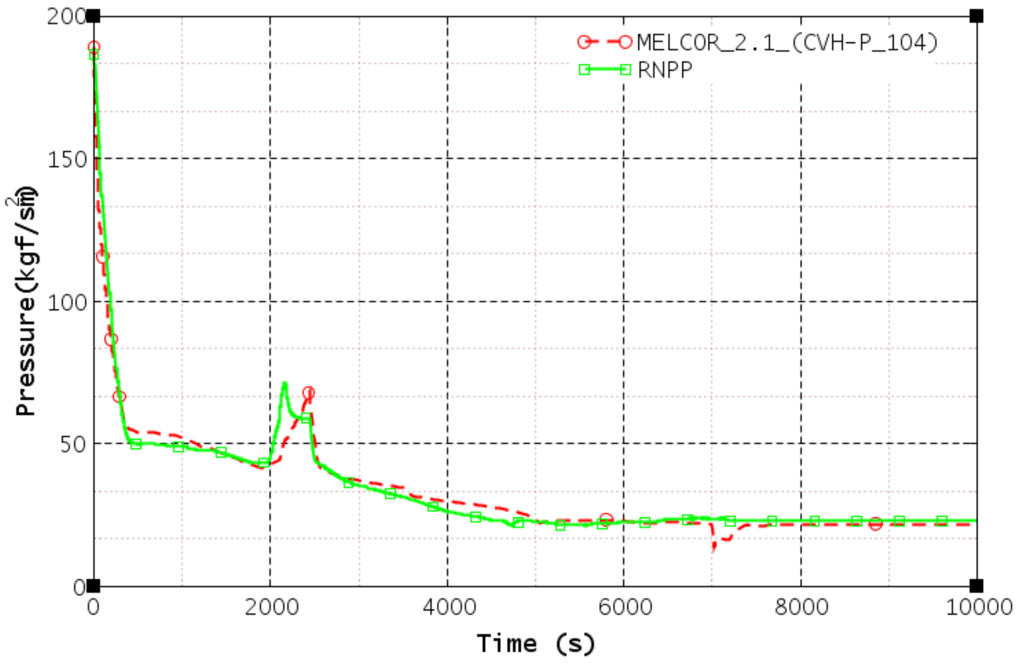


Figure 15. RC Pressure

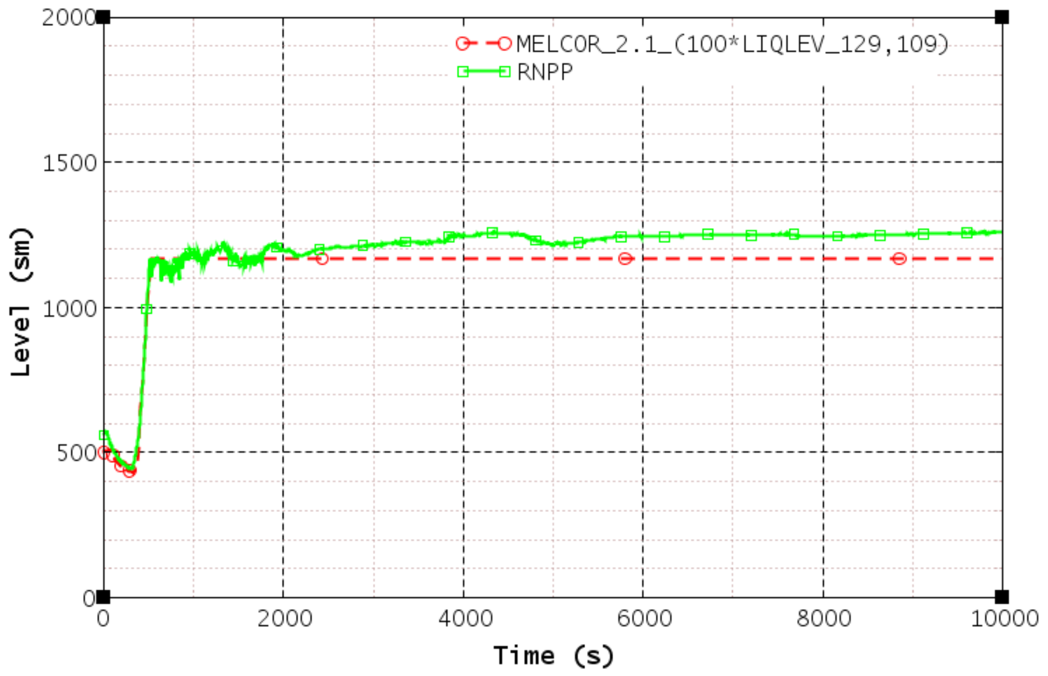


Figure 16. PRZ water Level

MELCOR Model validation

Scenario 2: RNPP Unit 3 PRZ PORV Stuck Open during Tests

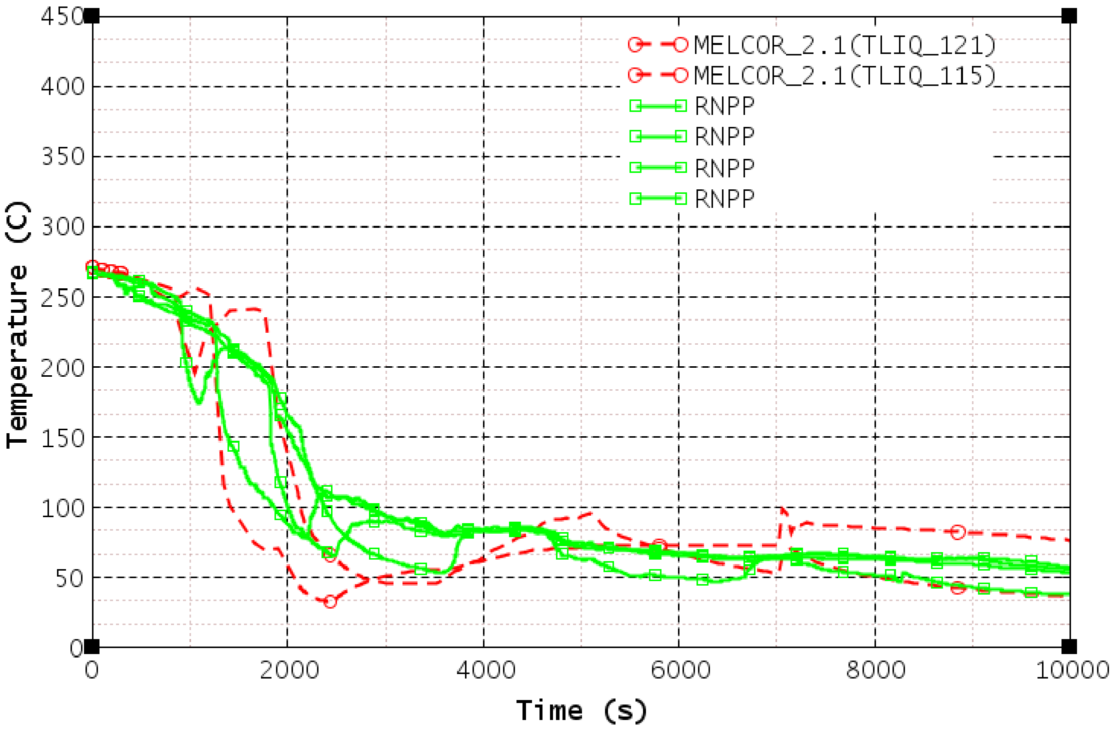


Figure 17. Coolant Temperature in Cold Legs

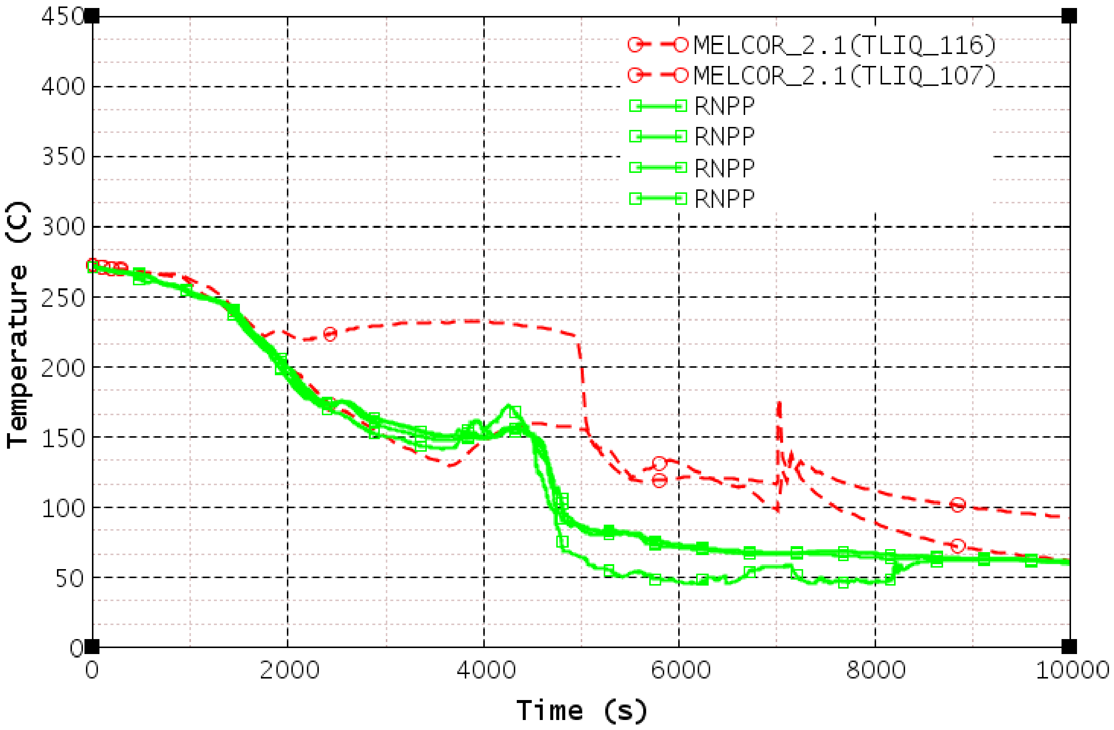


Figure 18. Coolant Temperature in Hot Legs

MELCOR Model validation

Scenario 2: RNPP Unit 3 PRZ PORV Stuck Open during Tests

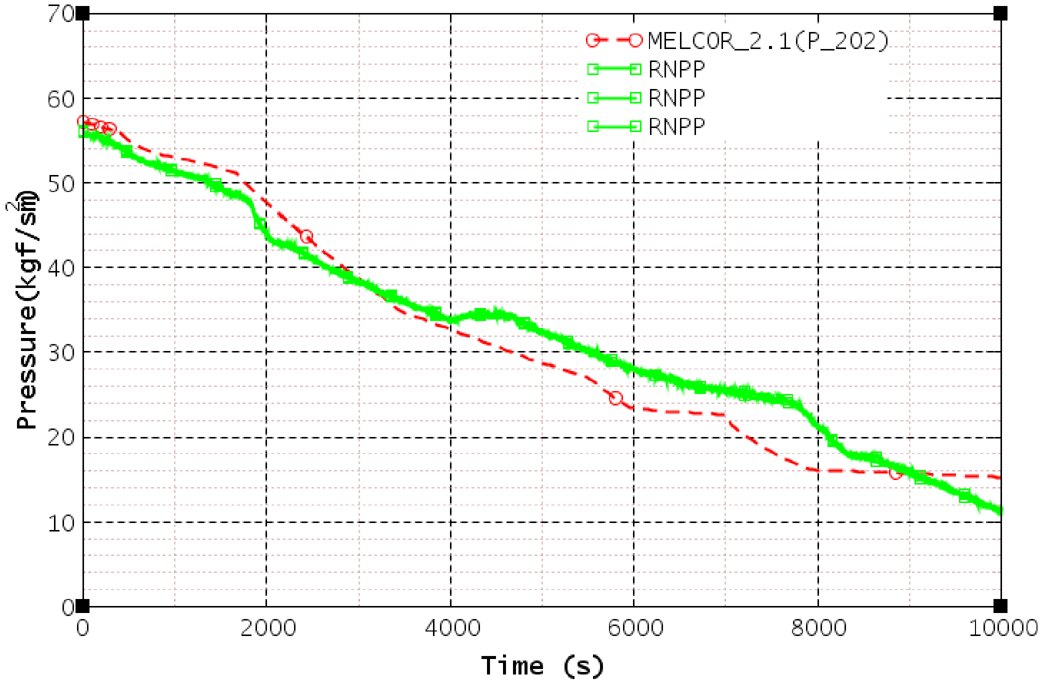


Figure 19. SG1, 2, 3 Pressure

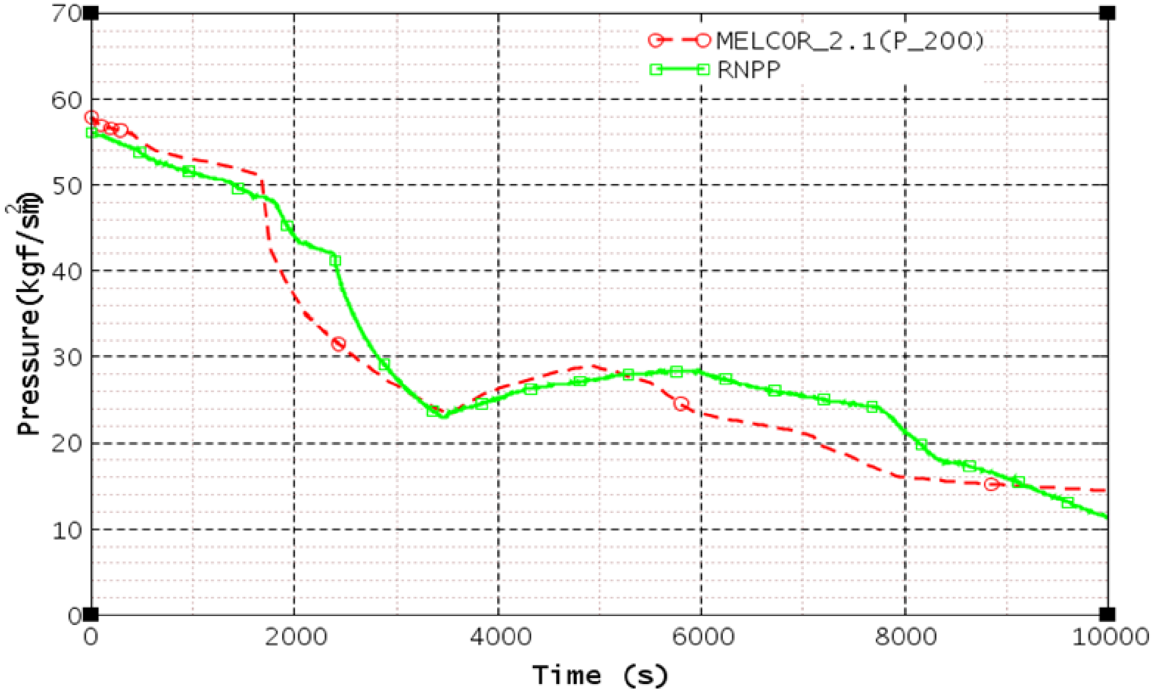


Figure 20. SG4 Pressure

MELCOR Model validation

Scenario 2: RNPP Unit 3 PRZ PORV Stuck Open during Tests

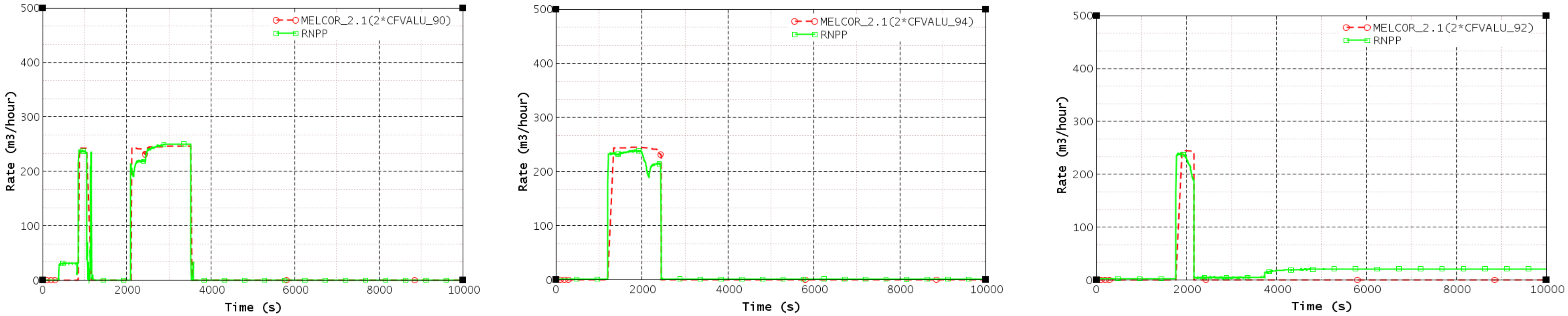


Figure 21. TQ13, 23, 33 HPIS Mass Flow Rate

MELCOR Model validation

Scenario 2: RNPP Unit 3 PRZ PORV Stuck Open during Tests

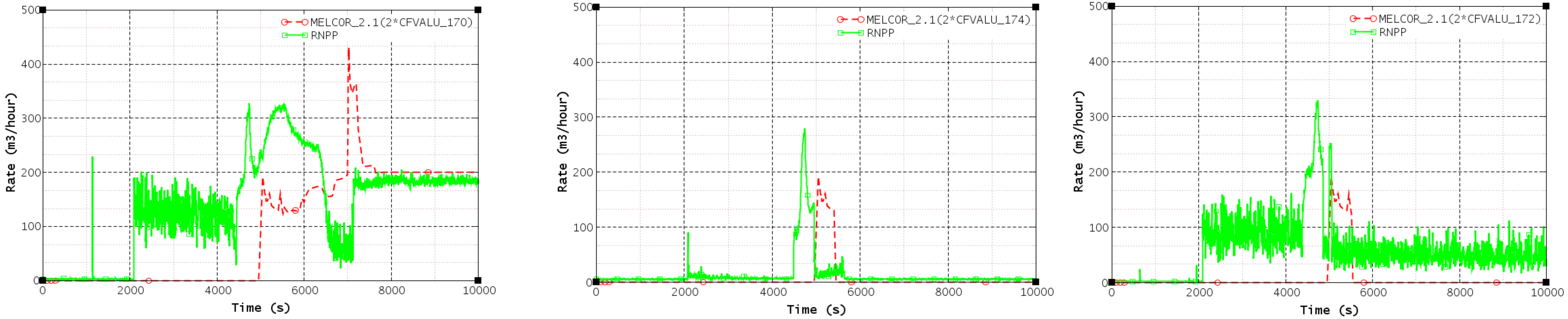


Figure 22. TQ12, 22, 32 LPIS Mass Flow Rate

MELCOR Model validation

Scenario 2: Conclusions

Comparison of calculation results with plant measured data demonstrates good correspondence for the main primary and secondary circuit parameters

Differences in low pressure safety injection are explained by slightly lower calculated RCS pressure following the trip of last operating high pressure safety injection pump, that is caused by simplified modelling of RCS loops (simulation of three RCS loops by one "triple" loop in the model)

MELCOR Model validation

Scenario 3: RNPP Unit 3 periodic containment integrity test

RNPP Unit 3 containment integrity tests

- carried out on August 24, 2019 to determine the actual containment leakage rate
- the containment pressure decrease rate was measured starting from initial 1.7 kgf/cm^2 abs.

Figure 23. VVER-1000 reactor building

MELCOR Model validation

Scenario 3: RNPP Unit 3 periodic containment integrity test

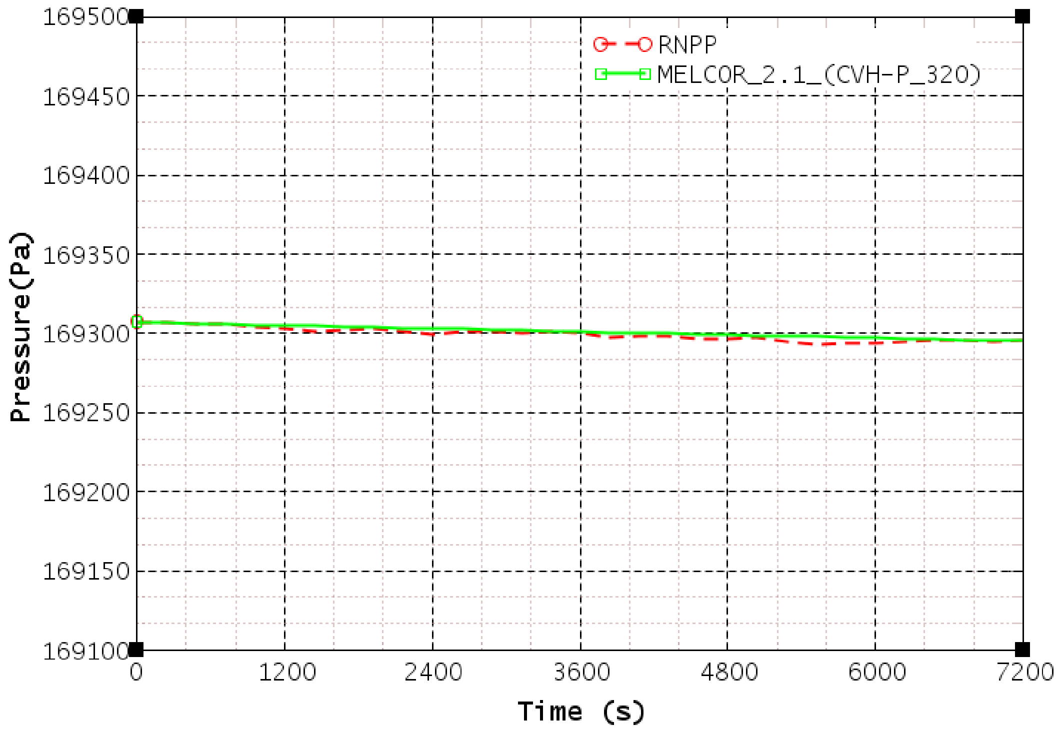


Figure 24. Containment pressure

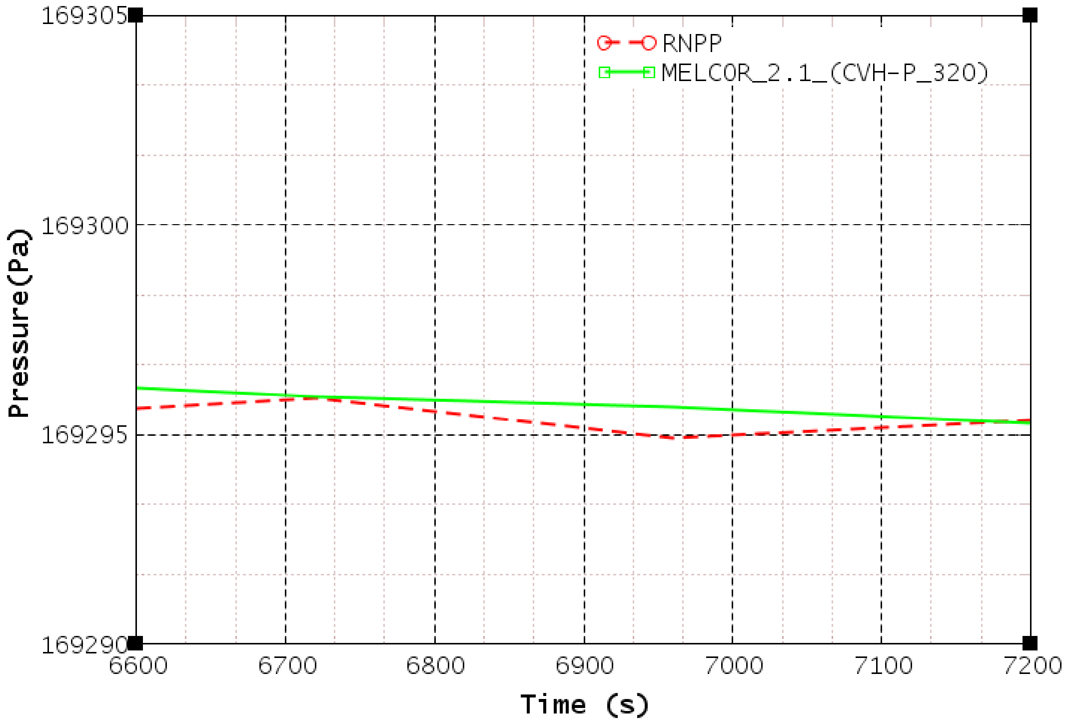


Figure 25. Containment pressure (fragment)

MELCOR Model validation

Scenario 3: RNPP Unit 3 periodic containment integrity test

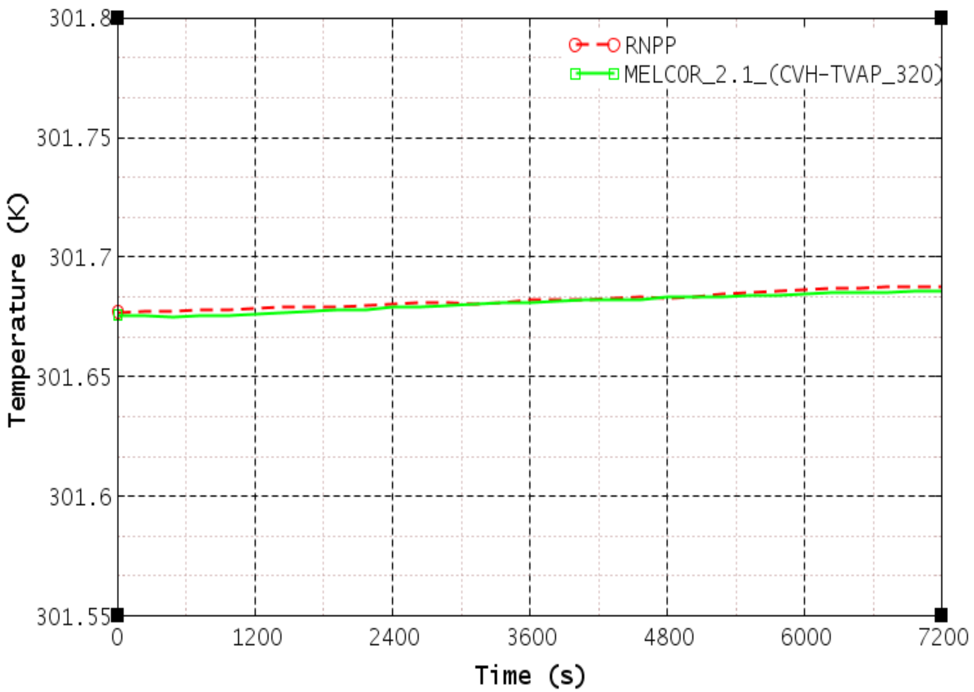


Figure 26. Containment temperature

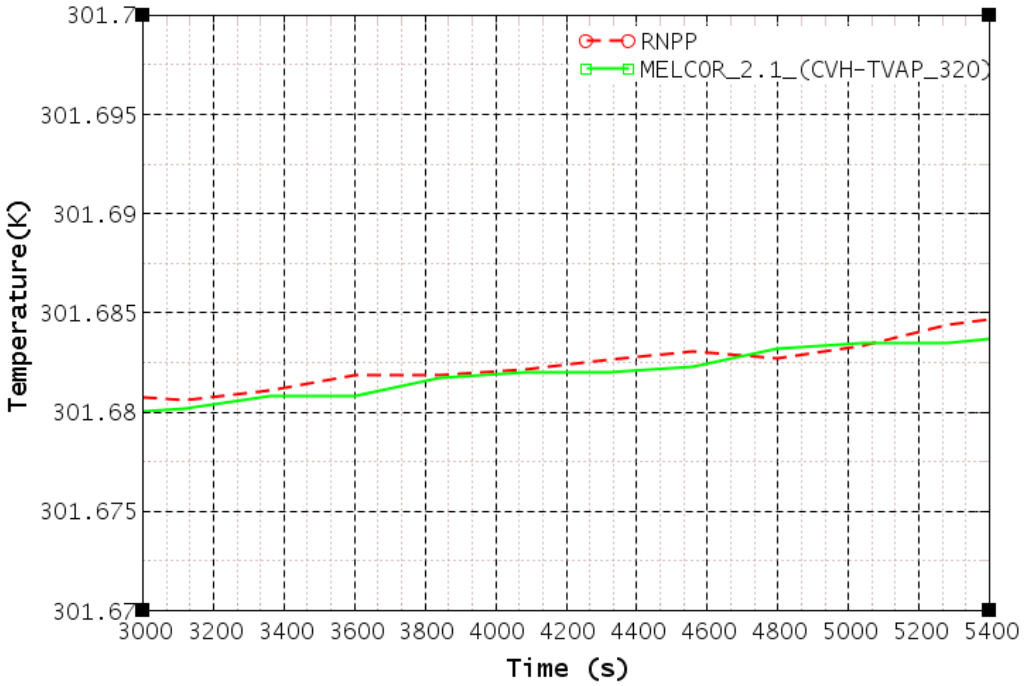


Figure 27. Containment temperature (fragment)

Conclusion: The results of calculation confirm correctness of containment leakage flow rate adjustment in the model

MELCOR Model validation

Scenario 4: Recombines model validation of NIS PAR type 44H capacity

Validation of NIS-PAR-44H models is performed for constant (time-independent) initial conditions in the control volume in order to determine/confirm the correctness capacity of MELCOR NIS-PAR-44H model and design.

MELCOR Model validation

Scenario 4: Recombines model validation of NIS PAR type 44H capacity

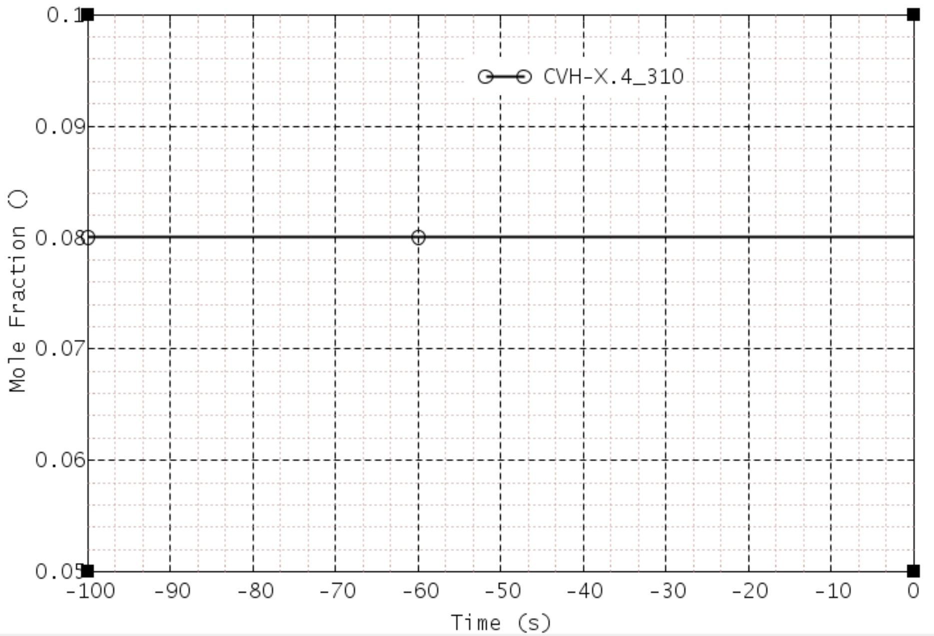


Figure 28. Hydrogen (X.4) concentration (mole fration)

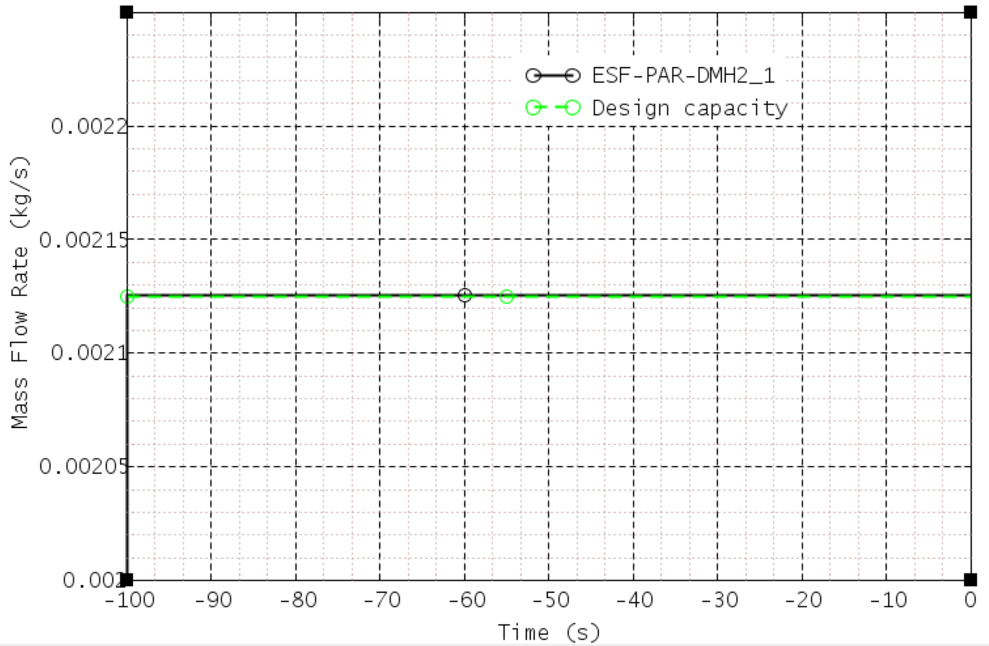


Figure 29. Calculated and design capacity of one NIS-PAR-44H (ex. Temperature 130°C, Pressure 0.3 MPa, Hydrogen concentration 8%)

Conclusion: The results of this calculation confirm correctness of NIS PAR type 44H productivity adjustment in the model

MELCOR Model validation

Scenario 5: Validation of FCVS model

Validation of FCVS model is performed for constant (time-independent) initial conditions

- temperature 149.25 °C
- pressure 5 kgf/cm^2
- steam concentration 86%
- air concentration 14%

by iterative adjustment of loss coefficient for connection 777 ('Filtr_tube') to fit the design rate of 7.41 kg/sec

MELCOR Model validation

Scenario 5: Validation of FCVS model

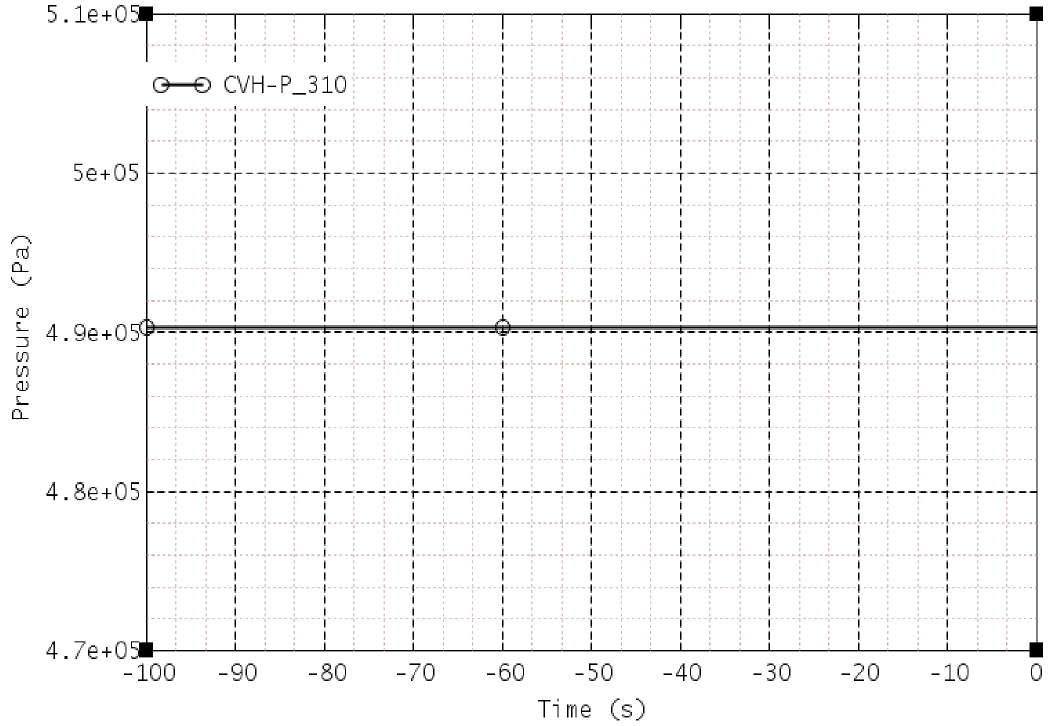


Figure 30. Containment pressure

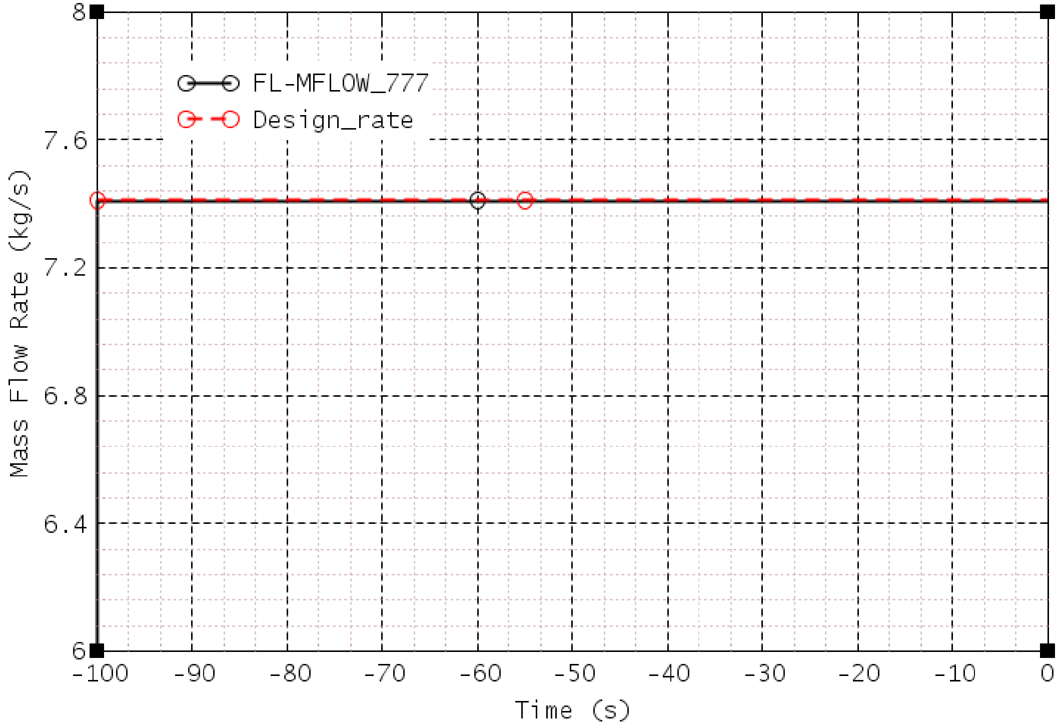
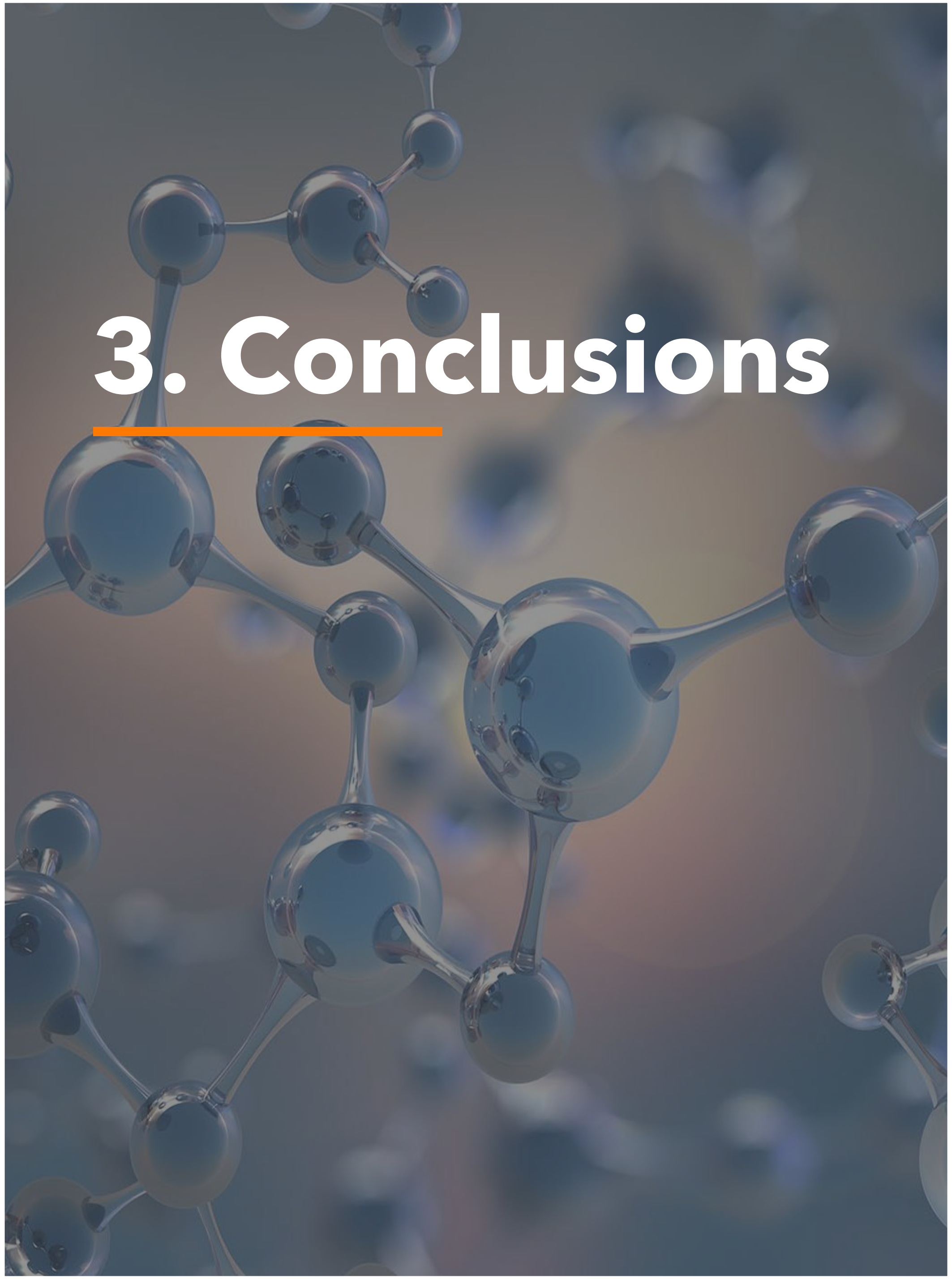


Figure 31. Calculated and design FCVS flow rate (149.25 °C, 5 kgf/cm^2, Steam / air concentrations 86% / 14%)

Conclusion: The results of calculation confirm correctness of FCVS flow rate adjustment in the model



3. Conclusions

- Based on the results of validation calculations of scenarios 1–5 it can be concluded that WWER-1000/V-320 thermal hydraulic model for MELCOR 2.1/2.2 code is adjusted to plant design characteristics, allows to reproduce plant response in transients and can be used for calculations of transients and accidents in support of regulatory review of safety analyses documentation

- For more accurate modeling of processes with LPIS operation further improvement of computational model (modelling of 4 independent circuit loops) is needed

Thank you for your attention!

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