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CATHARE2 V1.3E POST-TEST COMPUTATIONS OF SPE-1 AND SPE-2 EXPERIMENTS AT PMK-NVH FACILITY.

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ABSTRACT

This paper presents the first CATHARE2 V1.3E simulations of the SPE-1 and SPE-2 transients at PMK-NVH loop. The aim is to have a preliminary information on the CATHARE2 capability to represent the phenomena occurring during WWER-type transients. A simplified meshing is used (based on a previous KFKI input data deck). A 0-D secondary side steam generator model is used with only one SG primary tube.

Computations were performed with the standard code version. As a whole, for both tests, the results compared to experimental data are in good agreement with the transient chronology and the main phenomena are well predicted.

In both tests, the mass flow rate at the break seems overestimated, but an other computation of SPE-2 with experimental flow as boundary condition leads to an erroneous prediction of the transient chronology.

The calculated collapsed level in the core is lower than the measured one in the two tests. Hence, some partial dry-out appears to be due to the over-prediction of the break flow and to a non-realistic distribution of the water mass in the circuit.

The effect on the transient (including accumulators injection) of the modelling of the SG primary side is clearly outlined. The improvement of the description with a multi-tubes model seems crucial for CATHARE2 qualification on the WWER design.

INTRODUCTION

This paper deals with the simulation of WWER-type transients with the French safety thermalhydraulic code CATHARE2 V1.3E developed for Western PWR studies. In the framework of an IPSN working group, CATHARE is used in view of the verification of the predictive capability of the code to describe the behaviour of WWERs under accidental conditions. On this purpose, systematic computations are performed on existing test loops. In a first attempt to have some information on the CATHARE2 capability to represent the phenomena occurring during these specific transients, we present simulations of experiments carried out at the PMK-NVH facility for the two first Standard Problem Exercises (SPE-1 and SPE-2) organised by the IAEA [IAEA 1987 and IAEA 1988].

PMK-NVH is an integral test facility located in Hungary in KFKI laboratories. It is an electrically heated scaled-down model of the WWER-440/213 PAKS Nuclear Power Plant (NPP) operating at nominal conditions and with a single active loop. The SPE-1 and SPE-2 experiments were dedicated to the investigation of small LOCA due to a break of 3 mm diameter in the cold leg (equivalent to 7.4% break LOCA in the upper head of the NPP downcomer).

A HPIS pump was used (injection mass flow rate equal to 2/3 of the NPP total one). The accumulators (SIT, Safety Injection Tank) were not used for SPE-1 experiment whereas they were actuated in SPE-2 (3/4 of the NPP capacities).

SPE-1 AND SPE-2 EXPERIMENTATIONS AT PMK-NVH

Facility description

Figure 1 shows the flow diagram of the facility. The NPP vessel is represented by the downcomer and the reactor models (see figure 1). The upper head of the downcomer is volume shaped and the flow in the main part of its body is of annular type. The bottom part is of pipe type. A peculiarity of the reactor model is a pipe loop in the core outlet section. Loop seals are present both in the hot and cold legs. For the SG model, the two collectors and the

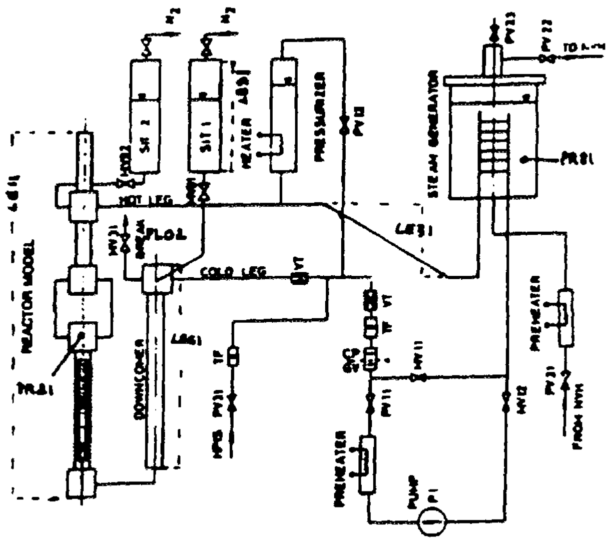

Figure 1 : Flow diagram of the PMK-NVH facility.

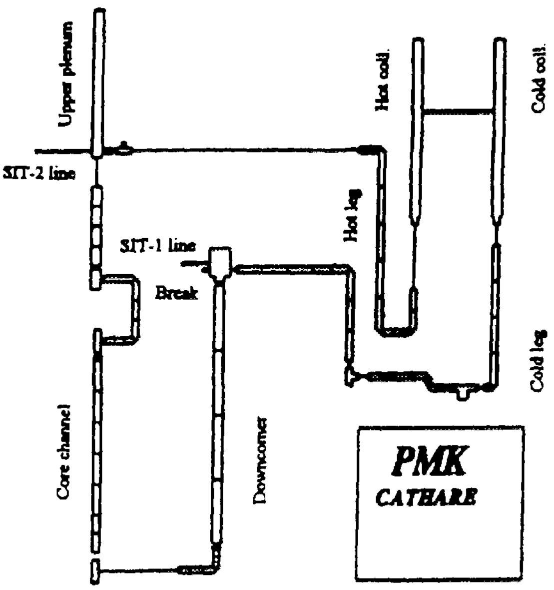

Figure 2 : CATHARE2 nodalization scheme.

bundle of 82 primary tubes are included in a vertical barrel constituting the SG secondary side. An other peculiarity is the existence of a pump by-pass line on the cold leg. This is due to the pump scale which is not in agreement with the facility one. Hence, the modelling of the pump coast down is performed by throttling of the PV11 valve.

The break device is located side by side to the downcomer upper head volume. It has a diaphragm of 3 mm inner diameter and of 15 mm long, with convergent and divergent sections. The break is opened by the MV31 valve located after the device (see figure 1).

Two accumulators are used for SPE-2 test : one connected to the downcomer upper head (SIT-1) and the other to the upper plenum (SIT-2). The injection point of the HPIS line is located on the cold leg.

Figure 1 shows some measurement locations used for the SPE-2 experiment.

Initial conditions

The initial conditions are presented in table 1 for SPE-1 and SPE-2 transients. The primary circuit is characterised by the upper plenum pressure, the loop mass flow rate, the coolant core inlet temperature, the core power, the pressurizer collapsed level, the SIT pressures and levels. The secondary circuit is characterised by his pressure, the feed water flow and the collapsed level.

Initial pressure distribution in the system is given in eight points distributed along the primary circuit.

At the beginning of the transient, the MV11 valve in the cold leg is closed and the MV12 and PV11 ones in the pump by-pass are opened. The initial pressures of SIT-1 and SIT-2 in SPE-2 test are 5.97 and 6.02 MPa respectively.

The measured total heat losses are around 24 kW and the heat added by the pump is around 18.5 kW.

	SPE-1		SPE-2	
	PMK	CATHARE	PMK	CATHARE
P_{up}	12.65	12.645	12.18	12.179
Q_{cl}	4.73	4.70	4.60	4.59
T_{ic}	538	537.8	546	546.4
L_p	1.53	1.53	1.55	1.50
W_c	654	654	662	662
W_{hl}	23.3	23.6	24.0	23.98
W_{pp}	18.5	18.49	18.5	18.49
L_{s1}	-	-	1.55	1.55
L_{s2}	-	-	1.98	1.98
P_{s1}	-	-	5.67	5.67
P_{s2}	-	-	6.02	6.02
P_{sg}	4.67	4.67	5.07	5.07
L_{sg}	2.25	2.255	1.67	1.675
Q_{sg}	0.353	0.353	0.406	0.396

Note (time in seconds) :

P_{up} : Pressure in upper plenum (MPa).
Q_{cl} : Primary circuit loop flow (kg/s).
T_{ic} : Core inlet temperature (K).
L_p : Collapsed level above bottom of pressurizer (m).
W_c : Core power (kW).
W_{hl} : System heat loss (kW).
W_{pp} : Heat added by the primary pump (kW).
L_{s1} : Collapsed level in SIT-1 (m).
L_{s2} : Collapsed level in SIT-2 (m).
P_{s1} : Pressure in SIT-1 (MPa).
P_{s2} : Pressure in SIT-2 (MPa).
P_{sg} : Pressure in steam generator (MPa).
L_{sg} : Collapsed level above bottom of SG secondary side (m).
Q_{sg} : Feed water flow (kg/s).

Table 1 : Initial conditions.

Transient description

The experiments start from steady-state conditions corresponding to normal operation at 100% power of the NPP. The test is finished at 997 s for SPE-1 and at 996 s for SPE-2. The main events are described below and reported

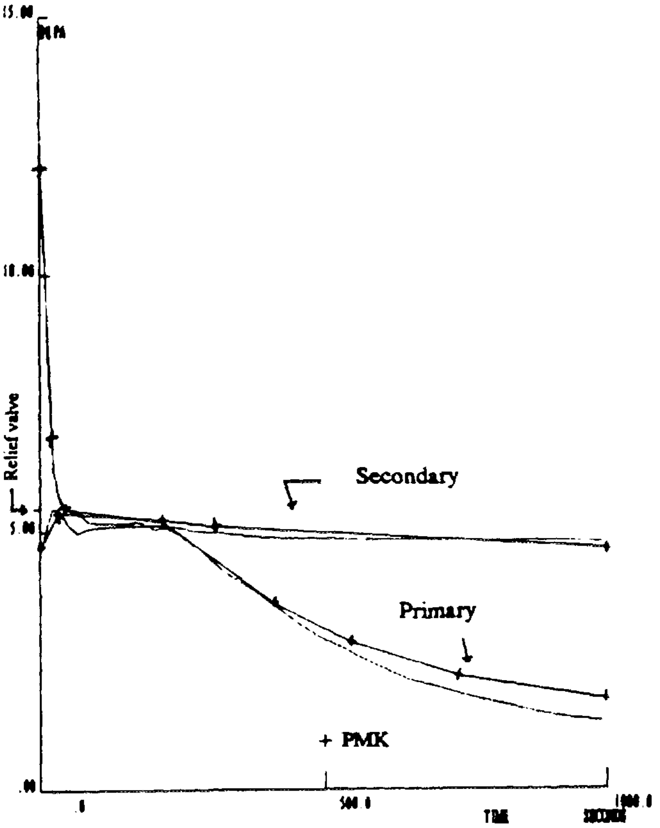

Figure 3 : SPE-1-Primary (PR21) and secondary (PR81) pressures.

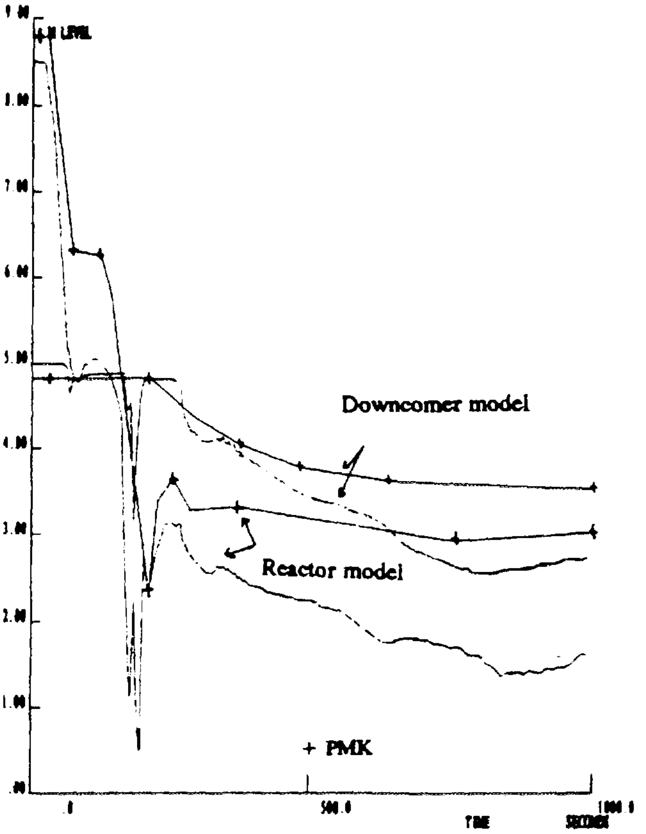

Figure 4 : SPE-1-Collapsed level for reactor (LE11) and downcomer (LE61) models.

in table 2.

SG isolation and relief valve. At the beginning of the transient, the SG is isolated with a closing time of 4 s. With regard to SPE-1 transient, the SG relief valve (PV23) was not opened. On the contrary, during SPE-2, it was opened at 5.45 MPa and closed at 4.96 MPa.

Power transient. When the primary pressure measured at the core outlet (PR21, see figure 1) during SPE-1 falls under 11.6 MPa (respectively 11.44 MPa for SPE-2), power transient is initiated without delay and following a law specified in advance.

Safety injection. The HPIS starts 60 s after the beginning of the power transient. The SIT injections begin automatically when primary pressure falls under the nominal accumulator pressure. They are closed on level criteria (SIT-1 : 0.25 m and SIT-2 : 1.35 m).

Modelling of the pump coast down. When the primary pressure, measured at the core outlet (PR21) during SPE-1, falls under 9.47 MPa (respectively 9.1 MPa for SPE-2), the simulation of the pump coast down is initiated The mass flow rate is throttled by the PV11 valve, following a law specified in advance. Between 150 s and 152 s after that, the MV11 valve is switched on, the pump is stopped and the MV12 valve is switched off.

	SPE-1		SPE-2	
	PMK	CATHARE	PMK	CATHARE
t_{bk}	0.	0.001	0.1	0.001
t_{po}	4.3	4.0	3.	2.5
t_{pu}	12.	11.4	11.	11.
t_{os}	-	22.7	15.	8.7
t_{b2}	-	-	38.	41.8
t_{b1}	-	-	39.	44.1
t_{hp}	65.3	65.0	64.	63.5
t_{cs}	-	64.6	71.	72.3
t_{e1}	-	-	391.	-
t_{e2}	-	-	405.	874.

Note (time in seconds) :

t_{bk} : Break valve completely opened.
t_{po} : Power transient is initiated.
t_{pu} : Beginning of the modelling of the pump coast down.
t_{os} : Opening of the secondary side relief valve.
t_{cs} : Closing of the secondary side relief valve.
t_{hp} : HPIS actuated.
t_{b1} : SIT-1 injection actuated.
t_{b2} : SIT-2 injection actuated.
t_{e1} : SIT-1 injection stopped.
t_{e2} : SIT-2 injection stopped.

Table 2 : Chronology of events.

CATHARE2 MODEL OF THE PMK LOOP

With the objective mentioned before, a simplified meshing is used based on a previous KFKI input data deck. A 0-D secondary side steam generator model is used with one SG primary tube.

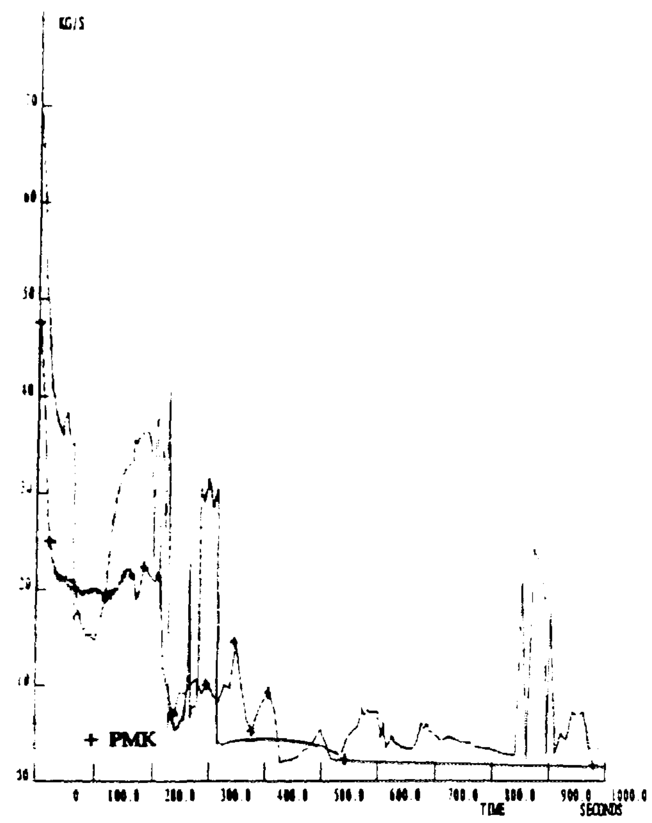

Figure 5 : SPE-2-Break flow (FL02).

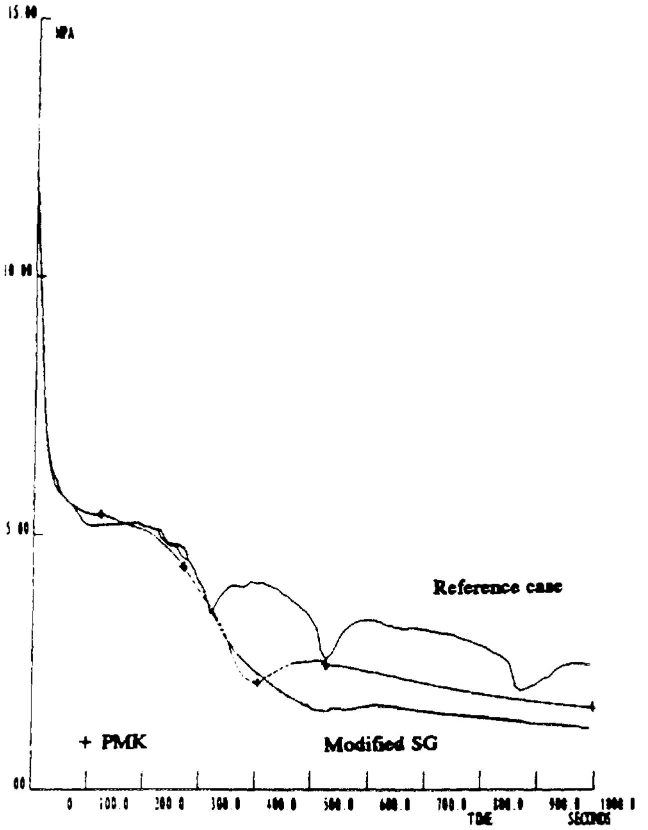

Figure 6 : SPE-2-Primary pressure (PR21).

As shown on figure 2 (not including the pressurizer and the pump by-pass line), the nodalization is made by 16 axial pipe modules (186 meshes), 8 volume modules, 3 tee modules and 34 junctions. A pump and three valve modules are associated with the meshing of the cold leg and the pump by-pass. The safety injection system is modelled by two accumulators and one source term. Three boundary conditions are used : one for the break model and two for the blind end of the SIT lines.

The diaphragm of the break device is modelled with 19 meshes. Each mesh length is between 0.3 and 1 mm.

The representation of the secondary side of the SG is a 0-D model. The primary side is modelled by a single pipe, 82 weighted and located at mid-height range of the bundle elevation. In its present version, CATHARE2 does not allow the coupling of several primary tubes with a unique 0-D SG secondary model.

The pipe loop above the core outlet is represented by an equivalent pipe, with a weight of two.

Except for the tees, the break and the SIT injection lines, a wall module is associated to each element with heat losses according to the overall measurements.

STEADY STATE COMPUTATIONS

The computation of steady state is performed by circuit initialisation and stabilised transient. The CPU time used was about 60 s on HP-715 workstation. On table 1 are reported the main parameters characterising the calculated steady state for SPE-1 and SPE-2. The loop mass flow rate and the exchanged powers are predicted at less than 1%. The maximal error on pressure at the measurement points is less than 12 kPa (0.1% of the nominal pressure). In the computations, the initial primary mass is 131.5 kg for SPE-1 and 129 kg for SPE-2, but was not measured in the tests.

Theses results are sufficiently close to the experimental data to provide adequate initial conditions for the transients.

SPE-1 TRANSIENT COMPUTATION

In the calculation, an automatic procedure is used for the adjustment of the PV11 valve pressure drop in order to reproduce the cold leg flow. The CPU time for the whole transient is about 6 hours on HP-715.

The chronology of events is reported on table 2 and the chronology of important phenomena occurrences on table 3. As a whole, the transient chronology and the main phenomena are well predicted. The results are generally among the other ones predicted by the participants of the SPE and most of the CATHARE2 and RELAP5/MOD1 results are in good accordance [IAEA 1987]. However, the computation and the experiment show some discrepancy concerning the opening of the SG relief valve. In the test, this valve did not open. But, as shown on figure 3, the maximum calculated pressure in the SG is just the relief valve opening value. The PMK team explained the relief valve behaviour by the heat losses of the secondary side, not modelled here.

The pressure evolution is well predicted up to 400 s (see figure 3). After this time, it is underestimated. At the end of the transient, the error is about 0.43 MPa (24% of the measured value). This pressure difference induces a difference for the saturation temperature of about 14 K. This is the order of magnitude typically found by others computations based on RELAP5/MOD2 code [SLOAN and

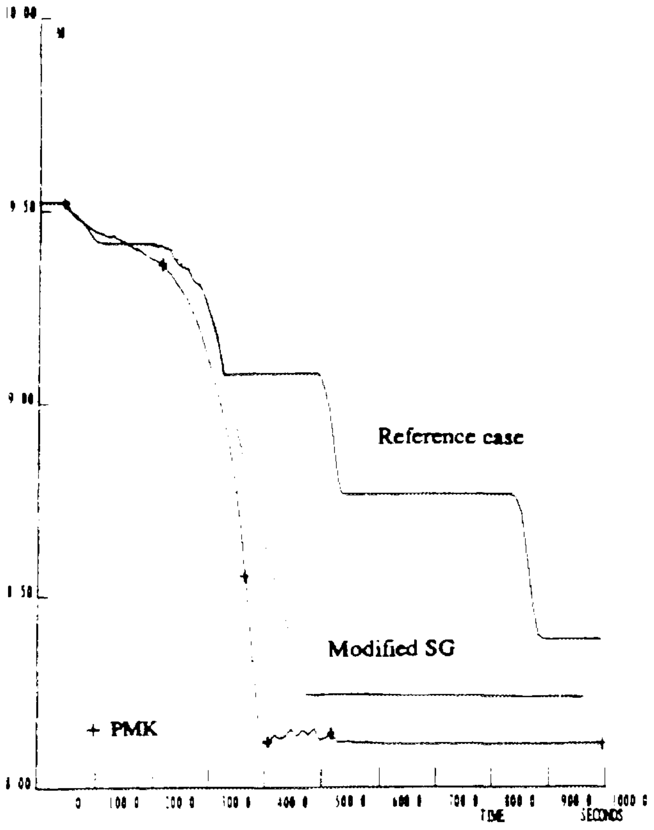

Figure 7 : SPE-2-SIT-1 level (LE91).

HASSAN, 1990].

	SPE-1		SPE-2	
	PMK	CATHARE	PMK	CATHARE
t_{pr}	15.	13.	15.	13
t_{hc}	83	20	69 427	20 -
t_{up}	73	67	60	60
t_{re}	> 124	160	> 185	165
t_{cu}	185	164	-	166
t_{ps}	150	177	200	204
t_{tw}	188	180	212	63 and 220
t_{dr}	203	193	-	170
t_{hl}	> 109	193	102 507	166 several
t_{cl}	208	233	367	260
t_{bu}	224	240	240	280

Note (time in seconds) :
t_{pr} : Pressurizer empty.
t_{dr} : Dryout first occurs.
t_{tw} : Break flow two-phases.
t_{bu} : Break uncovered.
t_{hl} : Hot-leg loop seal cleared.
t_{cl} : Cold-leg loop seal cleared.
t_{cu} : Core uncovery begins.
t_{re} : First reversal at core inlet flow not before.
t_{ps} : Primary pressure equals secondary pressure.
t_{up} : Mixture level in upper plenum drops to hot-leg elevation.
t_{hc} : Collapsed level in steam generator hot collector drops to elevation of uppermost SG tubes.

Table 3 : Chronology of the important phenomena occurrences.

The break flow rate seems overestimated, but the break flow and the total mass leaked through the break were not measured during the test. Then the comparison is difficult.

Despite the underestimation of the collapsed levels in the reactor model (see figure 4) and in the downcomer, the main tendencies of the evolution are in agreement with the measurements. In connection with the under-prediction of the core level, a partial dry-out (not seen during the experiment) appears in the upper part of the core. This temperature excursion may be due to the underestimation of the total primary mass inventory, consecutively to the overestimation of the break flow, or to an inexact prediction of the mass distribution in the circuit. Unfortunately, the primary mass inventory was not performed during the test, but the measured levels seem to confirm the first hypothesis.

Due to insufficient experimental data, the evaluation of the discrepancy causes between computation and experiment is masked by the too large uncertainties on the break flow values. For this reason, we focus now on SPE-2 test which was performed with a better instrumentation.

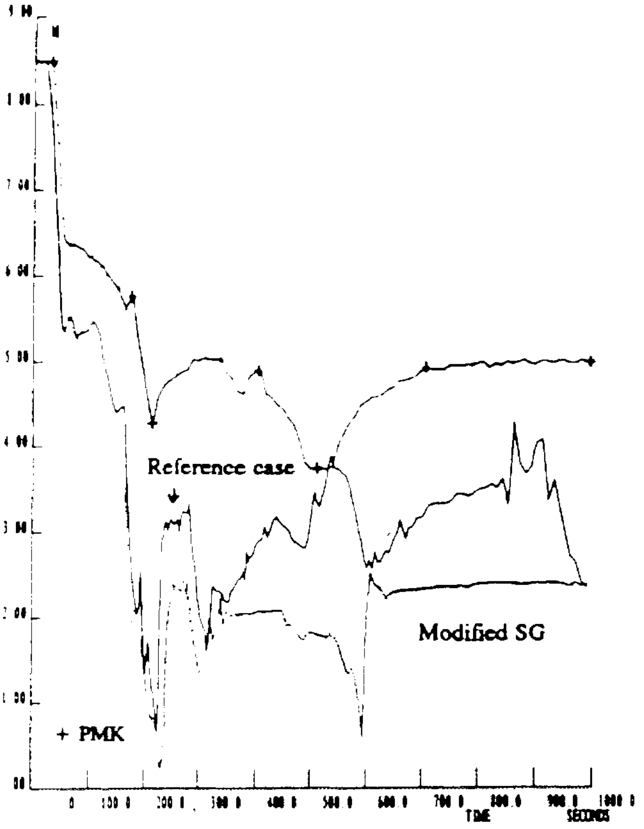

Figure 8 : SPE-2-Collapsed level for reactor model (LE11).

SPE-2 TRANSIENT COMPUTATION

As mentioned for the SPE-1 test, an automatic adjustment of PV11 valve head losses was performed for the computation of SPE-2.

A first computation was run with the above mentioned nodalization of SPE-1 and SIT working. We call this case, the reference one. Two additional computations were performed. They were dedicated to sensitivity studies (elevation of primary SG tube and break flow).

Reference case

The CPU time for the whole transient was about 15 hrs on HP-715. The chronology of events is reported on table 2 and the important phenomena occurrences on table 3.

The agreement between experiment events chronology

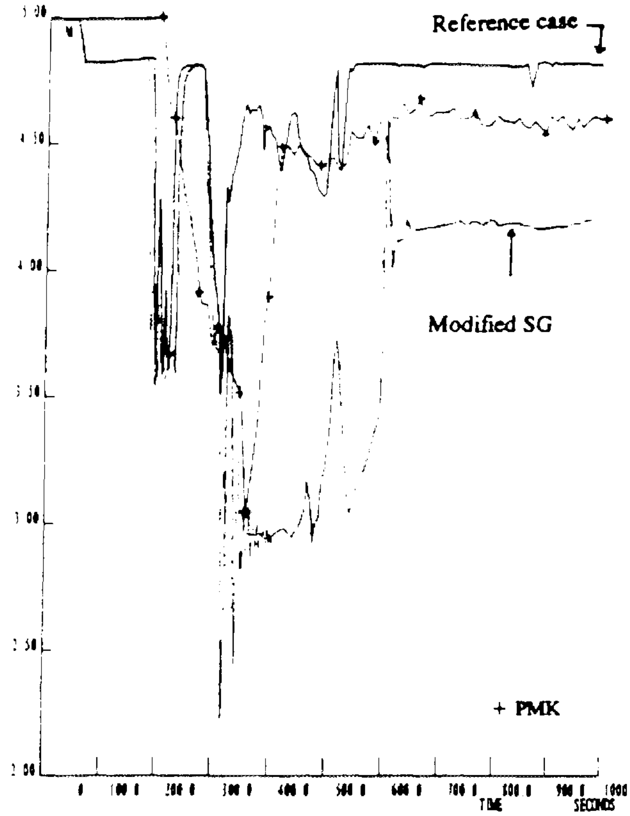

Figure 9 : SPE-2-Collapsed level for downcomer model (LE61).

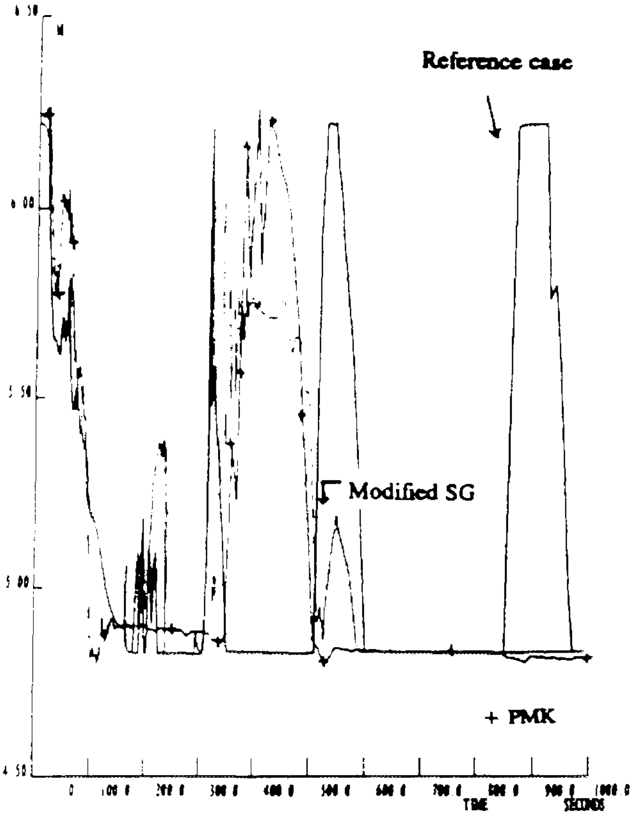

Figure 10 : SPE-2-Collapsed level for hot leg (LE31).

and the predicted one is good (except for SIT closing time). Confirming the SPE-1 results, the break flow evolution is qualitatively consistent with the experiment, but seems overestimated (see figure 5). However, the predicted total mass leaked through the break is not so far from the measured one (122 instead of 103 kg). The mean value of this overestimation is around 0.02 kg/s.

The predicted pressure evolution is close to the experimental data up to the time of the SIT discharge following the break uncovery (about 300 s, see figure 6). After this time, some pressurisations of the primary circuit are predicted. So, the time of SIT-2 closing is delayed (874 s instead of 400 s) and the closing of SIT-1 never occurs during the calculated transient (see figure 7). This successive pressurisations lead to a step by step working of the accumulators. This behaviour was already seen in others computations [IAEA 1988 and SONNENBURG and all 1991].

Concerning levels, if the collapsed level in the reactor model is lower, the downcomer one is higher than measured (see figures 8 and 9). But, the overall behaviour is in agreement with the experimental tendencies. Each SIT injection increases the level and the vaporisation rate in the core channel; as a result, the decrease of the primary pressure is slowed down.

Consequently to the calculated stepwise discharge of the SIT, the filling of the hot leg loop seal and of the hot collector are poorly predicted (see figure 10).

A more detailed analysis of the incomplete refilling of the hot leg observed in the calculation points out than the mixture level in the collector does not exceed the SG tube elevation. This is due to the steam compression in the upper part of this volume and an important vaporisation of the liquid in the steam generator tubes previously filled with vapour (see figure 11). This leads to the pressurisation of the circuit and stops the SIT injections. These results underline the close dependence between the SIT injection characteristics, the primary pressure, the mass distribution in the loop and the elevation of the equivalent pipe.

Sensitivity to the SG primary side modelling

In order to support the previous analysis, we performed a sensitivity test on the SG primary tube elevation parameter. To have a clear modification of the transient behaviour, we shifted the tube elevation to the uppermost level of the bundle (moved upward to permit the refilling of the hot collector with water before the steam compression stage).

With this modelling, the predicted SIT discharge is similar to the experimental one (see figure 7). The SIT-1 is empty at 447 s and the SIT-2 at 473 s, instead of about 400 s for the test. The pressure evolution plotted in figure 6 is more realistic. Particularly, the periodic pressurisations of the primary circuit are no more calculated. However, the re-pressurisation after the SIT closing time is delayed and less apparent then in the experiment. On figure 10, we can see that at this time, the refilling of the hot leg partially occurs in the calculation. Even if the amplitude is underestimated, the refilling and clearing time of the hot leg are well computed. Concerning the downcomer model, the decrease of the collapsed level after the uncovery of the break follows more closely the experimental one. But, the collapsed levels during the last part of the transient are lower than expected (see figures 8 ad 9).

As previously outlined, the elevation of the primary side SG tube plays an important role on the results. Figures 6 and 9 illustrate the fact that the experimental evolution is

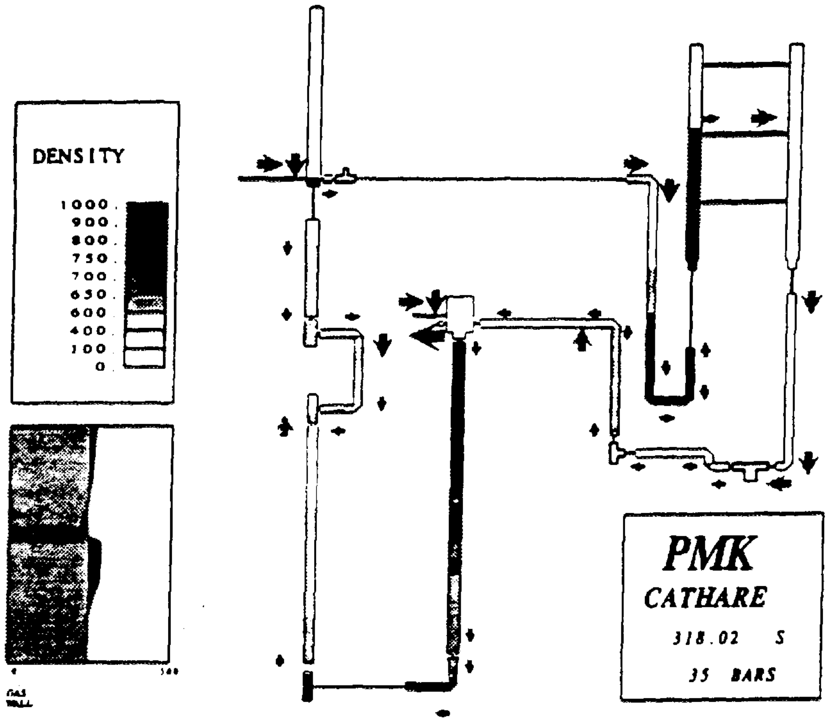

Figure 11 : SPE-2-Water mass distribution.

enclosed by the two computations.

	SPE-2	
	PMK	CATHARE
t_{bk}	0.1	0.001
t_{po}	3.	5.5
t_{pr}	15.	17.
t_{pu}	11.	19.3
t_{os}	15.	9.
t_{b2}	38.	78.
t_{b1}	39.	83.
t_{hp}	64.	66.5
t_{cs}	71.	83.
t_{ps}	200.	400.
t_{e1}	391.	-
t_{e2}	405.	-

Note (see tables 2 & 3) :

Table 4 : Chronology of events (Sensitivity to break flow modelling).

In contrast to SPE-1 computation, it looks necessary to represent the SG primary side with a multi-tubes model in order to get a correct prediction of the loop thermalhydraulic behaviour of the SPE-2 test.

Sensitivity to break flow modelling

The results of the reference case have pointed out too large break flow rate values in comparison to measured ones. This discrepancy is particularly important when the break flow is liquid or two-phase (for instance, before the uncovery of the break, see figure 5). In order to become free from this eventual overestimation, we performed a new calculation imposing the measured break mass flow rate as a boundary condition. The break energy flow rate is calculated according to the upstream flow conditions.

The chronology of the main events is reported in table 4. It is clear that during the blowdown of the primary circuit in liquid phase, the times of the main events are shifted. Quite often the duration of these time periods are doubled.

The collapsed level in the downcomer model drops to the break elevation not before 410 s (instead of 240 s in test) and this volume is never completely empty of liquid. In fact, at this time, the cold leg is still full of liquid (see figure 12). This point introduces an expedient in the computation. As a matter of fact, after 240 s the measured break mass and energy flows, including a steam fraction, decrease. Whereas in the computation, the upstream flow is still liquid at this time.

According to this results, the primary mass and energy inventories (built with experimental break flow) seem too large during the stage preceding the break uncovery. The overestimation of leak flows with break model does not appear to be as large as the previous results had shown.

CONCLUSION

In the framework of the verification of the capability of the CATHARE code to describe the thermalhydraulic behaviour of WWER-type facilities under LOCA conditions, modelling and computations of the PMK-NVH loop were performed. Two particular tests involving small break in the cold leg (SPE-1 and SPE-2) were calculated with the standard code version.

For both tests, the results compared to experimental data are in good agreement with the transient chronology and the main phenomena are well predicted. In particular, our results are close to the RELAP5/MOD2 ones.

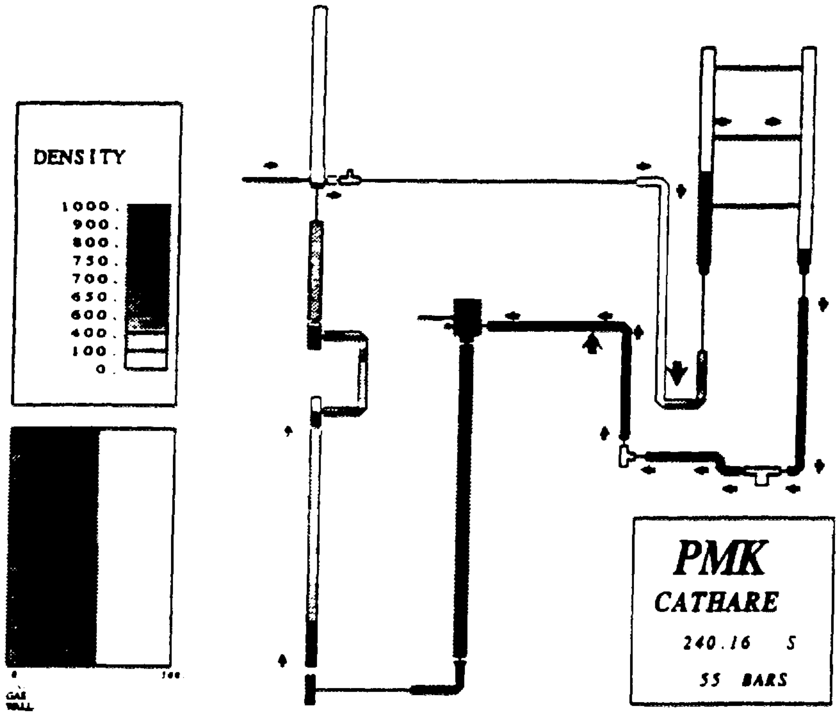

Figure 12 : SPE-2-Water mass distribution (Sensitivity to break flow modelling).

The calculated SPE-2 mass flow rate at the break seems overestimated. In other hand, a computation with experimental flow as boundary condition leads to a erroneous prediction of the transient chronology. The overestimation of the leak flow with break model does not appear to be as large as the comparison had shown.

The calculated collapsed level in the reactor model is lower than the measured one in the two tests. Hence, the calculated partial dry-out of the upper part of the core appeared to be due to a non-realistic distribution of the primary mass in the circuit.

Finally, the effect of the modelling of the SG primary side on the transient is clearly outlined in computation of the SPE-2 test. The primary pressure evolution and the accumulator injections are strongly influenced. A further improvement of the SG model will be its description using several tubes at different elevations.

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