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NUCLEAR SAFETY INSTITUTE OF RUSSIAN
ACADEMY OF SCIENCES

MELCOR 2.1

Verification on MARVIKEN Critical Flow Experiments

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Outline

- MELCOR 2.1 critical flow model
- Marviken experiments
- MELCOR 2.1 nodalization scheme
- Calculation results including sensitivity study
- Conclusions

Goal of the work

- To verify MELCOR critical flow model
- To suggest ways of code improvement

MELCOR Critical Flow Model

- Calculation of "critical" pressure difference value

$$\Delta P_{critical,j} = \xi_j \frac{\rho_j c_{s,j}^2}{2}$$

- Comparison of "critical" pressure difference value with actual pressure difference obtained as difference of linearly projected new pressures. If

$$\Delta P_j^{\tilde{n}} > \Delta P_{critical,j}$$

correction of local friction (form) loss coefficient to limit flow velocity by critical one

$$\xi_j^{corrected} = \xi_j \frac{\Delta P^{\tilde{n}}{}_j}{\Delta P_{critical.j}}$$

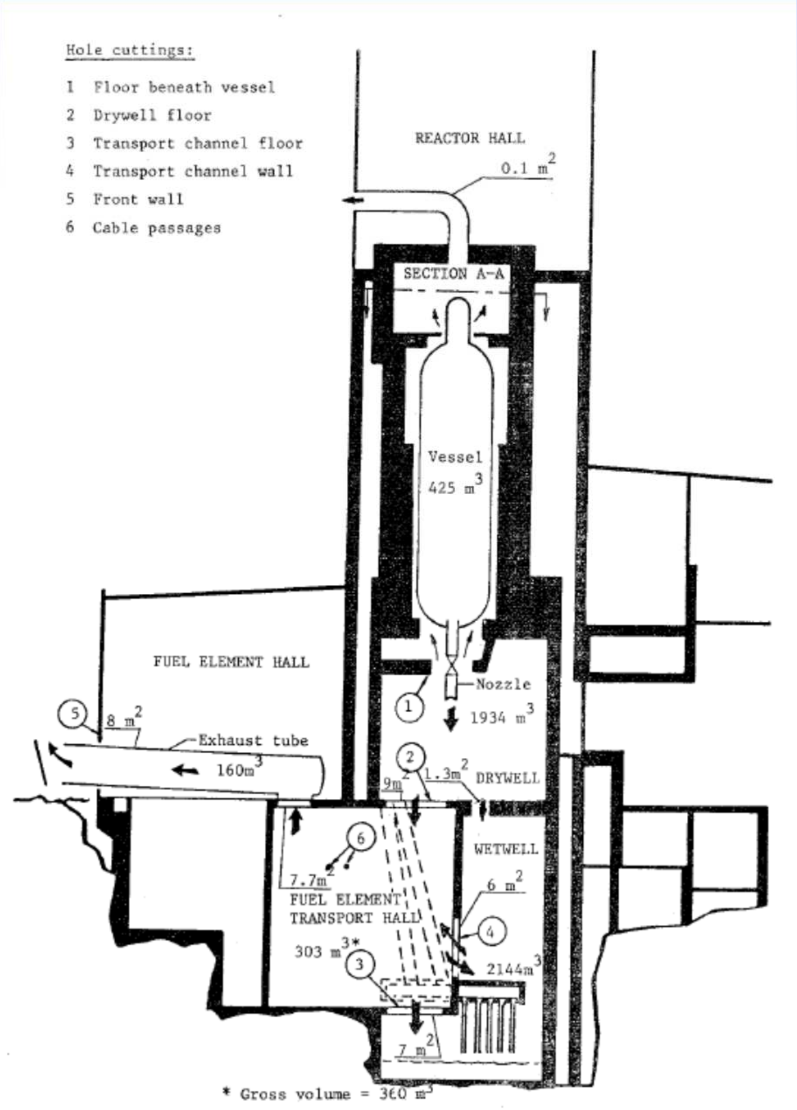
- Using of new (corrected) local friction (form) loss coefficient in global solution with no sub-iteration

Calculation of Sonic Velocity

- Only atmosphere – correlation based on [R. B. Bird, W. E. Stewart, and E. N. Lightfoot Transport Phenomena, John Wiley & Sons, New York (1960), Equation 15.5-42, with identification of the sound speed as $(\gamma P/\rho)^{1/2}$]
- Only pool – RETRAN model [RETRAN-02—A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Systems, Volumes 1-3, NP-1850-CCM, Electric Power Research Institute, Palo Alto, CA (May 1981)]
- Both phases – MOODY choking model

MARVIKEN Experimental Facility

- ❖ Marviken Power Station Facility (100 km from Stockholm)
- ❖ Conducted in 1978-1979
- ❖ 27 experiments
- ❖ Pressure vessel
  - Isolated using glass wool
  - 24.55 m high
  - 5.2 m inner diameter
  - Made of low alloy steel
- ❖ Discharge pipe
  - Total length – 6308 mm
  - Inlet diameter – 752 mm
  - Made of stainless steel



MARVIKEN Experimental Facility

- The pressure vessel with net volume 425 m^3, maximum design pressure 5.75 MPa and maximum design temperature 272°C
- The discharge pipe consisting of the ball valve and pipe spools which house the test nozzle upstream instrumentation
- The nozzles and rupture disc assemblies: a set of nozzles of specified lengths and diameters to which the rupture disc assemblies were attached
- The containment and exhaust pipes consisting of
  - The drywell with net volume 1934 m^3
  - The wetwell with net volume 2144 m^3
  - The fuel element transport hall with net volume 303 m^3, the ground level 3.2 m diameter and the upper 0.4 m diameter exhaust pipe

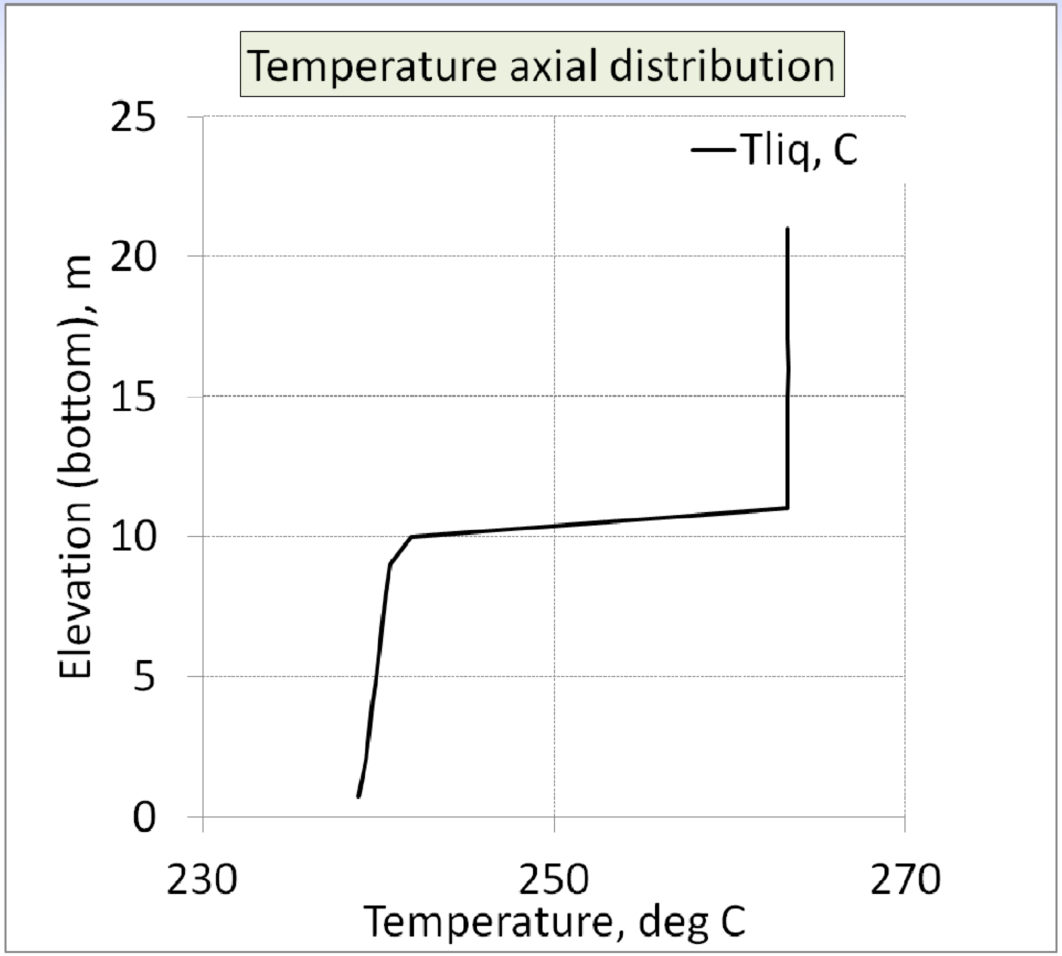
Nozzles

Nozzle type no	D mm	L mm	L/D	L1 mm	L2 mm	L3 mm	L4 mm	R mm	Used in tests no
1	200	590	3,0	0	100	100	100	100	13, 14
2	300	290	1,0	55	150	150	150	150	6, 7
3	300	511	1.7	0	150	150	150	150	25, 26
4	300	895	3,0	55	150	150	150	150	1, 2, 12
5	300	1116	3.7	0	150	150	150	150	17, 18, 19
6	500	166	0.3	0	225	225	250	250	23, 24
7	500	730	1.5	0	225	225	250	250	20, 21, 22, 27
8	500	1809	3.6	0	181	156	241	250	15, 16
9	509	1589	3.1	55	156	225	241	250	3, 4, 5, 8, 9, 10, 11

Initial and Boundary Conditions, Tests 1- 5

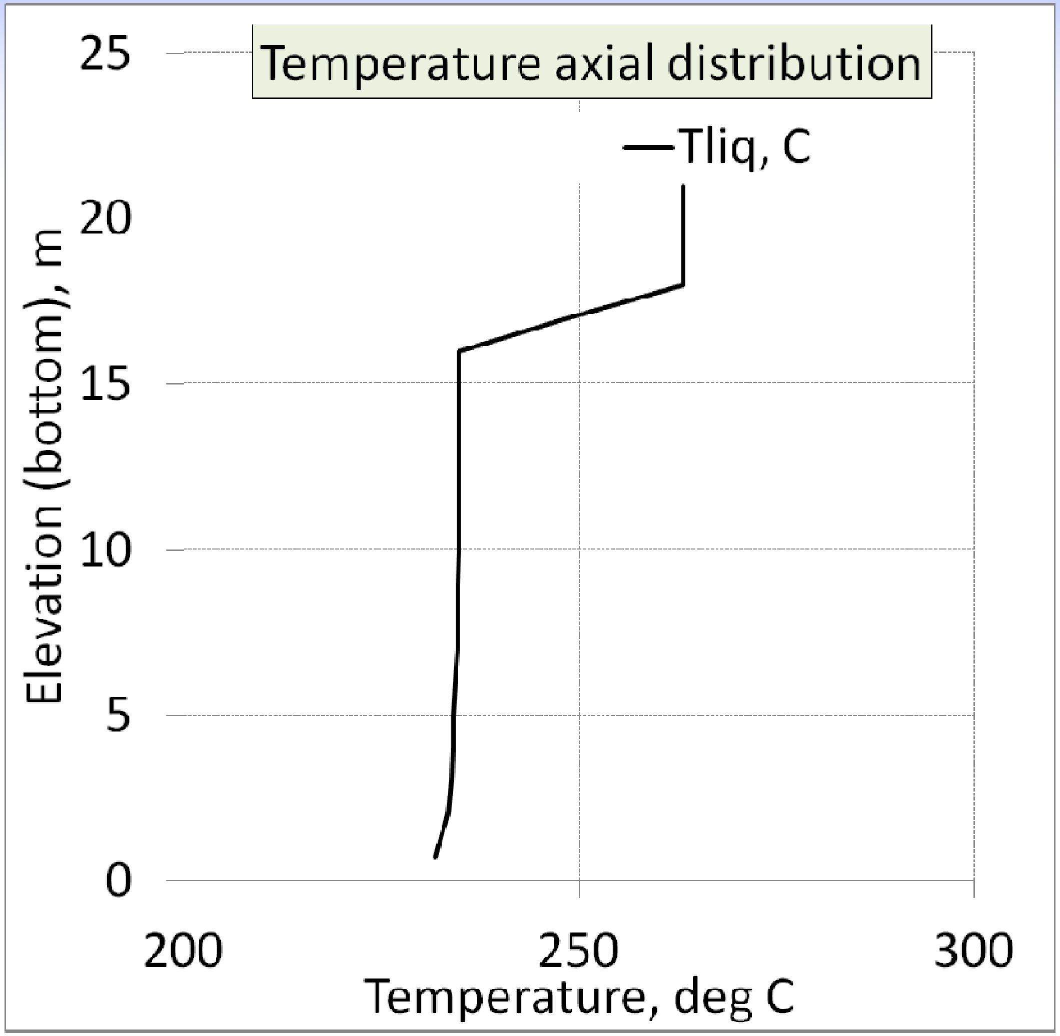
Test No.	1	2	3	4	5
Steam dome P, MPa	4.94	4.98	5.02	4.94	4.06
Saturation temp., C	263	264	264	264	251
Degree of nominal subcooling in the lower vessel, C	17-23	38	15-22	37	33
Min. fluid temperature in the vessel, C	238	226	243	224	218
Initial temperature at nozzle inlet, C	226	213	223	201	205
Mass of water and steam	287	284	274	286	286
Initial level in the vessel	17.84	17.41	17.06	17.59	17.44

Initial Conditions (1)



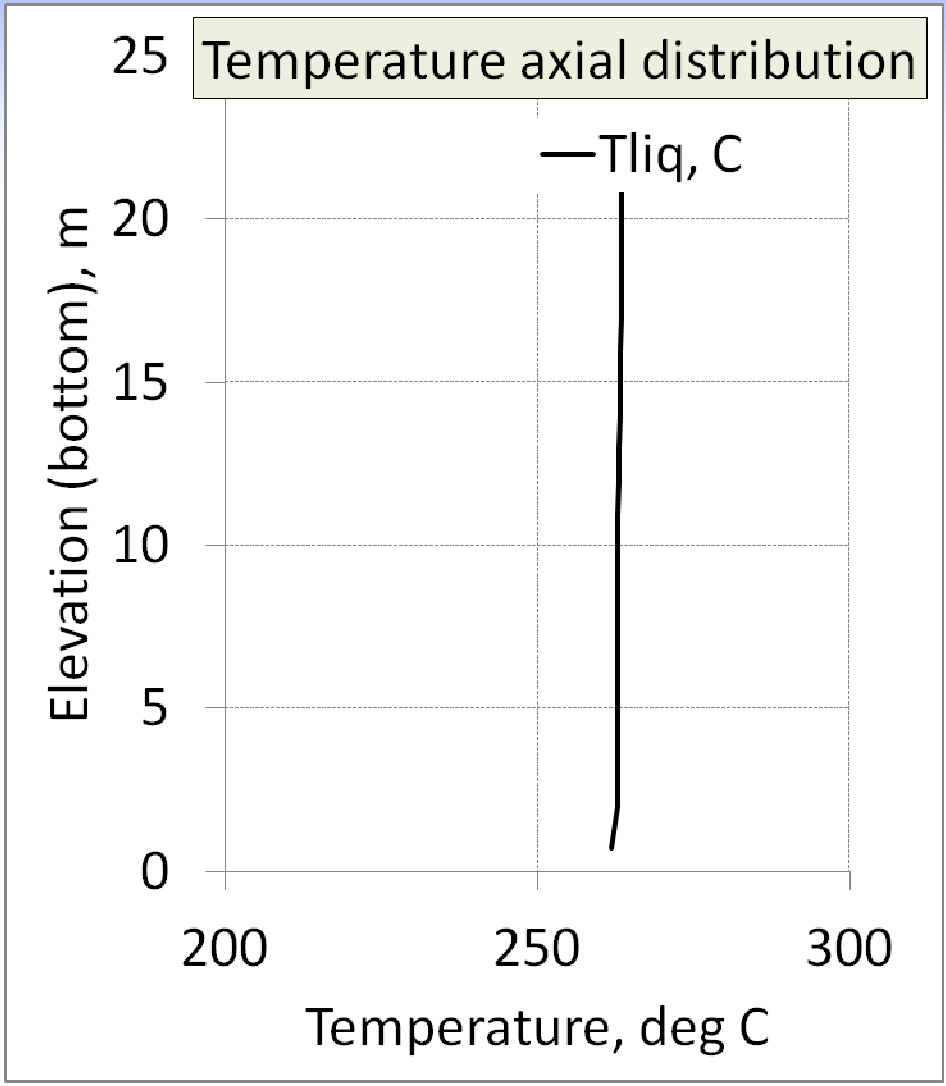
- The tests with water initially subcooled to 15 °C or more
- Tests numbers: 1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13, 16, 18

Initial Conditions (2)



- The tests with water initially subcooled to 30 °C or more
- Tests numbers: 15, 17, 21, 22, 24, 26, 27, 22

Initial Conditions (3)

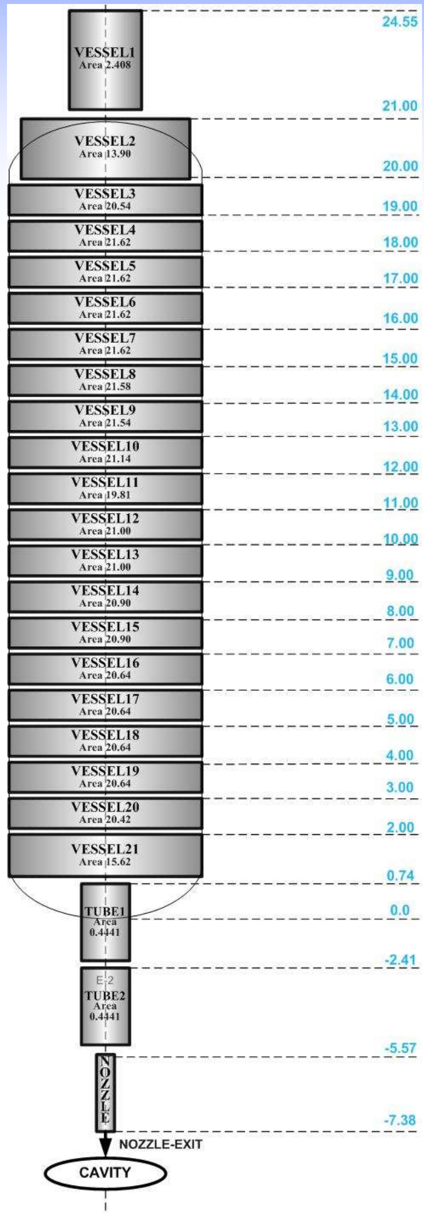


- The tests with water initially subcooled to less than 5 °C
- Tests numbers: 9, 10, 14, 19, 20, 23, 25

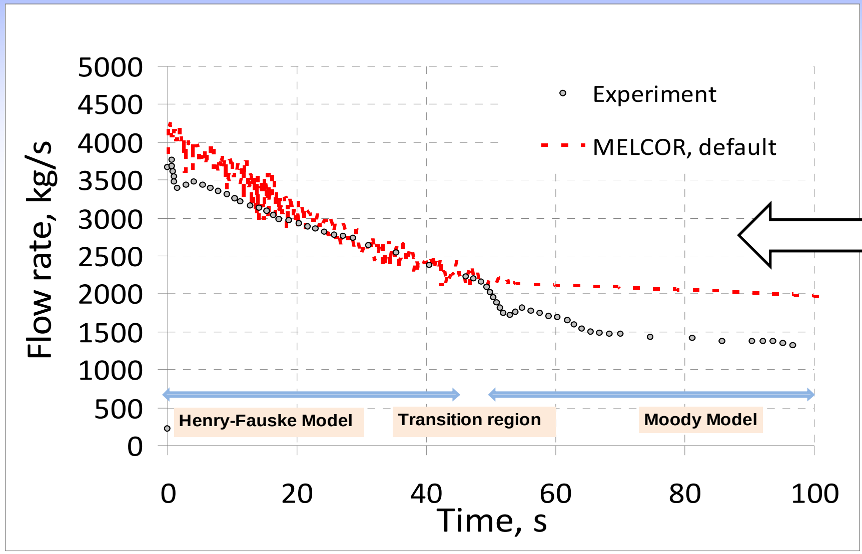
MELCOR 2.1 Nodalization Scheme

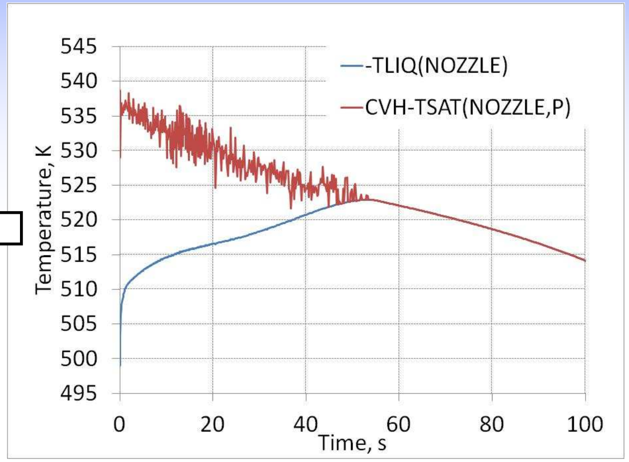
The nodalization scheme consists of

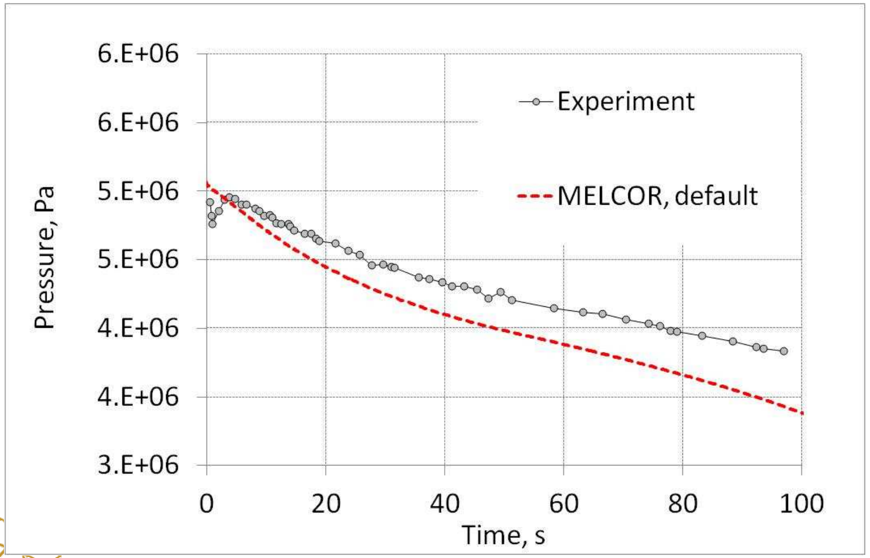
- 21 control volumes in the vessel
- 2 volumes in discharge pipe
- 1 volume in the noozle
- 1 time-independent volume for cavity

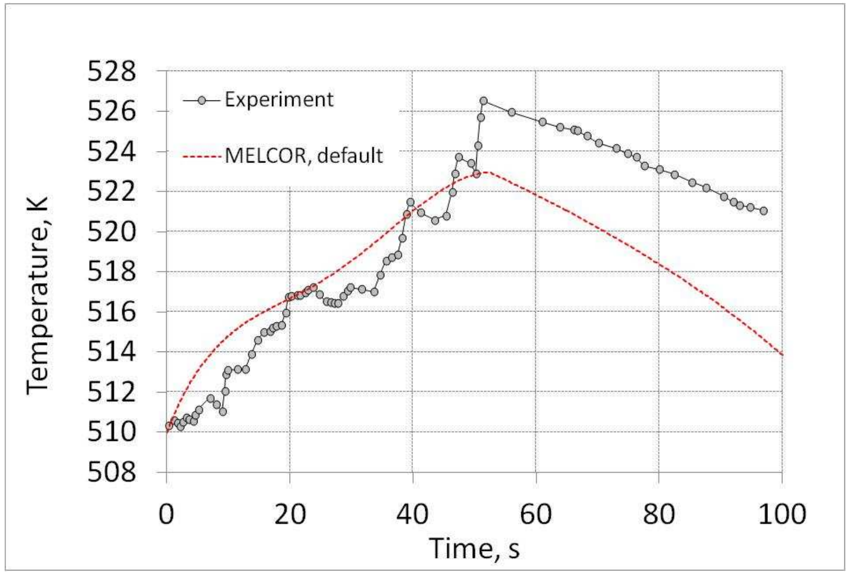


Test 1 Modeling

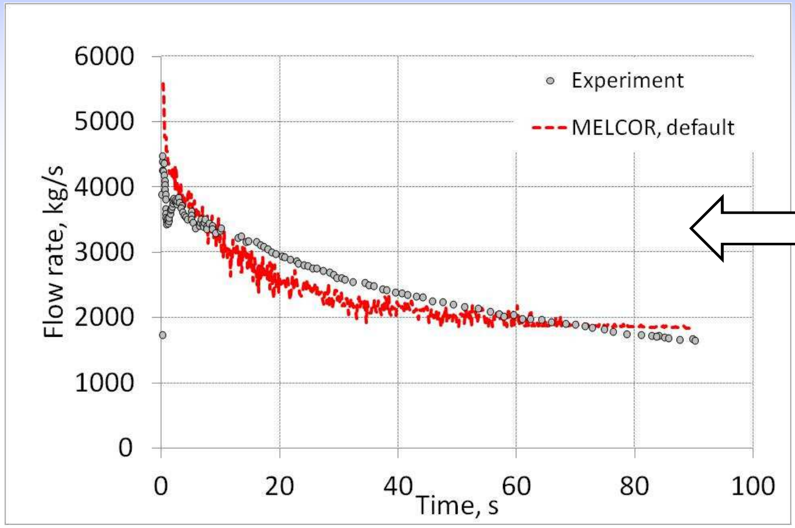


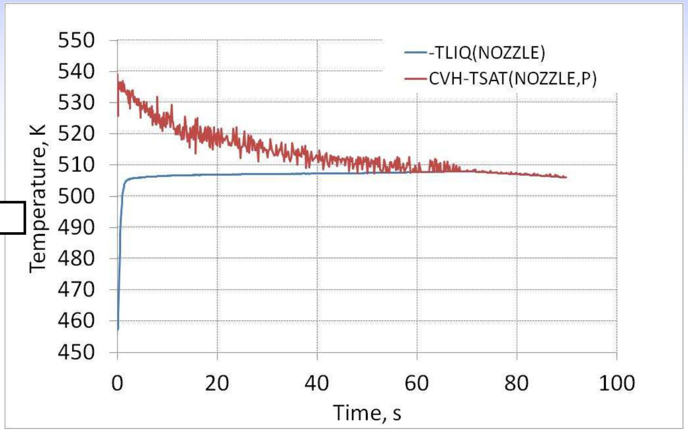


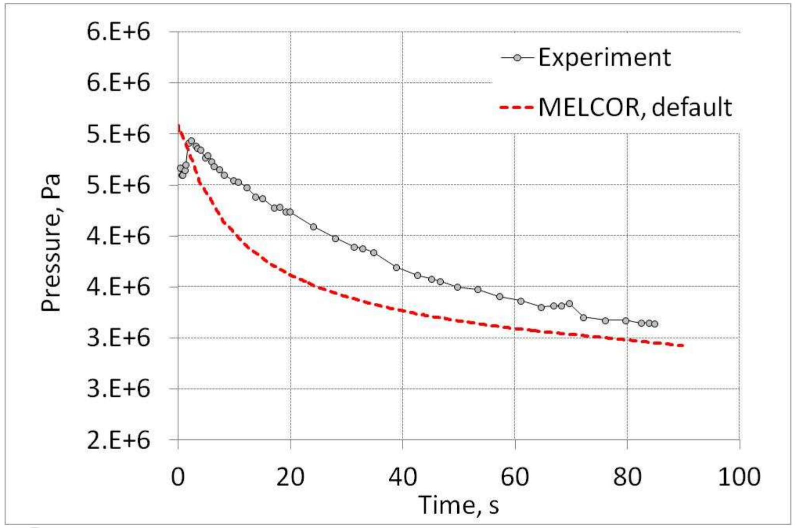


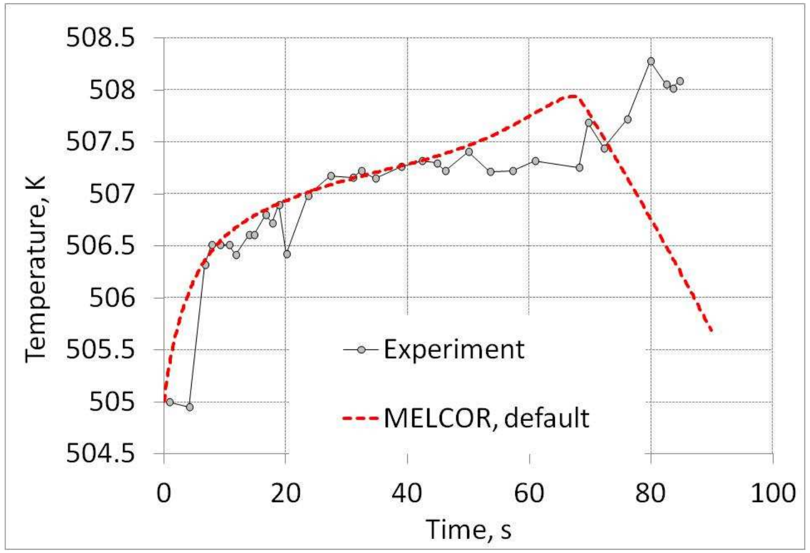


Test 17 Modeling



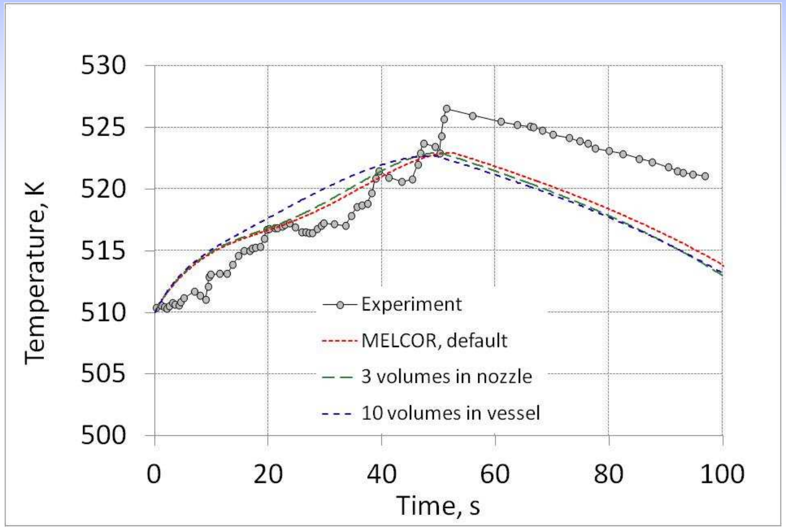


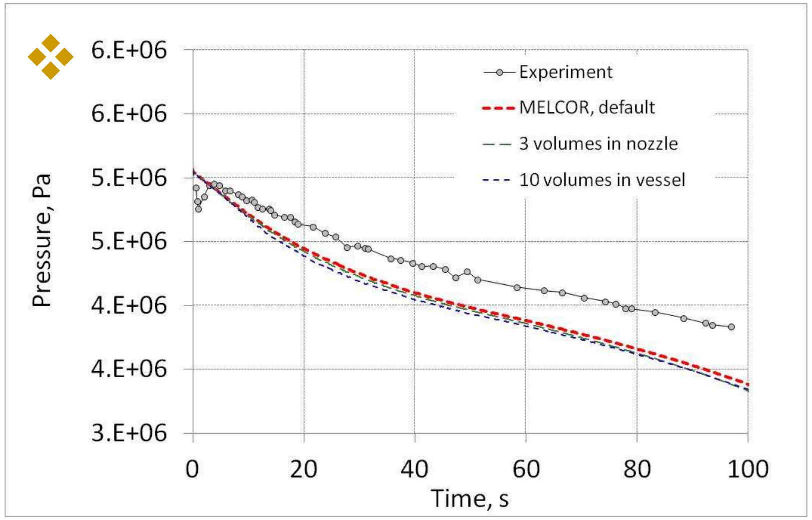


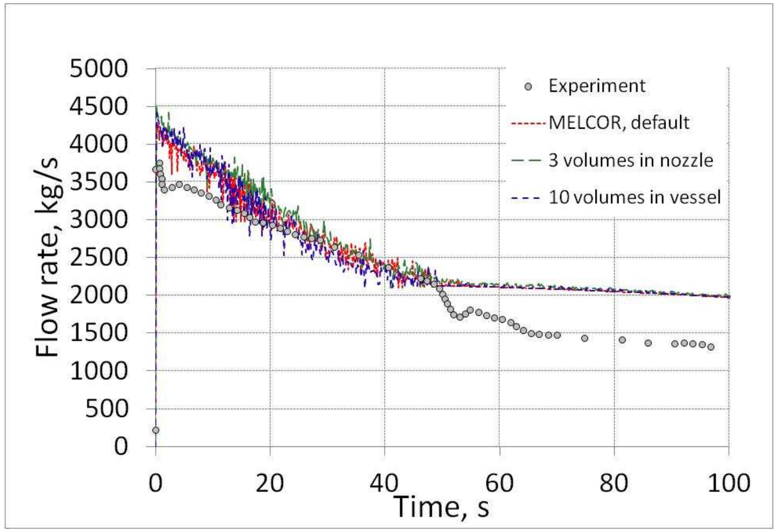


Sensitivity Study: Nodalization

- Default nodalization of the vessel was chosen typical for MELCOR and as a compromise between results' accuracy and time step size
- The detailed nozzle nodalization does not influence on the results







Sensitivity Study: Discharge Coefficients

Discharge coefficients - multipliers for the critical flow values calculated by implemented into the MELCOR code models.

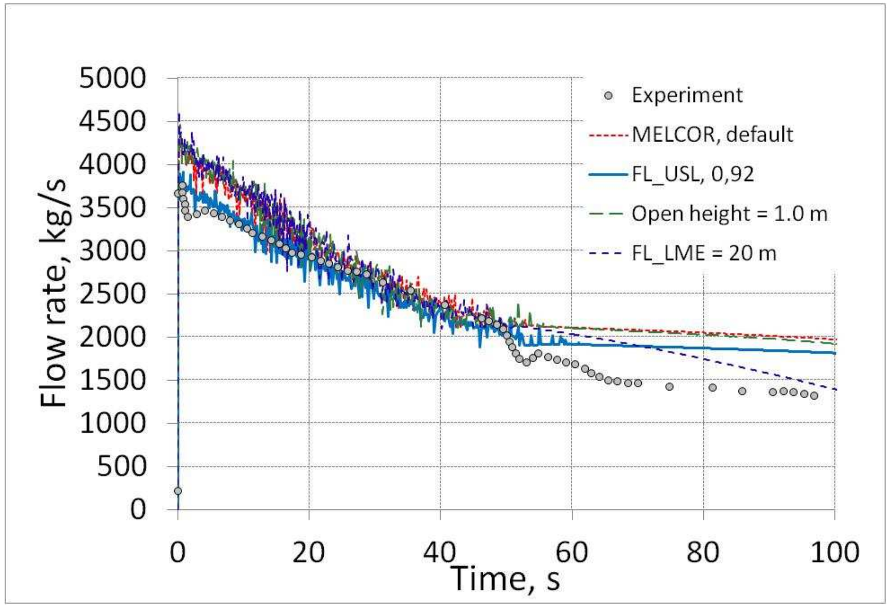
FL_USL – User Specified Loss Coefficients

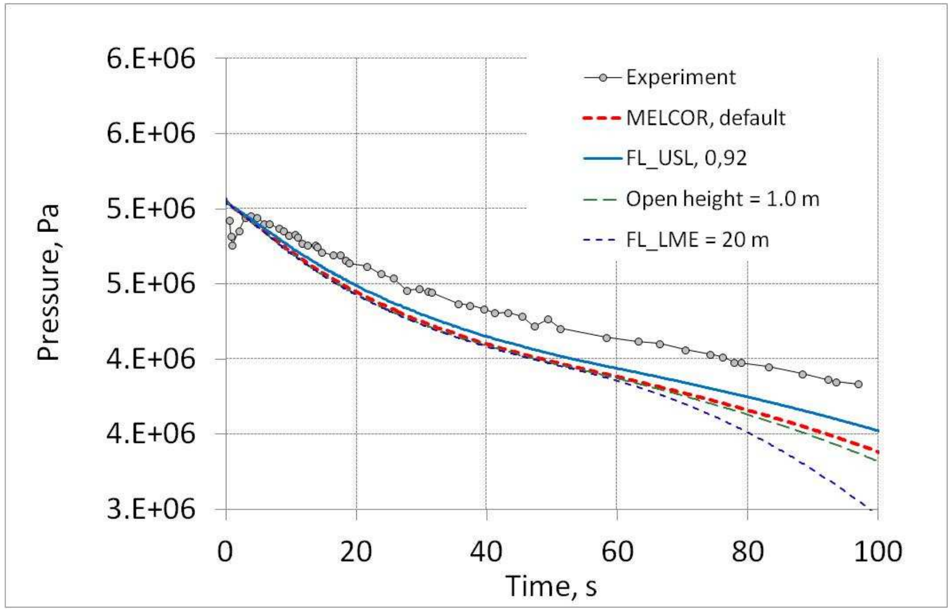
(3) CDCHKF
Choked flow forward discharge coefficient.
(type = real, default = 1.0, units = dimensionless)
(4) CDCHKR
Choked flow reverse discharge coefficient.
(type = real, default = 1.0, units = dimensionless)

Nozzle type No.	1	2	3	4	5	6	7	8	9
Discharge coefficient	0.98	0.96	0.97	0.92	0.94	0.92	0.92	0.94	0.94

Sensitivity Study: FL_GEO, FL_USL, FL_LME

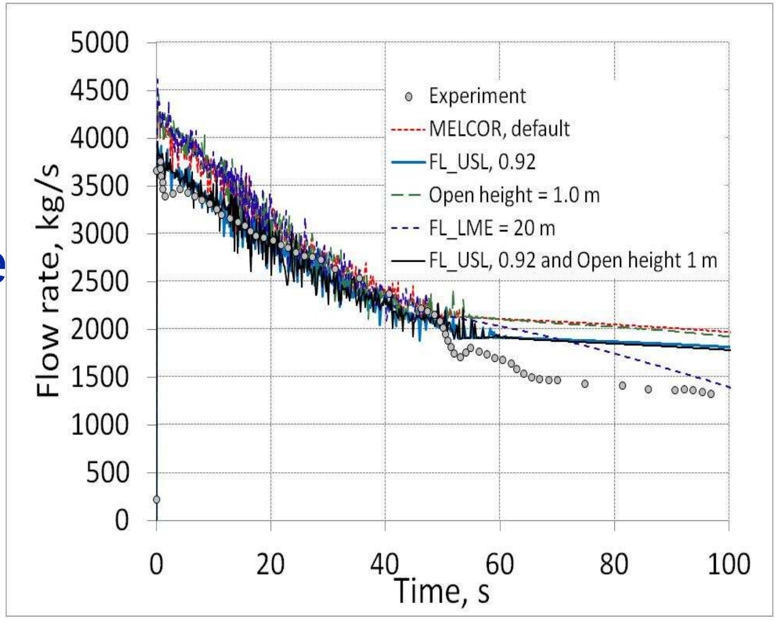
- Flow path opening height (FL_GEO: FLHGTT and FLHGTF)
- Interphase interaction length (FL_LME)





Sensitivity Study

- Use of choking coefficients calculated based on a particular nozzle/break geometry instead of default value for all calculations is recommended
- For transients with critical flow and high velocities the value of "opening height" parameter is recommended close to the height of connecting volumes with the purpose to take into account steam entrainment to a leak
- Influence of the "interface interaction length" variation to results is contradictory and not recommended for using other than default value



Conclusions

- MELCOR 2.1 satisfactorily models the Marviken critical flow experiments though overestimate critical flow rate for two-phase conditions at the nozzle entrance and doesn't predict pressure oscillations during initial few seconds of the blow-down transient
- The accuracy mainly depends on the choking coefficients in the nozzle, which should be calculated based on the nozzle geometry, and size of nodes in the vessel
- Main distinctions between experimental data and calculations results are caused by
  - Absence of superheated fluid model in MELCOR
  - Moody correlations or their implementation used for two-phase flow
- Way of code improvement: replacement or correction of Moody correlations