International Conference
Nuclear Energy for New Europe 2005
Bled, Slovenia, September 5-8, 2005

VVER-1000 Small-Medium Break LOCAs Predictions by ASTEC

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ABSTRACT

This paper deals with an assessment of ASTEC1.1v0 code in the simulation of small and medium break LOCAs (ranging from 30mm up to 70mm equivalent diameter). The reference power plant for this analysis is a VVER-1000/V320 (e.g. Units 5&6 at Kozloduy NPP). A preliminary comparison with MELCOR and RELAP-SCDAP severe accident codes will be discussed.

This investigation has been performed in the framework of the SARNET project (under the Euratom 6th framework program) by the FoBAUs group (Forum of Bulgarian ASTEC users). The FoBAUs group aims at the validation of the ASTEC code in the field of severe accidents. Future activities will target the ASTEC capability (as a PSA-level 2 tool) to simulate a large range of reactor accident scenarios with intervention of safety systems (either passive systems or operated by operators). The final target is to assess Severe Accident Management (SAM) procedures for VVER-1000 reactors.

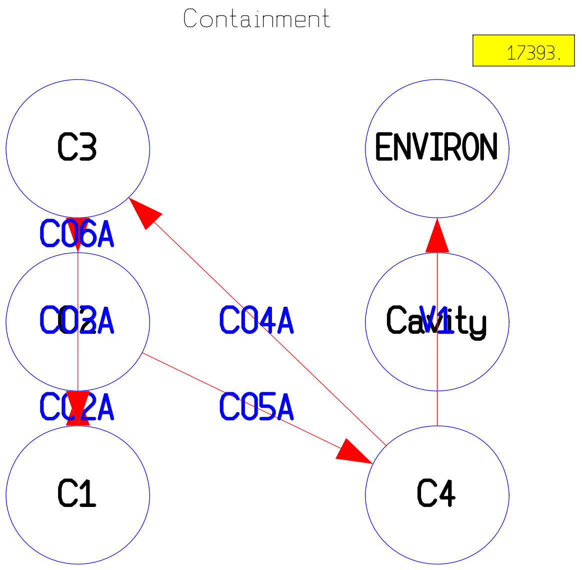
The ASTEC1.1v0 code version here used is the one released in June 2004 by the French IRSN (Institut de Radioprotection et de Sûreté Nucléaire) and the German GRS (Gesellschaft ReactorSicherheit mbH).

1 INITIAL CONDITIONS

ASTEC code has been used to model the in-vessel phase (up to the vessel failure). The ASTEC modules, used in a “coupled mode”, are CESAR, DIVA, SOPHAEROS and CPA, covering respectively the radioactive FP/aerosols release and transport in the primary circuit and the containment behaviour.

The input model includes the description of seven sub-components: 1) reactor core, 2) reactor pressure vessel, 3) primary loops, 4) pressurizer, 5) SG secondary side 6) reactor cavity, 7) containment.

Figure 1: ASTEC (CPA) containment nodalization



The VVER-1000 containment has been modelled, by CPA, using a nodalization with six cells. Five cells describe the containment building, which consists of a "lower compartment" (C1) including the sump and the cavity sub-compartments, a "medium compartment" (C2) where steam generators and the pressurizer are located, a containment annulus (C3) and an "upper compartment" or dome (C4). One cell, of the nodalization, describes the environment. Figure 1 shows the containment nodalization and the connections among the cells (note that figure 1 does not provide any information on the actual position, i.e. elevations, of the cells). The arrows of figure 1 show the direction of the steam/gas flow, at 17393 s, between the modelled compartments of the containment building.

The reactor core has been modelled, by the DIVA module, with five radial rings. One more ring has been added to model the downcomer. The axial discretization consists of ten identical meshes. The main core input parameters assume: 1) fuel rod cladding melting at 2400 K, 2) fuel relocation at 2550 K, 3) vessel bottom head failure at 1200 °C or when under a mechanical stress of 150 MPa, 4) relocation of control rod cladding at 1730K.

The SBLOCA analyses have assumed a break on the cold leg of the pressuriser loop with simultaneous loss of the high and low-pressure emergency systems (HPIS and LPIS) as well as the feed-water system (EFWS). In addition, immediately after the LOCA, also the main pumps are assumed to stop. The main assumptions of the sequence are: 1) opening of the break, reactor scram and stop of pumps at 0s; 2) turbine isolation at 10s; 3) loss of FWSGs (feed water to steam generators) at 10s; 4) spray system in direct mode at 135s. Diesel generators and backup batteries are not assumed to intervene.

The initial plant conditions, as modelled in the input decks, are listed in the following table:

Table 1: Initial Plant Conditions

PARAMETERS	**DESIGN**	**ASTEC**	**MELCOR**	**RELAP-SCDAP**
Core power, MW	3000	3000	3000	3000
Primary pressure, MPa	15.7	15.7	15.64	15.7
Average coolant temperature at reactor outlet, °C	320.15	320.55	320.4	318.2
Maximum coolant temperature at reactor inlet, °C	290.0	290.35	290.1	286.7
Mass flow rate through one loop, kg/s	4400.0	4363.1	4406.0	4406.0
Pressure in SG, MPa	6.27	6.418	6.31	6.21

Pressure in Main Steam Header, MSH, MPa	6.08	6.38	6.13	6.6
Steam mass flow rate through SG, (kg/s)	408	409.6	406	409.6

2 RESULTS

Four different cold leg (CL) break sizes have been investigated (30, 40, 60 and 70mm equivalent diameters). The influence of hydro-accumulators has been also studied. Therefore we have:

Four 30mm SBLOCAs calculations, with and without HAs injection, in table 2;

Four 40mm SBLOCAs calculations, with and without HAs injection, in table 3;

Four 60mm SBLOCAs calculations, with and without HAs injection, in table 4;

Two 30mm SBLOCAs calculations, with HAs injection, in table 5 (this ASTEC calculation differs from the previous one because of the use of the “RADL” model -heat transfer model between the degraded core and the lower plenum);

Two 70mm MBLOCAs calculations, with HAs injection, in table 5 (also in this case the ASTEC calculations have been run with the “RADL” model).

The timing of the main events, for the 16 performed calculations, is given in the following tables (table 2 to 5). Table 6 gives the predicted hydrogen mass, at the end of the in-vessel phase, as calculated by ASTEC and MELCOR.

Code predictions show a global agreement. Deviations are discussed in the following paragraph where an assessment of ASTEC predictions is given.

2.1 ASTEC Predictions

Main ASTEC-calculated in-vessel parameters, for a 60mm-break sequence, are shown in Figure 2. The calculated trends are displayed until about 8000 s to better focus on the first part of the in-vessel phase. Core temperature, vessel water level and core degradation (the three figures on the right) are those corresponding at time 7817 s.

Table 2: Sequence of main events for a 30mm SBLOCA

EVENT	**ASTEC with HA injection Time, s**	**MELCOR with HA injection Time, s**	**ASTEC without HA injection Time, s**	**MELCOR without HA injection Time, s**
Opening of break with D= 30mm equivalent diameter in (Loop1) cold leg next to the nozzle; Reactor scram; MCPs are switched off	0.0	0.0	0.0	0.0
Turbine stop valves (TSVs) are closed	10.9	10.0	10.9	10.0
Start of coolant injection by hydro-accumulators	3473.0	8250.0	-	-
First total core uncovery	3919.0	6980.0	3759.0	7390.0
First corium slump	4513.0	6988.0	5597.0	7522.0

Start of FP release from fuel pellets	4582.0	6261.0	4198.0	6692.0
Lower head vessel failure	21191.0	22500.0	18927.0	22828.0

Table 3: Sequence of main events for a 40mm SBLOCA

EVENT	**ASTEC with HA injection Time, s**	**MELCOR with HA injection Time, s**	**ASTEC without HA injection Time, s**	**MELCOR without HA injection Time, s**
Opening of break with D= 40mm equivalent diameter in (Loop1) cold leg next to the nozzle; Reactor scram; MCPs are switched off	0.0	0.0	0.0	0.0
Turbine stop valves (TSVs) are closed	10.97	10.0	10.97	10.0
Start of coolant injection by hydro-accumulators	3083.5	4723.0	—	—
First total core uncovery	3533.8	4036.0	3545	4410.0
First corium slump	3904.4	3634.0	3652	4174.0
Start of FP release from fuel pellets	4649.8	4950.0	4597	5340.0
Lower head vessel failure	17732.6	27753.0	15412	17235.0

Table 4: Sequence of main events for a 60mm SBLOCA

EVENT	**ASTEC with HA injection Time, s**	**MELCOR with HA injection Time, s**	**ASTEC without HA injection Time, s**	**MELCOR without HA injection Time, s**
Opening of break with D= 60mm equivalent diameter in (Loop1) cold leg next to the nozzle; Reactor scram; MCPs are switched off	0.0	0.0	0.0	0.0
Turbine stop valves (TSVs) are closed	10.0	10.0	10.9	10.0
Start of coolant injection by hydro-accumulators	2771.7	1908.0	-	-
First total core uncovery	3706.9	2517.0	3732.0	2312.0
First corium slump	4353.9	2592.0	3966.0	2240.0
Start of FP release from fuel pellets	4332.4	3210.0	4401.0	3040.0
Lower head vessel failure	18477.8	15358.0	22597.0	13500.0

Table 5: Sequence of main events for 30&70mm LOCAs with HAs

EVENT	ASTEC 30mm+RADL Time, s	SCDAP/ RELAP5 30mm Time, s	ASTEC 70mm+RADL Time, s	SCDAP/ RELAP5 70mm Time, s
Opening of the break with D=30mm/ (Loop#1) cold leg; Reactor scram; MCPs are switched off	0.0	0.0	0.0	0.0
Turbine stop valves (TSV) are closed	11.2	15.0	11.2	15.0
Beginning of oxidation	2455.2	11032.0	2455.2	6491.0
Start of coolant injection by hydro-accumulators	3441.0	13151.0	1889.4	7237
First total core uncovery	3553.2	5822.0 (voiding at core upper part)	3287.2	2220.0
First corium slump	4123.2	12886.0	4105.4	8571
Start of FP release from fuel pellets	5362.2	11915.0	4105.4	7237
Lower head vessel failure	30851.7	n/a	13716.0	n/a

Table 6: Hydrogen mass released during the in-vessel phase

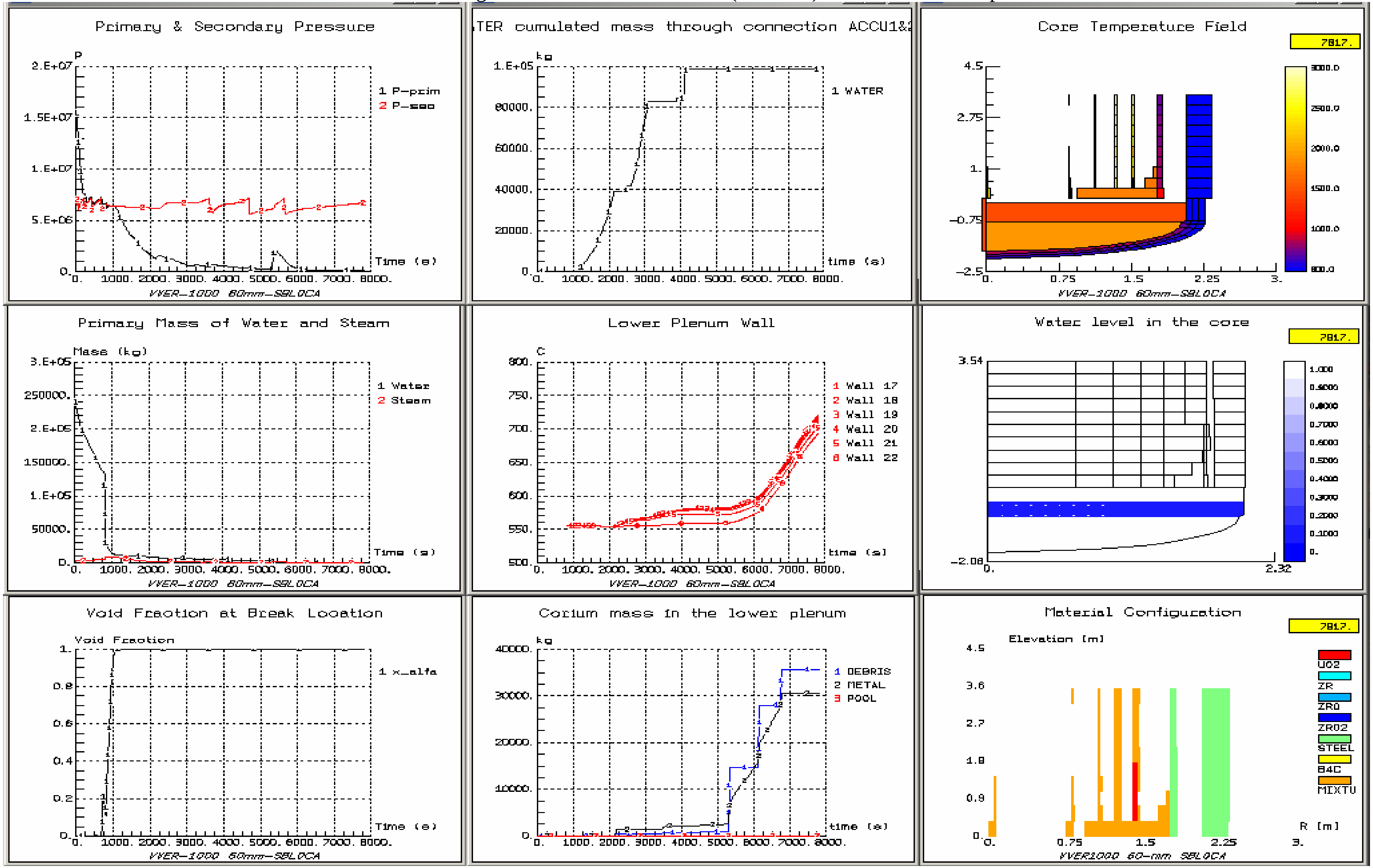
Break Size	ASTEC		MELCOR	
	with HAs injection (kg)	without HAs injection (kg)	with HAs injection (kg)	without HAs injection (kg)
30mm break	330	370	330	380
40mm break	360	440	390	410
60mm break	225	260	430	450

At the onset of the accident sequence (during the first 400 s), primary pressure decreases very rapidly due to the loss of coolant through the break. Injection of coolant by HAs depends on the value of the primary pressure: when primary pressure decreases below 60 bar, injection occurs (in figure 2 only the coolant mass injected by one couple of HAs in the proximity of the downcomer is shown; one more couple of HAs is connected to the vessel upper plenum).

At about 400 s (up to 1000 s in figure 2) primary pressure reaches the saturation pressure (at 60 bar saturation temperature is about 276°C). As a consequence, the two-phase flow at the break becomes, at about 1000 s, a single-phase flow (void fraction is 1). The secondary side is also at saturation pressure (the steam relief valves are opened and pressure exhibits a cycling behaviour). During this period of time, heat is still removed by the secondary system, but because of the loss of coolant at the break, after 1000 s the primary pressure becomes smaller than the secondary pressure and coolant injection by HAs starts.

Corium mass starts falling in the vessel bottom head at around 2100 s, but corium formation increases especially after 5000 s, that is when HAs injection has ended (after 4000 s). Vessel (lower plenum) wall temperature increases, to a much larger extent, because of the increase of corium mass. As a result of this, the lower plenum wall temperature is increasing steadily until the vessel failure.

Figure 2: Visualization of main (in-vessel) ASTEC-calculated parameters



The corium slumps into the lower plenum, observed until 7817 s, are also the cause of some in-vessel pressure increases (e.g. the peak exhibited at about 5400 s).

At the end of the in-vessel sequence almost all water is evaporated (the upper part of corium in the lower plenum is cooled down to a lower temperature because of the water layer).

3 COMPARISON BETWEEN ASTEC, MELCOR AND RELAP-SCDAP

ASTEC predictions have been studied, for the in-vessel phase of the accident, and mainly compared to those of MELCOR and RELAP-SCDAP. Results are coherent, but both codes have shown some “random” behaviour: for example, both have predicted, in two cases, a later bottom-head failure when hydro-accumulators are not available (the opposite behaviour is normally exhibited).

With respect to hydrogen generation, the core degradation models of the two codes have shown an unclear influence of the break size (for the range here studied). However, code predictions are reasonably close (e.g. for the 30mm-break case with HAs injection, H2 released mass, at the end of the in-vessel phase, is 330 kg for ASTEC, 330 kg for MELCOR and 260 kg for RELAP-SCDAP) and usually the H2 release increases with the break size (table 6). As for the influence of HAs on hydrogen generation, all predictions are larger when HAs are not available.

SBLOCA-induced core degradation increases with the assumed break size: core relocation into the bottom head is faster and the vessel fails earlier. Figure 3 here below summarises the results listed in tables 3, 4, and 5 (with the exclusion of two above-mentioned unreliable results). If HAs are not available ASTEC predicts a further faster degradation especially for small break sizes. MELCOR shows a similar behaviour for larger break-sizes.

In the lower range of SBLOCAs (e.g. around 30mm) ASTEC and MELCOR differences are more enhanced: MELCOR-predicted primary pressure decreases rather slowly and the core heat-up delays HAs intervention (which occurs 4700 s after the one predicted by ASTEC).

ASTEC usually exhibits a core degradation which causes large corium slumps and consequential sudden large peaks in the pressure and temperature trends, whilst MELCOR predictions exhibit smoother trends (but this “smoother” behaviour is also predicted by ASTEC for example when the “RADL” modelling is used –this modelling has improved the heat transfer model between the degraded core and the lower plenum).

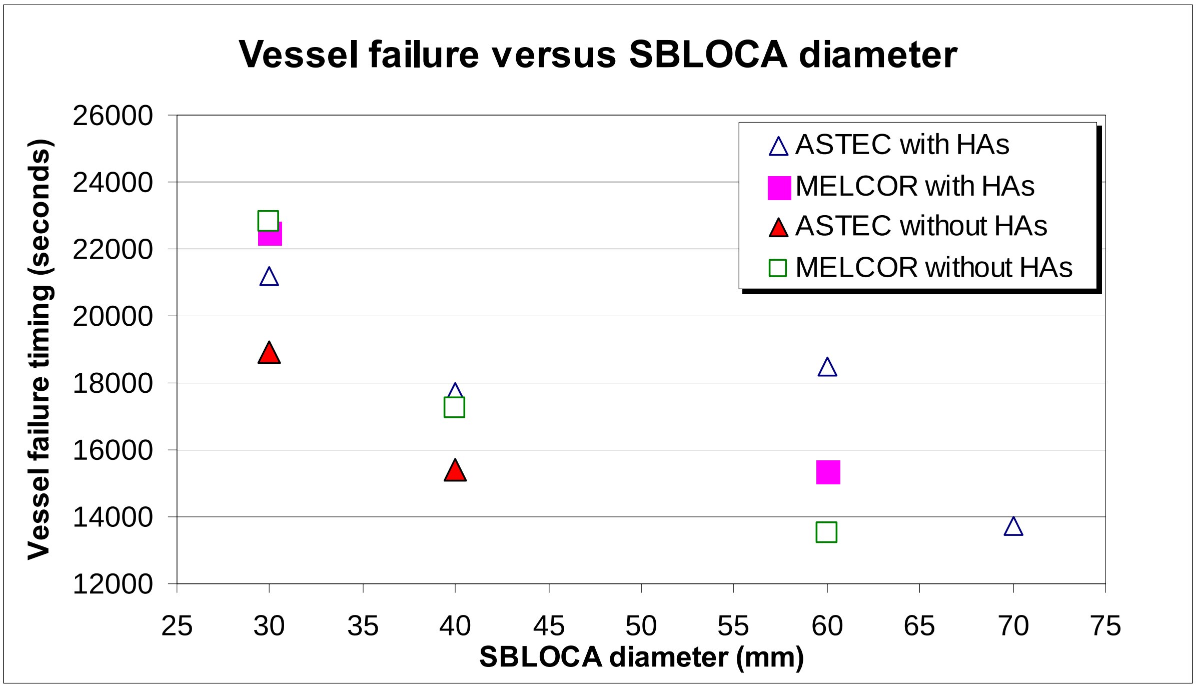
When assuming non availability of hydro-accumulators (HAs), ASTEC exhibits coolant temperatures at the reactor inlet location which are higher than coolant temperatures at the reactor outlet. This is never predicted by MELCOR or RELAP-SCDAP. This discrepancy should be understood. When HAs are operational, the three codes here compared predict an outlet temperature higher than the inlet one (with MELCOR predicting much larger temperatures at the outlet location than ASTEC and RELAP-SCDAP).

4 CONCLUSIONS

Four breaks sizes (30mm, 40mm, 60 and 70mm equivalent diameter), with and without hydro-accumulators availability, have been investigated in a VVER-1000 severe accident scenario (no ECCS and EFWS) by means of the ASTEC code.

ASTEC predictions, up to the in-vessel phase of the accident, have been compared to those of MELCOR and SCDAP-RELAP. Results are coherent, but, for example, with respect to hydrogen generation, the core degradation models of the two codes have shown a non clear influence of the break size (for the range here studied). SBLOCA-induced core degradation increases with the assumed break size: core relocation into the bottom head is faster and the vessel fails earlier. If HAs are not available ASTEC predicts a further faster degradation especially for small break sizes. MELCOR shows a similar behaviour for larger break-sizes.

Figure 3: Vessel failure timing as predicted by ASTEC and MELCOR



When assuming non availability of hydro-accumulators (HAs), ASTEC exhibits coolant temperatures at the reactor inlet location which are higher then coolant temperatures at the reactor outlet. This is never predicted by MELCOR or RELAP-SCDAP. This discrepancy might depend on the degree of coolant bypass (from the hotter inner part of the core) modelled by ASTEC. When HAs are operational, the three codes here compared predict an outlet temperature higher than the inlet one (with MELCOR predicting much larger temperatures at the outlet location than ASTEC and RELAP-SCDAP).

FoBAUs members envisage a meeting at Cadarache in mid September in order to verify these results with the IRSN ASTEC team.

5 REFERENCES

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