РОССИЙСКАЯ АКАДЕМИЯ НАУК
Институт проблем безопасного развития атомной энергетики
RUSSIAN ACADEMY OF SCIENCES
Nuclear Safety Institute (IBRAE)

MELCOR 2.1 code verification on ISP-38 experiment at BETHSY facility

Nastasia Mosunova

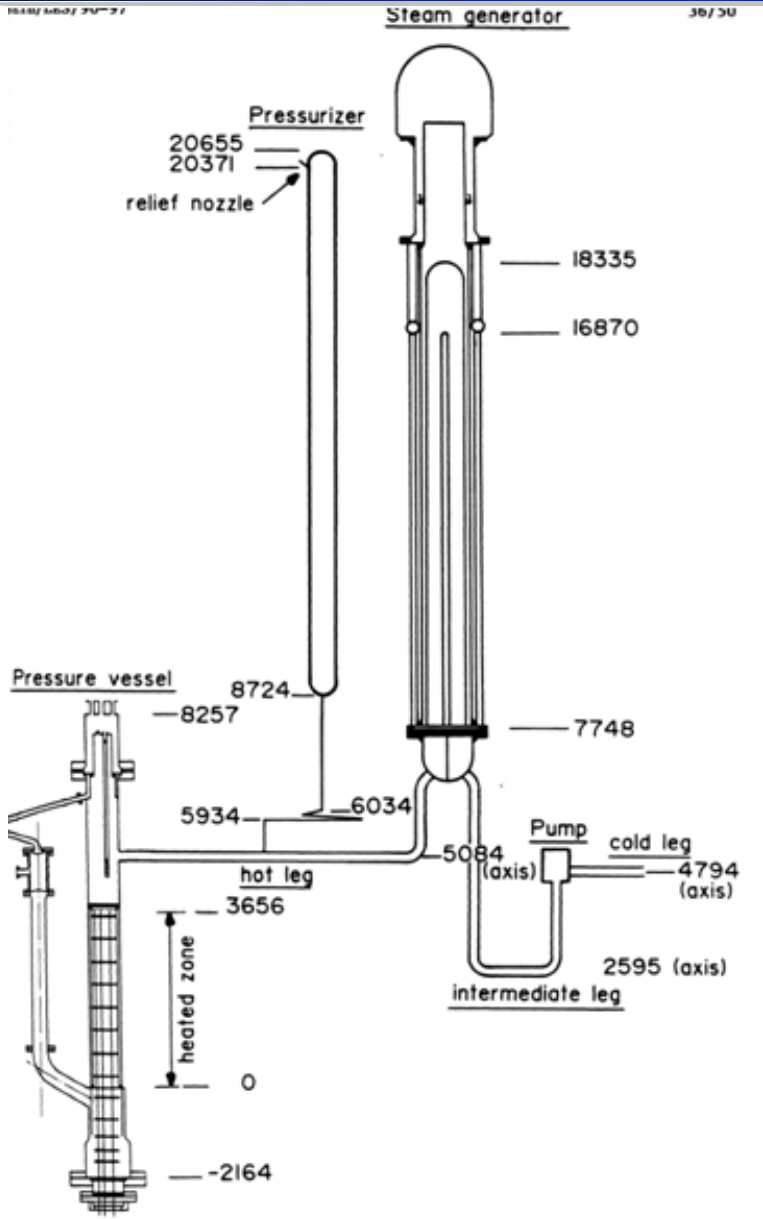
EMUG-4
GRS mbH Cologne, Germany
April, 16, 2012

Contents

- BETHSY facility
- ISP-38 experiment
- Nodalization scheme for MELCOR 2.1
- Calculation results
- Sensitivity study

Experimental Facility (1)

- Located at the Nuclear Center of Grenoble
- Integral test facility for investigation of PWR transients
- The reference nuclear power plant is a three-loop 900 MW_e (2775 MW_{th}) Framatome PWR
- The three primary loops of the reference PWR are simulated
- Full pressure facility



Experimental Facility (2)

- The overall volume scaling factor from the reference plant is approximately 1/100
- The design of the primary coolant piping hot legs preserve the Froude number
- The scaling factor for elevations of every component is 1:1

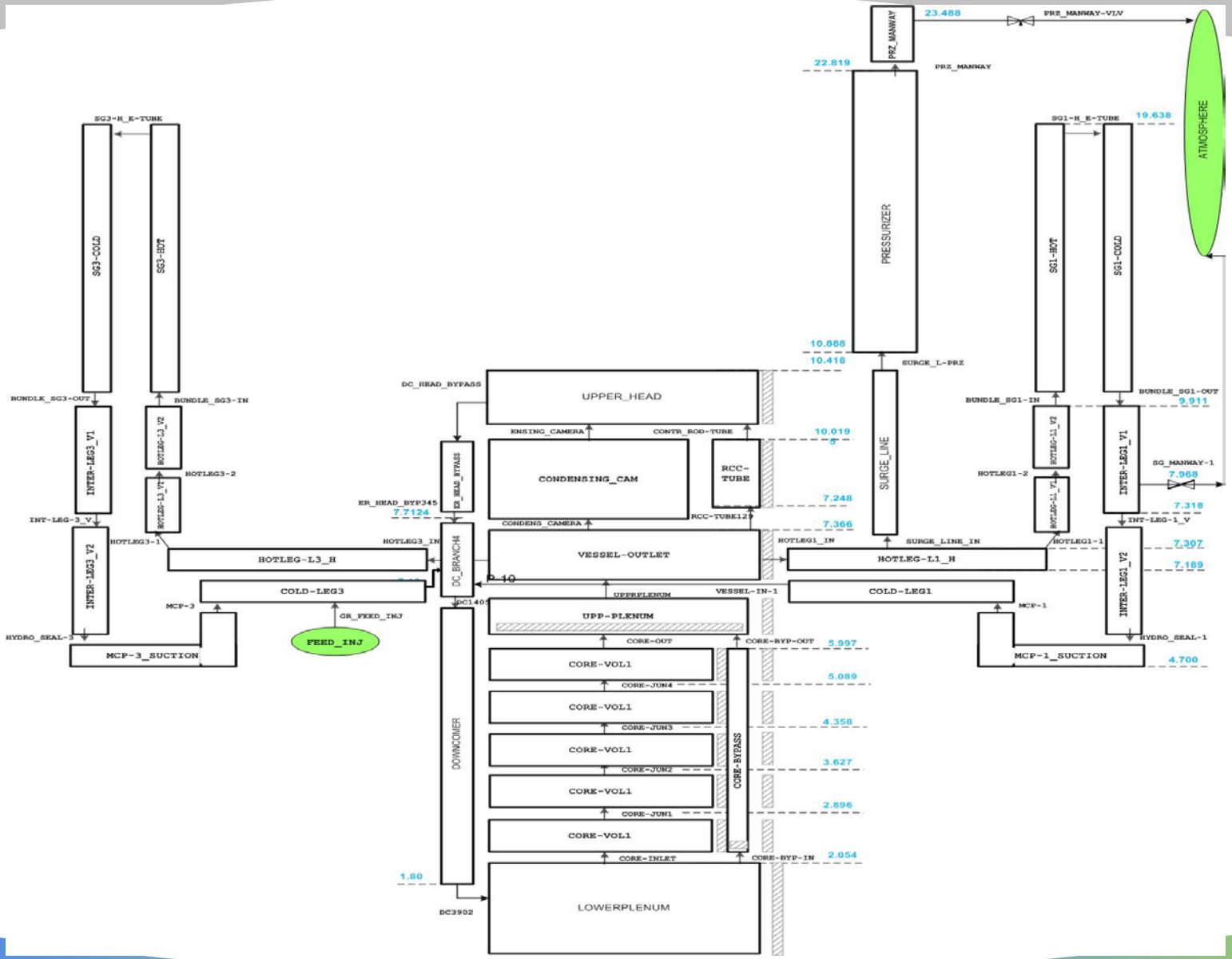
ISP-38 Experiment

- Loss of residual heat removal system simulated by increasing the core power
- Mid-loop operation transient at 0.5 % (138 kW) of nominal core power value (the liquid level is at the axis of the hot legs)
- The pressurizer and steam generator outlet plenum manways open
- The secondary side is full of air and isolated
- The trace heating system in order to make environmental heat losses negligible

The Transient Phases

- Phase 1: The reactor vessel mixture level is close to the axis of the hot legs. Flow through the manways is a two-phase flow through the SG manway and a steam single flow through the pressurizer manway.
- Phase 2: The two-phase reactor vessel level is decreasing thus leading to core uncovery and core cladding temperature rise. Lasted till the maximum core cladding temperature reached 523.15 K when LPIS injection started.
- Phase 3: The LPIS water (T = 311.15 K) is filling the primary cooling system to the midloop conditions.

MELCOR Nodalization Scheme



Steady-State Calculations

Parameter	Experiment	Calculation
Upper plenum pressure, kPa	104±2	105
Primary mass inventory, kg	1085±15	1086
Vessel mass inventory, kg	700±9	707
Fluid temperatures, C		
Upper plenum	102±2	101.3
Upper head	104±2	101.3
Pressurizer	101±2	102.7
Core heated length	102±2	101.2
Downcomer	99±2	99.2
Lower plenum	101±2	100.6
	L1/L2/L3	L1/L2/L3
Hot leg void fraction	0.59/0.55/0.52	0.59/0.59/0.59
Cold leg void fraction	0. /0./0.	0. /0./0.
Loop mass, kg	127/129/129	126/126/126

Major Events and Experimental/Calculation Data

Simulated parameter	Experiment	Calculation
Pressure peak in the upper reactor chamber, Pa	1.25e5	1.31e5
Time of two-phase mixture outflow from the SG-1 manway, s	0-1450	75-2320
Total mass of coolant flowed out over the two-phase mixture outflow time, kg	240	360
Hot leg empty, s	2880	380
Upper plenum empty, s	3390	2560
Time of cladding heating onset, s	4630	4040
Time of water injection onset from the ECCS, s	5660	4930
Time of maximum cladding temperature achievement, s	6150	6210
Maximum temperature of fuel claddings, K	578	710
Time of minimum water mass achievement in the system, s	5740	5080
Time of cladding cooling, s	6820	6600
Total mass of coolant flowed out via the SG-1 manway over the experiment, kg	591	633
Total mass of coolant flowed out via the pressurizer manway over the experiment, kg	139	131
Total mass of water injected from the ECCS over the experiment, kg	430	518

Calculation Results for Base Model

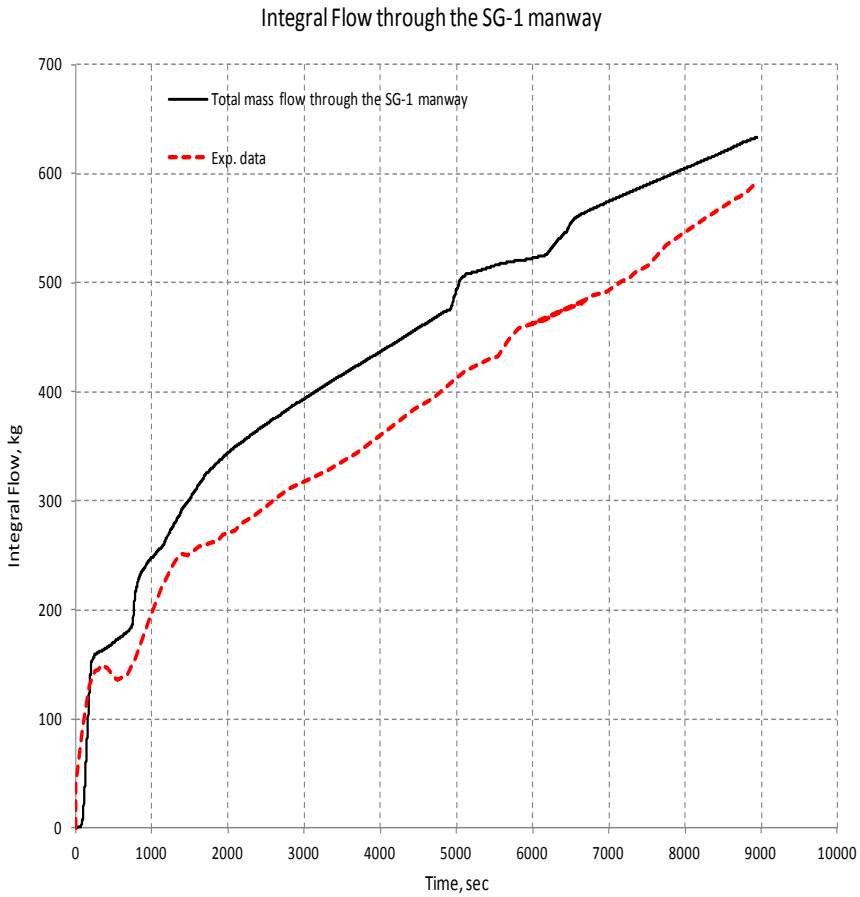
- The performed calculation demonstrates a qualitative agreement with the experimental data and simulates all physical phenomena at all phases of the experiment.
- Excess of the total outflow of liquid via the SG-1 manway by more than 50 kg achieved in the calculation
- Discrepancy between the calculation and the experiment concerns the behavior of cladding temperatures

Calculation Results with the Bubble Floating Rate SC4407(1) = 0.6

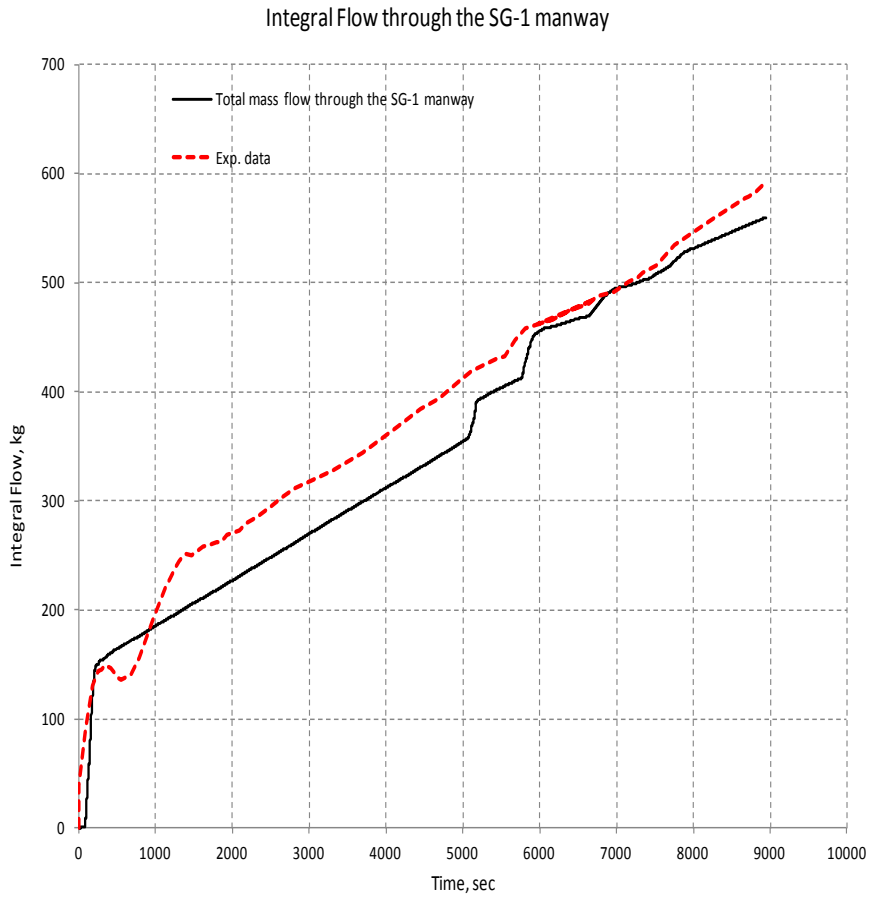
Simulated parameter	Experiment	Calculation (1)	Calculation (2)
Pressure peak in the upper reactor chamber, Pa	1.25e5	1.31e5	1.31e5
Time of two-phase mixture outflow from the SG-1 manway, s	0-1450	75-2320	77-1250
Total mass of coolant flowed out over the two-phase mixture outflow time, kg	240	360	204
Hot leg empty, s	2880	380	430
Upper plenum empty, s	3390	2560	3040
Time of cladding heating onset, s	4630	4040	4980
Time of water injection onset from the ECCS, s	5660	4930	5730
Time of maximum cladding temperature achievement, s	6150	6210	7700
Maximum temperature of fuel claddings, K	578	710	710
Time of minimum water mass achievement in the system, s	5740	5080	5960
Time of cladding cooling, s	6820	6600	7880
Total mass of water flowed out via the SG-1 manway over the experiment, kg	211	295	224
Total mass of coolant flowed out via the SG-1 manway over the experiment, kg	591	633	560
Total mass of coolant flowed out via the pressurizer manway over the experiment, kg	139	131	148
Total mass of water injected from the ECCS over the experiment, kg	430	518	401

Integral Flow through SG Manway

SC4407(1) = 0.3

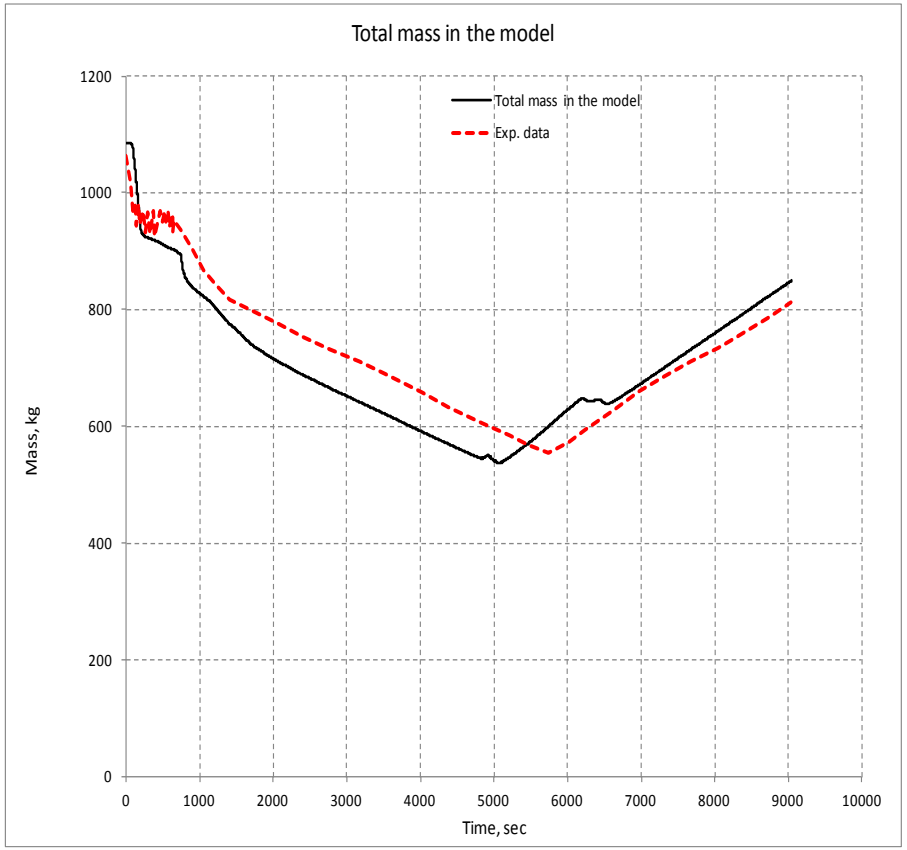


SC4407(1) = 0.6

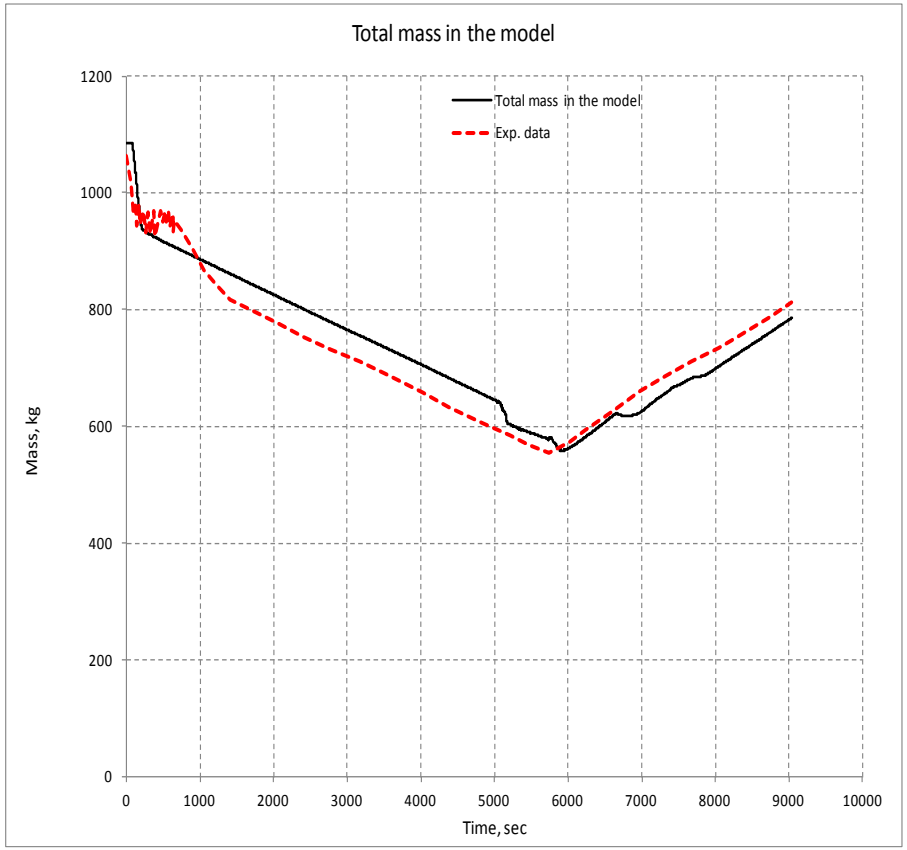


Total Mass in the Model

SC4407(1) = 0.3

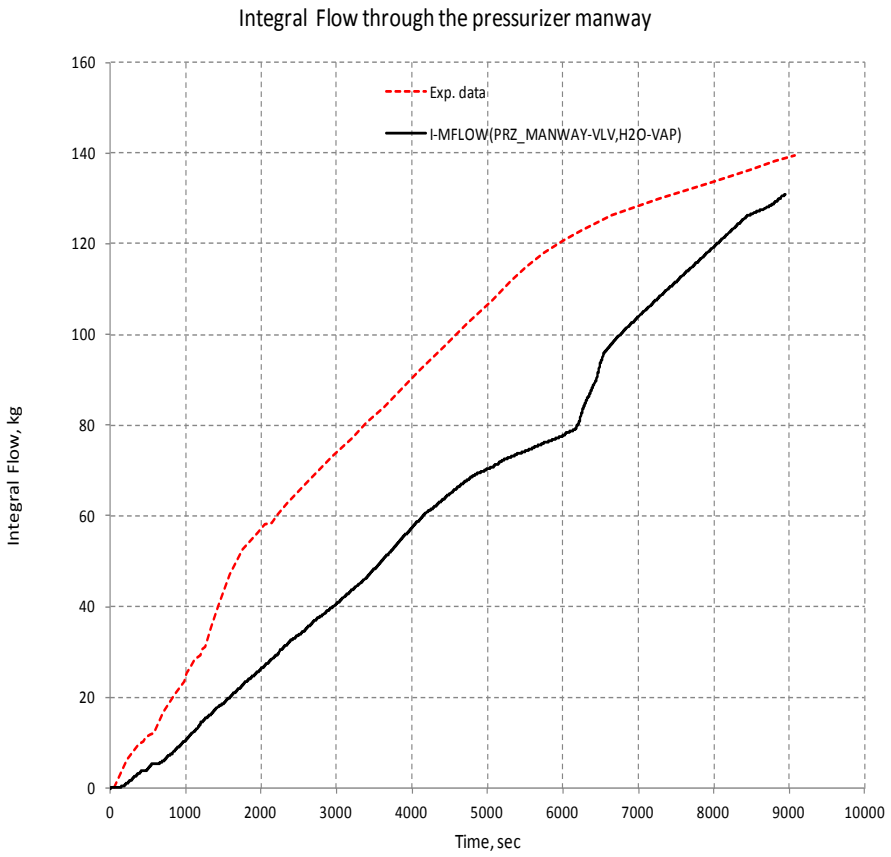


SC4407(1) = 0.6

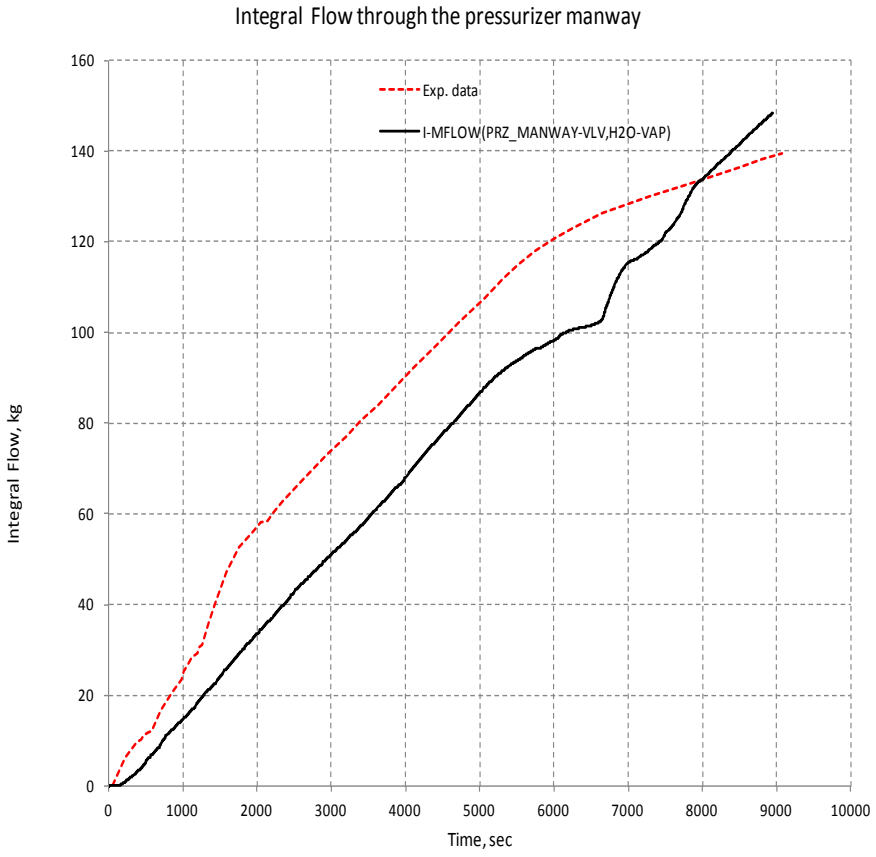


Integral Flow of Steam through the Pressurizer Manway

SC4407(1) = 0.3

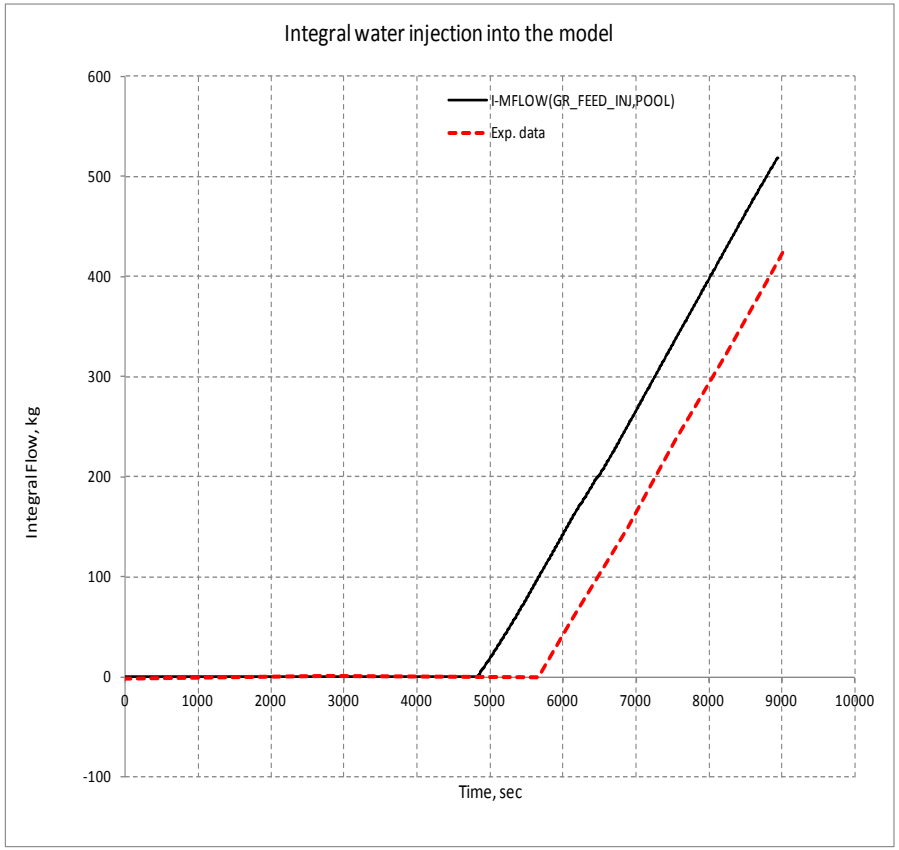


SC4407(1) = 0.6

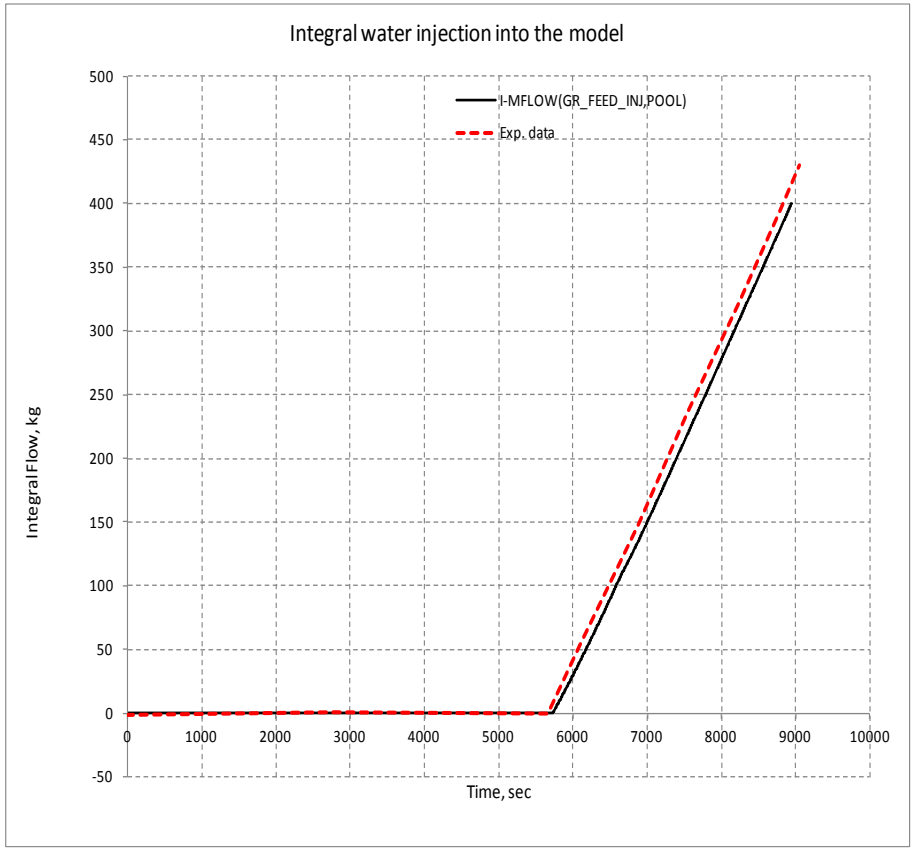


Integral Water Injection into the Model

SC4407(1) = 0.3



SC4407(1) = 0.6



Calculation Results with SC4407 = 0.6

- A considerable improvement of the integral results of simulation
- Decrease in the outflow of liquid from the system via the SG-1 manway
- From the viewpoint of the entire facility the effective averaged value of 0.6 reflects more adequately the conditions of the regime under consideration

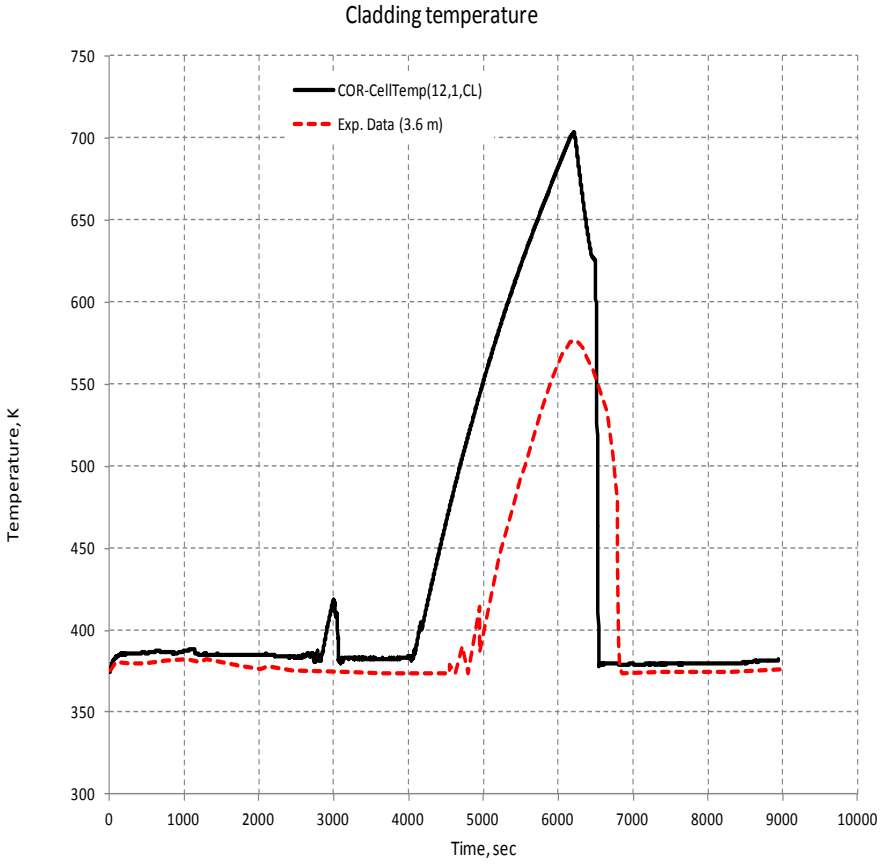
Calculation Results with Detailed Core Nodalization

Simulated parameter	Experiment	Calculation (1)	Calculation (2)
Pressure peak in the upper reactor chamber, Pa	1.25e5	1.31e5	1.31e5
Time of two-phase mixture outflow from the SG-1 manway, s	0-1450	75-2320	673
Total mass of coolant flowed out over the two-phase mixture outflow time, kg	240	360	201
Hot leg empty, s	2880	380	430
Upper plenum empty, s	3390	2560	3040
Time of cladding heating onset, s	4630	4040	5060
Time of water injection onset from the ECCS, s	5660	4930	5900
Time of maximum cladding temperature achievement, s	6150	6210	6920
Maximum temperature of fuel claddings, K	578	710	660
Time of minimum water mass achievement in the system, s	5740	5080	6000
Time of cladding cooling, s	6820	6600	7020
Total mass of water flowed out via the SG-1 manway over the experiment, kg	211	295	199
Total mass of coolant flowed out via the SG-1 manway over the experiment, kg	591	633	535
Total mass of coolant flowed out via the pressurizer manway over the experiment, kg	139	131	151
Total mass of water injected from the ECCS over the experiment, kg	430	518	385

Cladding Temperature , 3.6 m

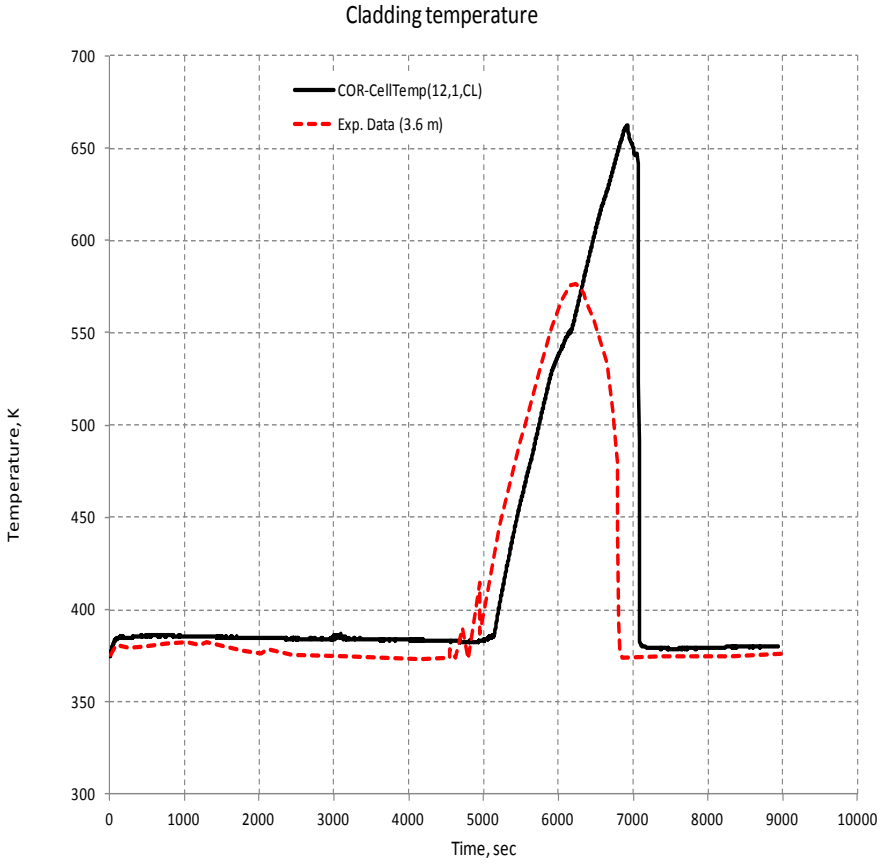
Original nodalization

5 Calculated Volumes



Detailed nodalization

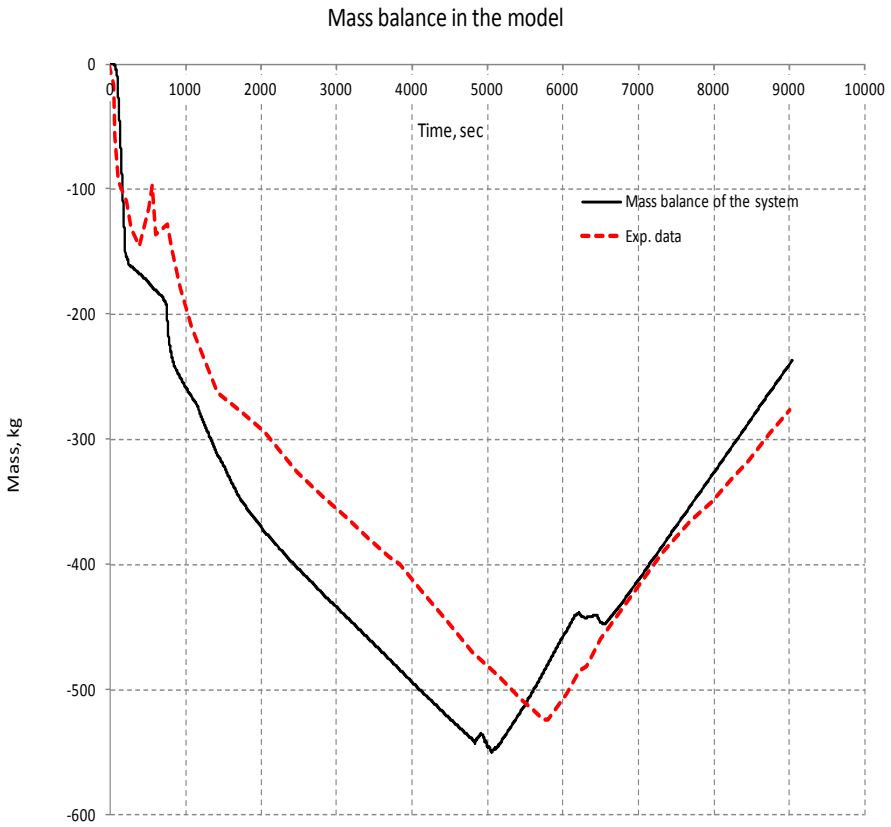
10 Calculated Volumes



Total Mass in the Model

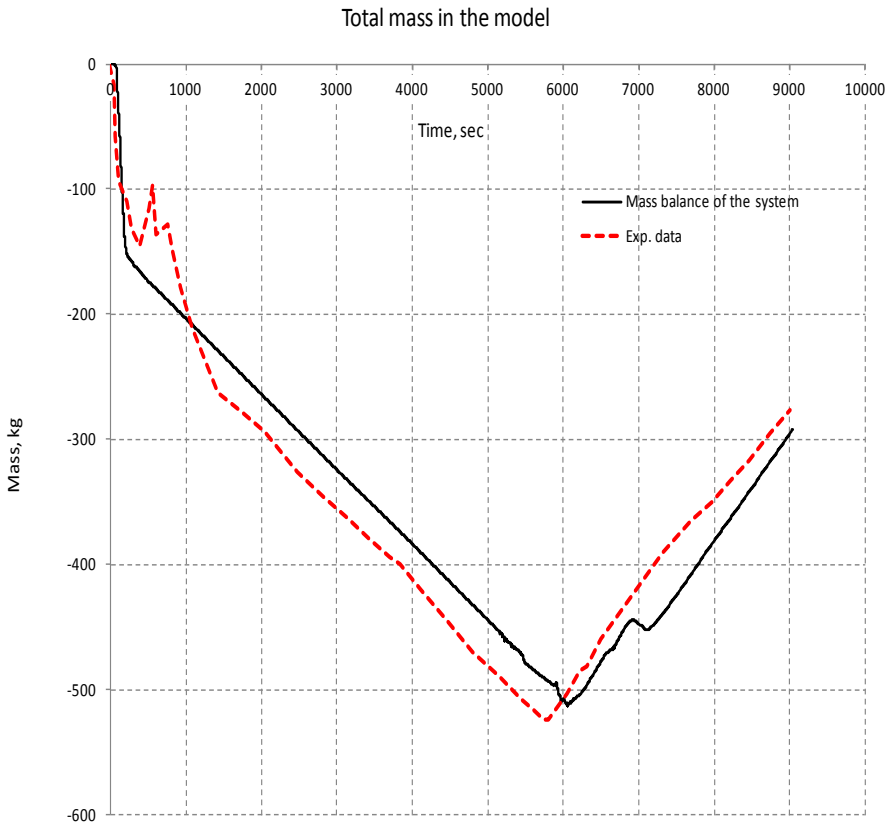
Original nodalization

5 Calculated Volumes



Detailed nodalization

10 Calculated Volumes



Calculation Results with Detailed Core Nodalization

- All integral parameters and the times of major events are in a good agreement with the experiment.
- An appreciable improvement has been obtained for cladding temperatures: the peak-temperatures and the time of full cooling of the core elements have decreased.
- The results achieved confirm the possibility of improving the results of cladding temperature simulations through a more detailed nodalization of the in-core volume.

Conclusions

- A special calculated model was developed and a calculated simulation of the experimental series 6.9c conducted at the BETHSY facility.
- MELCOR 2.1 code reproduces at a qualitative level all key thermal-hydraulic processes in reactor installations in case of accident with residual heat removal system loss.
- An appreciable improvement of the calculation results is achieved via fitting of the sensitivity coefficient SC4407(1).
- The agreement between the calculated local parameters in the core (cladding temperatures) and the relevant experimental data is improved when a more detailed nodalization is used.