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Thermal-Hydraulic Analysis of the 2nd Stage Hydroaccumulators Impact in MB/LBLOCA Sequences along with SBO

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ABSTRACT

VVER are one of the most common reactor types in the world. Moreover, a significant percentage of the Gen-III/Gen III+ reactors that are currently being built or have recently come into operation are VVER. Therefore, there is a growing interest in studying their behavior under both anticipated and accidental transients.

These advanced reactors have improved their safety to ensure reactor integrity by implementing passive safety systems that do not require human actions or external power sources, as the passive 2nd stage hydroaccumulators (HA-2) system.

In the present study, it is demonstrated how the implementation of the HA-2 passive safety system prevents the core damage in the MB/LBLOCA + SBO sequences with break sizes above 3”.

1 INTRODUCTION

A joint effort between the Universidad Politécnica de Madrid (UPM) and the Karlsruhe Institute of Technology (KIT) has been made, within the ISASMORE project, in order to develop an integral plant model of a VVER-1000/V-320 reactor for TRACEp5 code [1]. In this work, the aim is to analyze the impact of implementing in the VVER-1000/V-320 model, the passive 2nd stage hydroaccumulators system, HA-2, present in some VVER Gen III/III+ reactor designs.

The paper is organized as follows: Section 2 provides a description of the VVER-1000/V-320 reactors, going in depth into the design of the HA-2 passive safety systems, while Section 3 discusses the thermal-hydraulic model used in the simulations. Section 4 shows the results obtained from analysis of the MB/LBLOCA + SBO sequence for a wide range of break sizes, between 2” and the double ended guillotine break (DEGB), along with a sensitivity analysis and the description of the complete sequence for the DEGB LBLOCA. Finally, the conclusions are summarized in Section 5.

2 SHORT DESCRIPTION OF THE VVER-1000 AND PASSIVE SAFETY SYSTEMS

VVER-1000/V-320 is a Gen-II pressurized water-cooled reactor with a thermal power of 3000 MW_t, and an electric output of 1000 MW_e. The RCS (Reactor Coolant System) consist of four loops, including one RCP (Reactor Coolant Pumps), one cold leg and one hot leg each. The hot legs are attached to the RPV (Reactor Pressure Vessel) in the same angular position as the cold legs. The core consists of 163 hexagonal fuel assemblies (61 of which contain control rods), each comprises 312 fuel rods that are arranged in a triangular grid and made of Zr1%Nb alloy.

The ECCS (Emergency Core Coolant System) comprises active systems (High and Low Pressure Injection Systems) and the passive hydroaccumulator system (HA-1). Besides, in this analysis a second passive safety system has been added, HA-2 system. Both passive safety systems are described in the following sections.

2.1 First Stage Hydroaccumulators (HA-1)

There are four HA-1 each containing 50 m^3 of water, and nitrogen at a pressure of 5.9 MPa. Two of them are connected to the RPV upper plenum and the two others are connected to the RPV downcomer, ensuring top and bottom core flooding. When the reactor is in normal operation, the HA-1 are isolated form the RCS by check valves.

2.2 Second Stage Hydroaccumulators (HA-2)

This system consists of four trains including two HA-2 tanks each, Figure 1. The two HA-2 of each train are coupled at the top to a common head, which is attached to the cold leg through a line with a special check valve that opens when the RCS reaches a pressure of 1.5 MPa. At the bottom, they are connected to the HA-1 injection lines, so this system also ensures top and bottom core flooding. The total water volume is 960 m^3 (8 x 120 m^3) [2]. The HA-2 have been designed taking into account the flow rate needed to compensate the decay heat, see Table 1 [3]. The first time this system was implemented was at the Kundankulam Nuclear Power Plant, a Gen-III VVER-1000/V412 reactor [4].

The HA-2 system has been specially designed for MBLOCA and LBLOCA sequences along with SBO, for which the system is intended to passively supply the RCS with borated water for 24 hours.

Table 1: HA-2 mass flow rate

Stage interval (s)	100 - 4000	4001 - 10000	10001 - 30000	30000 - 86400
Flow rate from one HA-2 tank (kg/s)	5	2.5	1.65	0.89

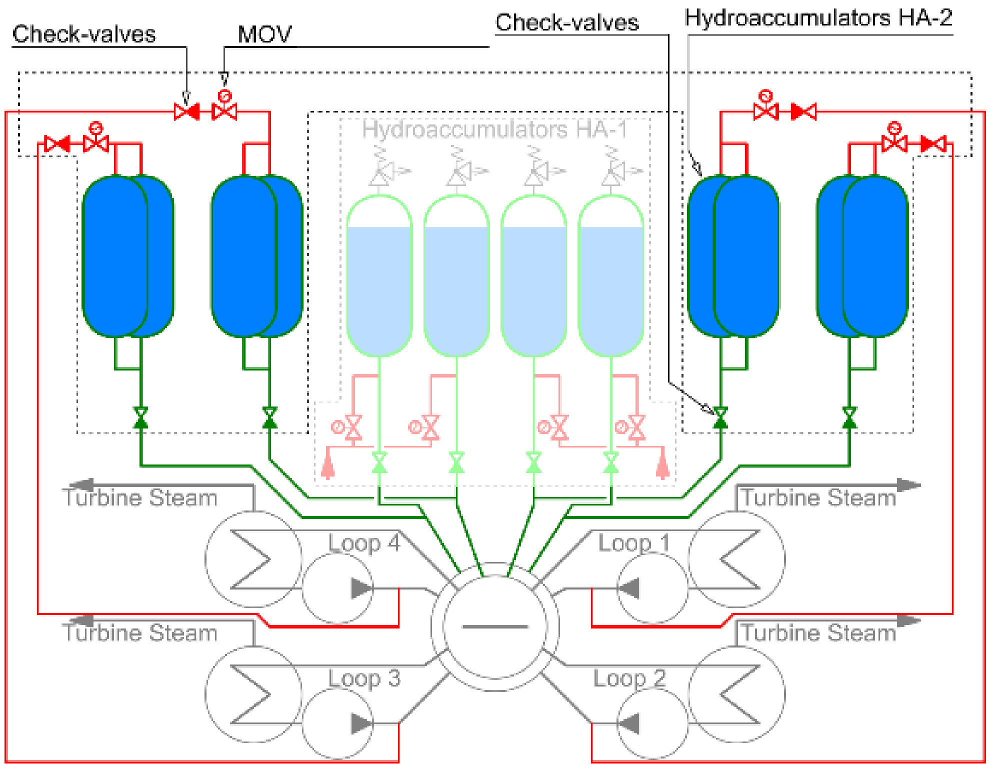

Figure 1: HA-2 system

3 THERMAL-HYDRAULIC VVER-1000/V-320 MODEL

The TRACE thermal-hydraulic (TH) model for the RCS and secondary side, including the safety and some control systems, is built from a previous VVER-1000/V-320 RELAP5 model, [5] [6], see Figure 2. It consists of following elements:

- Primary loops: cold legs, hot legs and RCPs.
- Pressurizer (PZR): containing sprays, safety valves and heaters.
- RPV: containing the downcomer, the lower plenum, the upper plenum, the bypass and the core.
- Steam Generators: In the primary side, the SG-tubes are modelled by three horizontal PIPEs. In the secondary side, the heat transfer zone is modelled on three horizontal levels. In the upper part is placed the liquid/steam separator.
- Steam Lines: including the relief valves to atmosphere BRU-A, the safety valves and the BROK valves (Main Steam Isolation Valves)

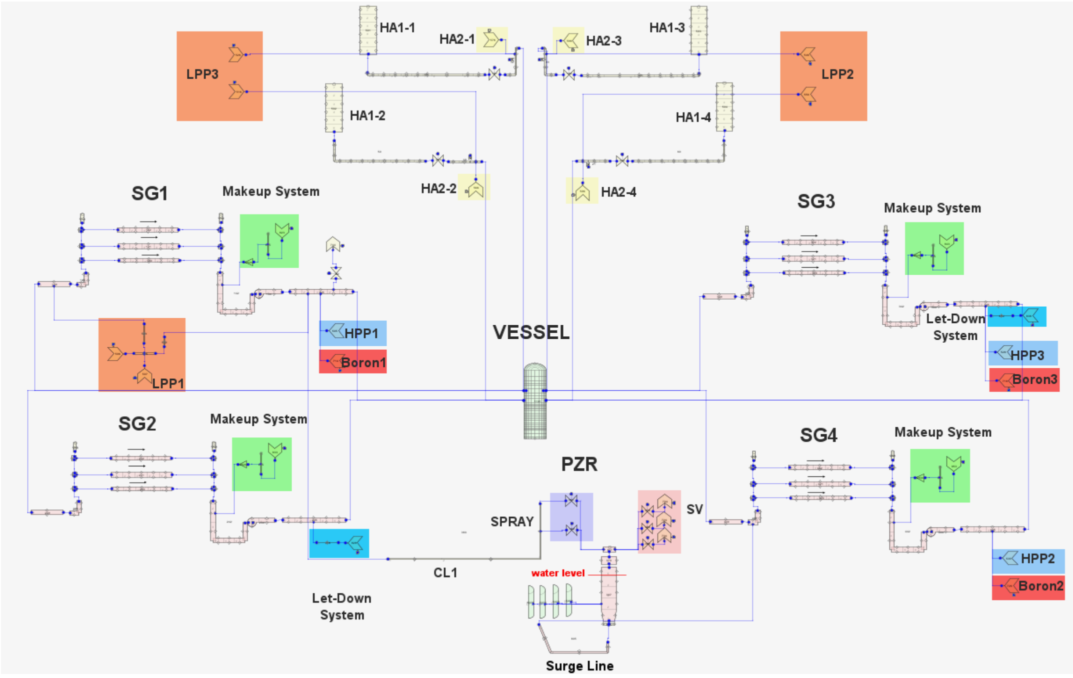

Figure 2: VVER-1000/V-320 RCS TH model (including passive HA-2 system)

4 LOCA ALONG WITH SBO RESULTS

MB/LBLOCA + SBO sequence analyses have been performed for ten different break sizes. Then, a sensitivity analysis on the required HA-1 trains has been carried out. Finally, the results of a DEGB LBLOCA + SBO sequence with and without the HA-2 system are discussed in detail.

4.1 Steady State

A stable Steady State has been obtained after 300 *s* of simulation, see Table 2.

Table 2: VVER-1000/V-320 Steady State results

Parameter	Measured [7]	TRACE5P5
Core Power (MW_{th})	3010	3010
RCS Pressure (MPa)	15.70	15.73
PZR Level (m)	8.70	8.71
Cold Legs Temperature (K)	560.85	561.07
Hot Legs Temperature (K)	591.55	591.61
SGs Outlet Pressure (MPa)	6.27	6.27
Main Feed Water Mass Flow (kg/s)	409.00	409.44
SGs Level (m)	2.50	2.40

4.2 MB/LBLOCA + SBO sequences analysis with HA-2 systems

A wide range of MB/LBLOCA + SBO sequences (from 2” to DEGB located in cold leg) along with SBO has been analyzed, in which the only passive safety systems injecting water into the RCS are the HA-1 and the HA-2.

Results have shown that HA-1 and HA-2 systems are enough to prevent core damage for break sizes from 3” to DEGB, Figure 3, as the pressure drops quickly allowing the two passive safety systems to start injecting borated water in time to avoid the core temperature exceed 1477 K. Even thought for breaks larger than 25” the core is uncovered during the first 1000 *s* of the sequence. For break sizes smaller than 3”, the pressure decreases slowly, Figure 4, so that the core is uncovered before reaching the HA-2 setpoint.

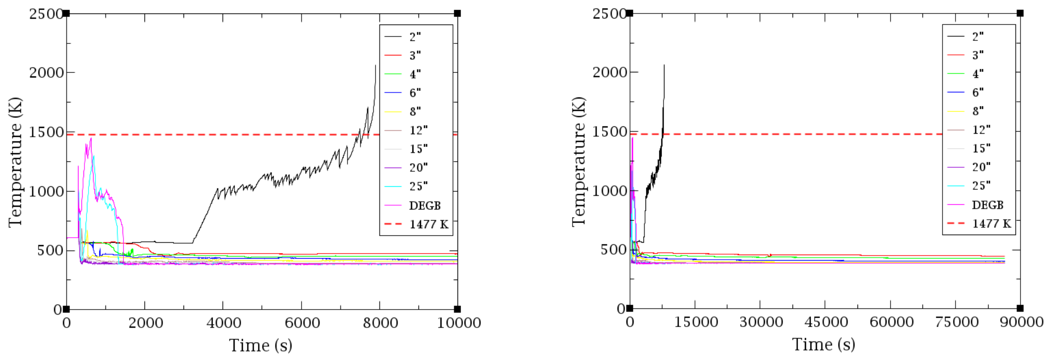

Figure 3: PCT (enlarged from 0 to 1E+4 s and full transient). MB/LBLOCA + SBO sequence (2” – DEGB) with HA-2

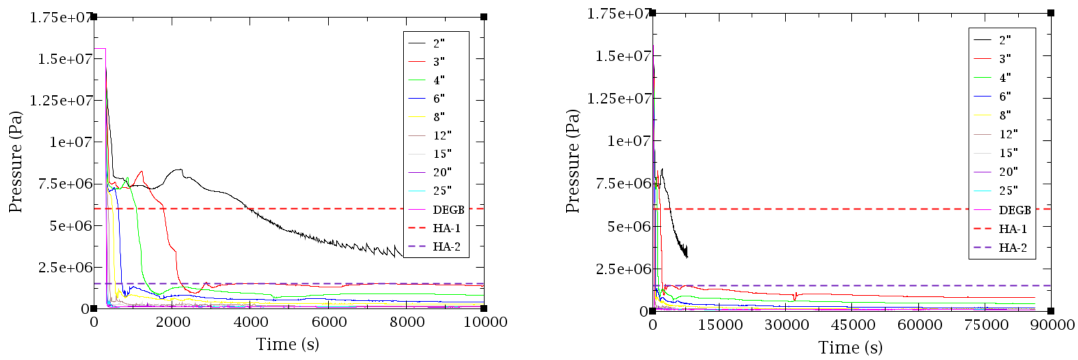

Figure 4: RCS Pressure (enlarged from 0 to 1E+4 s and full transient). MB/LBLOCA + SBO sequences (2” - DEGB) with HA-2

The rate at which the pressure decreases determines the time it takes for the HA-2 to start discharging water into the RCS. Table 3 shows how in a 3” MBLOCA + SBO the HA-2 inject 2030 s after the beginning of the transient, while in a DEGB LBLOCA + SBO, they take only 115 s.

Table 3: HA-2 actuation time and PCT for MB/LBLOCA + SBO

MB/LBLOCA Diameter (inches)	HA-1 (s) (begins/ends)	HA-2 (s) (setpoint + 100 s of delay)	PCT (K)
2”	3570/ -	-	>1477
3”	1475/ 31683	2030	607
4”	785/ 4353	1140	607
6”	325/ 1520	520	607
8”	180/ 505	350	669
12”	70/ 185	210	684
15”	45/ 140	175	642
20”	25/ 100	140	818
25”	20/ 95	130	1303
DEGB	10/ 75	115	1449

4.3 Sensitivity analysis on the required HA-1 trains in the MB/LBLOCA + SBO sequence

Having verified that the combined performance of the HA-1 system together with the HA-2 system is enough to avoid core damage for break sizes above 3”, the minimum HA-1 system configuration required to not exceed 1477 K in the core has been found.

As can be seen in Table 4, for break sizes smaller than 8”, no HA-1 passive safety system train is needed. For break sizes between 8” and 25”, 1 out of 4 HA-1 train is necessary and for break sizes between 25” and 30”, 2 out of 4 HA-1 trains are also necessary.

For break sizes above 30”, it is required to surpass the HA-1 system success criterion, 3 out of 4 HA-1 trains, as it is mandatory to inject 4 out of 4 HA-1trains to avoid the core damage. This can be justified by the fact that the success criterion of the HA-1 system is designed for scenarios in which active ECCS, not only passive safety systems, are also available.

Table 4: Number of HA-1 trains required to avoid damage in MB/LBLOCA + SBO sequences with the HA-2 system performance

MB/LBLOCA break size	3” – 8”	8” – 25”	25” – 30”	30”- DEGB
HA-1 number of trains	0 out of 4	1 out of 4	2 out of 4	4 out of 4

4.4 Comparison of a LBLOCA along with SBO, with and without HA-2 systems

The sequence of a DEGB LBLOCA + SBO has been analyzed taking into account two options, with and without HA-2 system, see Table 5.

In both cases, there is a peak in the PCT as soon as the break occurs (300 s), Figure 5 right, which lasts for a few seconds as the RCS pressure drops fast enough for the HA-1 to supply water within 10 s of the transient, flooding the core. After 15 s, the HA-2 check valves set point is reached, but due to a delay of 100 s, the system does not start injecting water until 415 s. From 460 s onwards, the PCT in the first case starts to be lower than in the second case due to the collapsed core liquid level stats to increase, Figure 5 left. Finally, the sequence without the HA-2 system reaches core damage at 508 s.

Table 5: DEGB LBLOCA along with SBO w/wo HA-2 sequence

w/HA-2 (s)	wo/HA-2 (s)	Event
300	300	DEGB LBLOCA + SBO (SCRAM, MFW pumps and RCPs trip, TT, loss of the condenser, CVCS off)
304	304	Control rods fully inserted
310	310	HA-1 injection begins
375	375	HA-1 injection ends
415	-	HA-2 injection begins
460	-	The collapsed core level starts to increase
-	508	PCT > 1477 K
630	-	Maximum PCT
1460	-	End of the reflood phase
86700	-	HA-2 injection ends

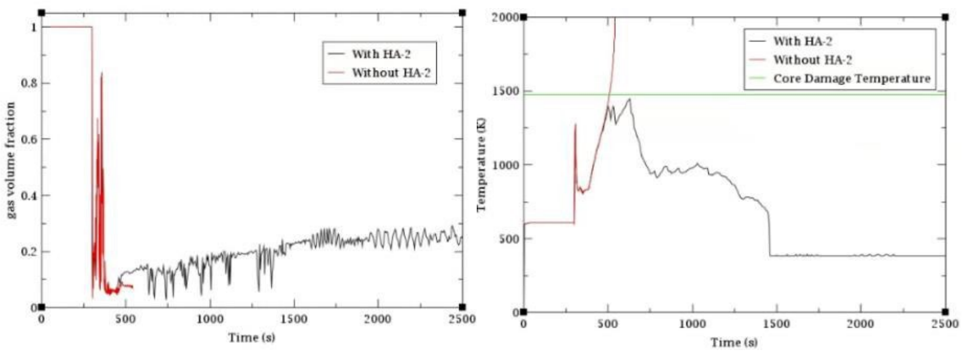

Figure 5: Collapsed core level and PCT (DEGB LBLOCA + SBO w/wo HA-2 system)

5 CONCLUSIONS

A wide range of MB/LBLOCA sequences with SBO has been analyzed in the VVER-

1000/V-320, incorporating the HA-2 passive safety system. The following conclusions have been reached:

- It has been confirmed that HA-2 system is able to cool the core for 24 hours, without reaching core damage for 3” to DEGB MB/LBLOCA along with SBO sequence.
- MBLOCA, between 2” and 8”, along with SBO do not require the HA-1 system actuation to prevent the core damage if the HA-2 system actuates properly.

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