Three-dimensional simulation of a LBLOCA in an AP1000® Containment Building.

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I. INTRODUCTION

The simulation of containment Design Basis Accidents (DBAs)is usually conducted with lumped parameter models for licensing analysis. The lumped parameters approach takes assumptions such as: instantaneous mixing of the fluid inside a control volume, neglecting three dimensional effects of the flow patterns, instantaneous contact of all thermal structures with the fluid inside a control volume, neglecting the thermal diffusion between control volumes or neglecting forced convection. The codes normally used by Westinghouse Electric Company (WEC) for that license analysis are WGOTHIC or COCO, which are suitable to provide an adequate estimation of the overall peak temperature and pressure of the containment. However, given the complex geometry and phenomena inside an **AP1000** and for the detailed study of the thermal-hydraulic behavior in every room and compartment of the containment building, it could be adequate to model the containment with a detailed three dimensional representation of the geometry of the whole building.

The main objective of this project is to simulate a LBLOCA in a three-dimensional **AP1000** containment model made in the Nuclear Safety group of the UPM. In this paper the accident is presented and analyzed.

II. DBA MODELING WITH GOTHIC

GOTHIC [1] is a Thermal-Hydraulic (TH) code widely used for accident analysis licensing for containment buildings. Several methodologies have been developed by the main vendors, for Generation II reactors containment analysis such as Westinghouse or AREVA [2],[3]. In addition, GOTHIC has been used also for Generation III+ reactors, such as the AP600 and **AP1000**, the ABWR[4], or the IRIS reactor [5].

The most common accidents in PWR containment analysis are usually the Loss Of Coolant Accident (LOCA) and the Main Steam Line Break (MSLB).

The main variables of interest involved in this kind of accidents are: peak pressure in the containment, peak temperature in the containment, peak temperature in the liner of the containment, peak temperature of the heat sink and long-term evolution of pressure and temperature in the containment.

Due to the fact that, the containment is the final barrier that prevents the escape of radioactive elements to the environment, these main variables need to be kept below the acceptance criteria against DBAs. With this purpose, the containment building is designed to address such accidents by incorporating mechanisms to extract heat and to accommodate the pressure and temperature peaks resulting from a LOCA or MSLB.

The lumped models used for licensing with the GOTHIC code allow a proper calculation of the averaged TH variables in the containment in case of LOCA or MSLB. Nevertheless, to predict with enough accuracy the pressure and temperature distribution in each location of the containment, a 3D subdivided volume model of GOTHIC could be needed, especially for slower release scenarios, such as SLOCA. Some detailed 3D studies have been performed in the past using GOTHIC sub-divided models and other CFD codes to simulate accidents in a PWR containment, see [6] .

III. AP1000 CONTAINMENT MODEL

The evolution of Generation II containments toward Generation III+ has brought some unique changes. The **AP1000** containment is a revolutionary model of the classic containment [7]. One of the main changes, Figure 1, is that the liner is not attached to the concrete in the upper part. This space is reserved for air flowing to the outside and a water film flow that cools the steel containment through natural convection and evaporation. The classic PWR containment has evolved into the steel containment and the shield building. The steel containment is now simplified compared to PWR classic containments. During normal operation it is passively cooled by atmospheric air.

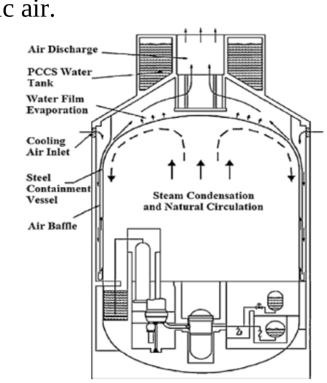

Figure 1. **AP1000** Containment

Another difference is the In-Containment Refueling Water Storage Tank (IRWST), which provides a suppression pool for steam release through the Automatic Depressurization System (ADS). Steam is released at high temperature and pressure in the IRWST, and then it is condensed avoiding a pressure increase in containment. The IRWST acts also as the sink for the water condensed in the containment liner. This is important because it is a passive system that can maintain the plant in safe conditions. This systems will be modeled in the three dimensional model.

The containment 3D modeling in GOTHIC has followed the modeling steps given by Bocanegra et al. [6]. First a detailed CAD model was created, a detailed followed by a simplified CAD model, and finally this model is imported into GOTHIC creating a TH model, Figures 2 and 3. For detailed information about the model see [9].

The GOTHIC **AP1000** containment model include the IRWST, PRHRS, ADS and the metallic liner. The model does not have a explicit simulation of the PCCS, a boundary condition is placed outside the metallic liner to simulate the circulating air.

The version of the code used is GOTHIC 8.0 (QA).

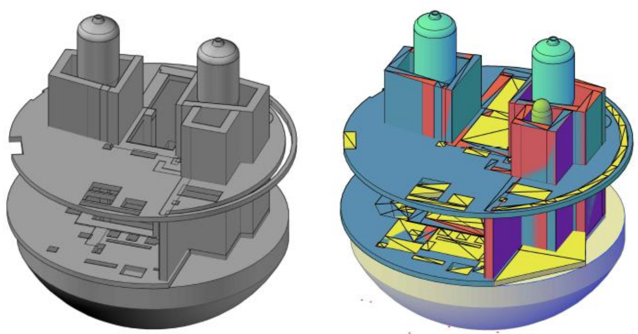

Figure 2. Detailed and simplified CAD Models

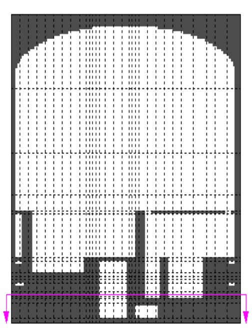

Figure 3. **AP1000** GOTHIC containment model

IV. Mass and Energy Release

In order to create a mass and energy release input for the GOTHIC model, a TRACE model of the **AP1000** is used, for more details of this model see [10].

This model include the entire primary and secondary system, with high level of accuracy, all the main components such as Vessel, Steam Generators (SGs) , Pressurizer, Reactor Coolant Pumps (RCPs) and connecting pipes as well as the passive safety systems, Core Makeup Tanks (CMTs), Accumulators (ACCs), Automatic Depressurization System (ADS) and Passive Residual Heat Removal system (PRHR) are included in the model.

The RCS pressure evolution after the break for the accident simulated is shown below:

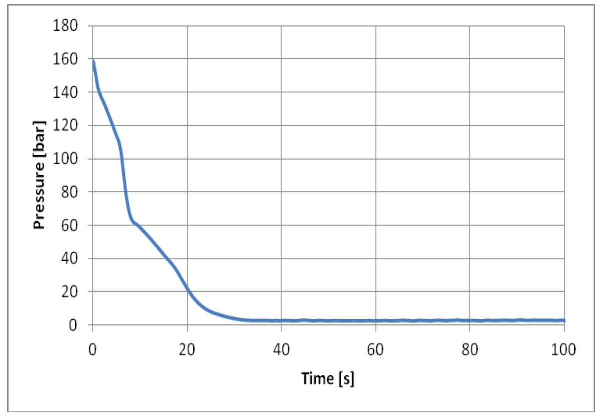

Figure 4. LBLOCA RCS pressure evolution after the break.

V. LBLOCA Results

As a consequence of the accident, there is an increase of the containment temperature and pressure. The break occurs 20 seconds after the beginning of the simulation. The results of the LBLOCA simulation are shown in Figure 4 and Figure 5.

The evolution of the pressure is homogeneous within the containment during the whole transient, as shown in Figure 7. The pressure does not vary significantly, excluding the IRWST, where the pressure increases in 50 kPa due to the pressure of the water column. The evolution of the average temperature for different containment compartments is shown in Figure 5. As shown, the containment has a heterogeneous distribution of temperatures, this also can be seen in Figure 6.

The evolution of pressure and temperature, are post-processed with ProTON (UPM proprietary Code) and ParaView [11]. Those are necessary codes for the complete description of the three dimensional phenomena during a LBLOCA in the **AP1000**.

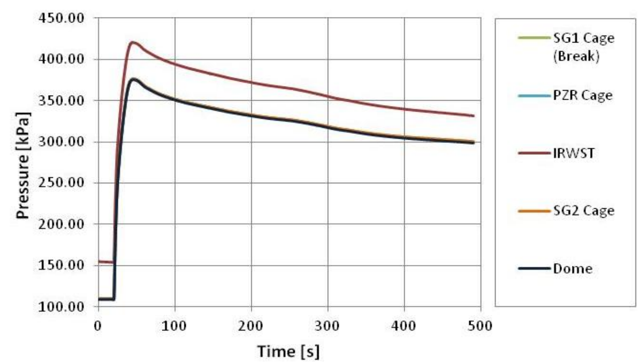

Figure 4 Average pressure evolution in different containment compartments during LBLOCA.

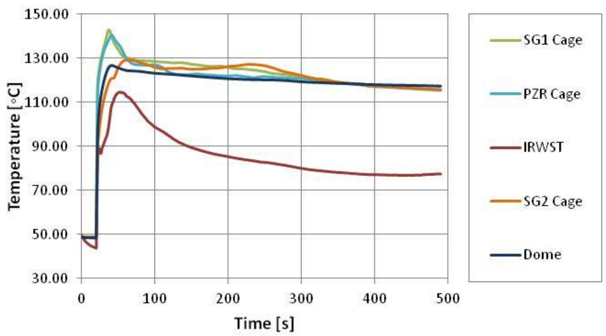

Figure 5 Average temperature evolution in different containment compartments during LBLOCA.

The first pressure and temperature peak occurs 15 s after the break. It is located in the loop of the break, and in the pressurizer cage, which is in the same loop as the break. The peak reaches 376 kPa and 142 ºC. The IRWSRT reaches its peak 38 seconds after the break, with a delay compared to the higher peaks, with a value of 114ºC. At that time, the pressure in containment is 368 kPa and the saturation temperature for this pressure is 143ºC approximately, so the inventory in the IRWST doesn't reach boiling.

After the peaks the vapor condensation in the IRWST and PCCS reduces the temperature and pressure in containment.

The flow patterns during the accident can be seen in Figure 8. Practically all the inventory released from the break flows upwards through the SG cage of the break and then it homogenizes over the dome. During the first 10 s after the accident the flow reaches 50 m/s, forced convection is therefore present. After 20 s, the velocities are below 10 m/s and natural convection is the main convective heat transfer process.

In addition to convection processes, condensation is also present. After 500 seconds, the heat transfer structures, including the PCCS, as well as the IRWST have condensed 20000 kg of steam.

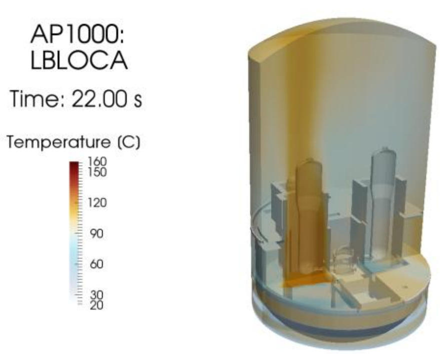

Figure 6. Temperature distribution at 22 s

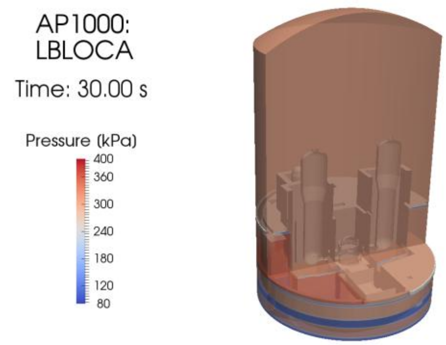

Figure 7. Pressure distribution at 30 s

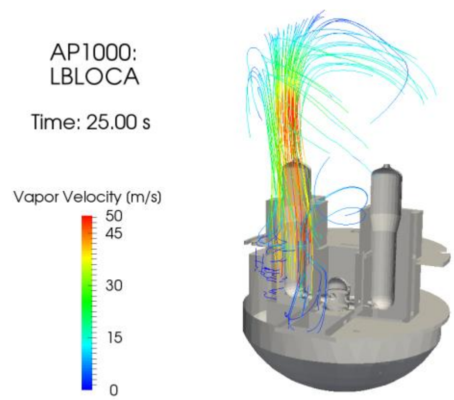

Figure 8. Vapor flow patters at 25 s

VI. Conclusions

In this paper, the capacity of GOTHIC for simulating different a LBLOCA in a three dimensional AP1000 containment model has been tested.

The subdivided volume option as well as tools as ProTON and ParaView allow to perform a three dimensional analysis of all relevant variables, as well as streamlines in the containment during the accident.

In conclusion, it has been proved that taking into account three dimensional phenomena, which is neglected in lumped models, could lead to more accurate simulations and an increase in the understanding of the accident.

Acknowledgment

K.F. thanks Carlotta Cosials for her support and for making this work quite easier.

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