Three-dimensional Containment Accident Analysis using different approaches in Almaraz NPP

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Containment Design Basis Accident analysis are usually performed using lumped-parameters models as this kind of models do not require high computational resources. Moreover, they offer overall good results of average pressure and temperature evolution. However, in order to perform a detailed local analysis, a thermal-hydraulic behavior study of every containment room may be necessary. To achieve this goal, a more detailed containment 3D model is imperative for capturing the local phenomena which occurs during a mass and energy release accident. During the last years in the collaborative project between the UPM and CNAT, several Almaraz NPP containment 3D models have been developed. The most precise one, called Detailed Integral Model, is able to obtain results with a very high resolution. However, this approach requires also high computational resources. For this reason two new models, called Multi-Zone Models, were developed with a coarser nodalization and therefore a lower computational requirement is needed. In this paper, the new modeling approach is described. A LBLOCA has been simulated in the Multi-Zone Model and it has been compared with the results obtained from the Detailed Integral Model. After analyzing the results, it can be concluded that the thermal-hydraulic evolutions are similar although the local variables differ in some cases. Taking into account the differences between models, a criteria in the use of the different approaches described has been stated depending on the analysis objective.

1. INTRODUCTION

Loss of Coolant Accident (LOCA) and Main Steam Line Break (MSLB) containment accident are usually simulated in GOTHIC using Lumped Parameters Models (LPM), because these kind of models are considered adequate for licensing analysis [1, 2, 3, 4, 5]. However, in order to perform a detailed thermal-hydraulic analysis in each and every containment room, it could be necessary a three-dimensional model with a more realistic geometry representation [6].

The objective of the UPM-CNAT collaboration is the development of three-dimensional containment models with the GOTHIC code [7] for PWR Westinghouse type Almaraz NPP (CNA).

To better study the containment response to transients, several models were created for CNA. The main differences between those models is the nodalization scheme and the geometrical precision. On one hand, the Multi-Zone Models (MZMs) have seven control volumes which are subdivided in cells of 2.5 meters long in the MZMA model and 5 meters long in the MZMB model. On the other hand, in the Detailed Integral Model (DIM), the whole containment is represented just in one subdivided control volume with a heterogeneous mesh.

The goal of the analysis presented in this paper is to compare the different models for a LBLOCA accident.

2. MODELS DEVELOPMENT

The methodology used to develop the GOTHIC 3D containment models is based on the methodology developed at the UPM, more details in [6]. The process is divided in three steps (Figure 1):

- Detailed 3D CAD model
- Simplified 3D CAD model
- GOTHIC model

The three-dimensional detailed CAD models have been built departing from the digitalization of the available schemes, most of them done several decades ago. The main documents used come from the Final Safety Analysis Report (FSAR) [8] .

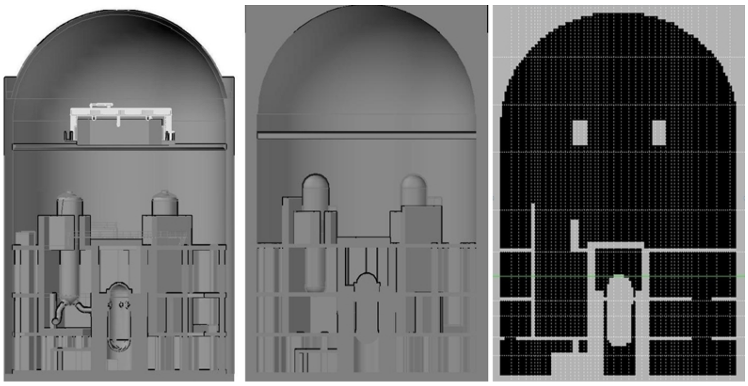

Figure 1: CNA modeling scheme (Detailed-Simplified-GOTHIC)

The objective of the simplified CAD models is to be a link between the detailed and GOTHIC model. The building process includes simple geometric figures, used by the GOTHIC code to model the geometry, keeping the highest detailed level achievable.

To add a certain flexibility to the simulations, different model approaches have been developed. A high resolution mesh implies high computational requirement. Therefore, three models have been built for CNA, one, in which all the containment is represented in a unique subdivided control volume, and two MZM with different mesh resolution. In this case, the containment is represented using several control volumes connected between each other by flow paths.

The CNA-DIM (***Figure 2***) is modeled in one control volume subdivided. Therefore it was not necessary the use of flow paths or 3D connectors to link the different compartments. It is composed of 18480 hexahedral cells distributed in a 42x44x10 (X,Y,Z) mesh. The heat sinks are modeled using 159 thermal conductors, 7 conductor surfaces and 6 different materials.

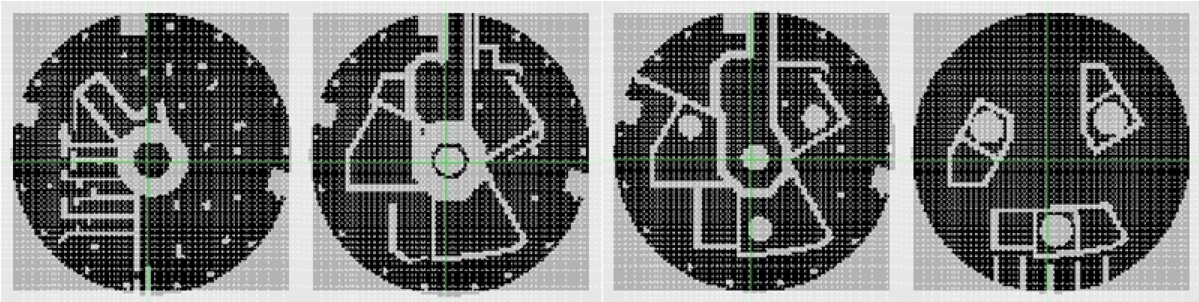

Figure 2: CNA DIM GOTHIC model

The CNA-MZMs are modeled using 7 subdivide control volumes with a homogeneous mesh. These models need the use of flow paths and 3D connectors to achieve an adequate thermal-hydraulic behavior, linking the different control volumes. As it was concluded in [6], the mesh size is determinant in the spent computing time, thus two MZMs have been developed using different mesh sizes. The CNA-MZMA is composed of 13167 cells, 34 flow path and 123 thermal conductors. The CNA-MZMB has a 1407 cells mesh, 34 flow paths to link the control volumes and 117 thermal conductors.

3. LBLOCA SIMULATION

The postulated accident consist in a Doubled Ended Large Break Loss of Coolant Accident (DE LBLOCA) located in the cold leg 1. The input data has been extracted from published data [10, 6]. The break is located in the Steam Generator 1 (SG1) cage, as can be seen in Figure 3.

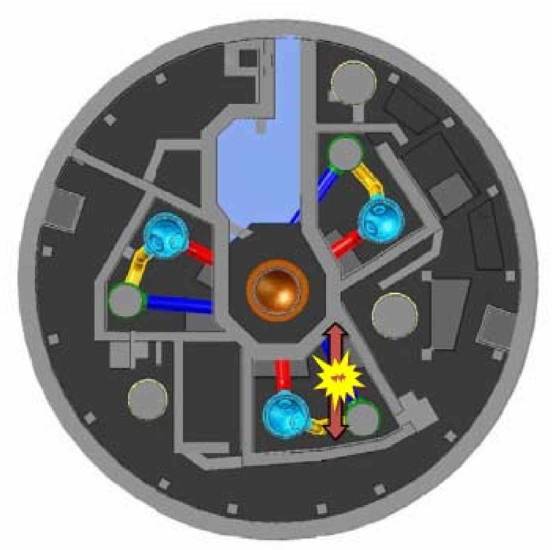

Figure 3: CNA break location

4. POST-PROCESSING AND RESULTS

The output files generated by the GOTHIC models become an enormous quantity of data to analyze. Therefore, a specific tool, named ProTON, has been developed at the UPM to process the GOTHIC data. With this code, temperature and heat flux throughout the walls and compartment average pressure and temperature can be obtained. For a qualitative post-processing, the open source ParaView software is used.

4.1. CNA-DIM Results

CNA-DIM average pressure is shown in Figure 4. The increasing pressure behavior during the blowdown phase presents a smooth raise with pressure peak 15.54 s after the pipe break.

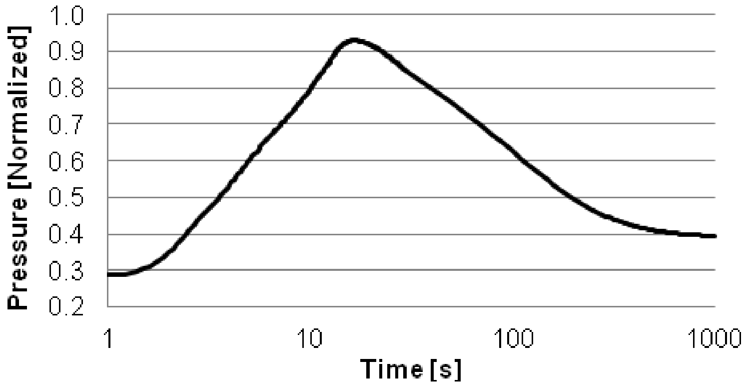

Figure 4: CNA- DIM Average Pressure

In addition, different rooms pressure evolution are compared in Figure 5. The pressurization is almost homogeneous, due to it occurs at a sonic velocity.

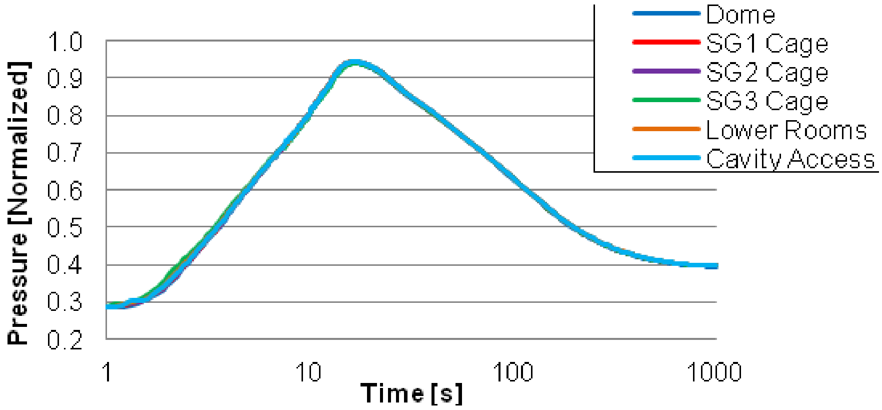

Figure 5: CNA-DIM Compartments Pressure

The average temperature (Figure 6) present a behavior similar to the pressure curve, ascending progressively to reach a maximum at 14.44 s, two seconds earlier than the pressure peak.

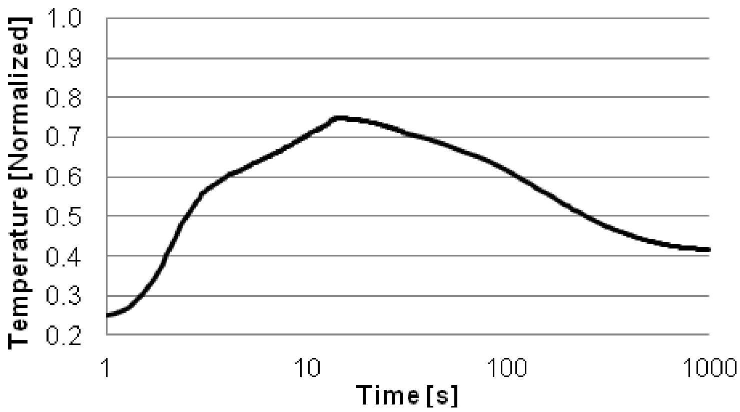

Figure 6: CNA-DIM Average Temperature

In contrast, if temperature is analyzed room by room (Figure 7), can be observed that the temperature progression is not homogeneous. The temperature is a convective-diffusive process, and the fluid velocity and diffusion are the propagation media. Since the steam is not propagated at sound speed, like the pressure does, the temperature increment does not occur at the same time in the whole building. Therefore, the temperature evolution differs between compartments, being the higher peak (at 13.43 s) registered in the SG3 Cage, where the break is located.

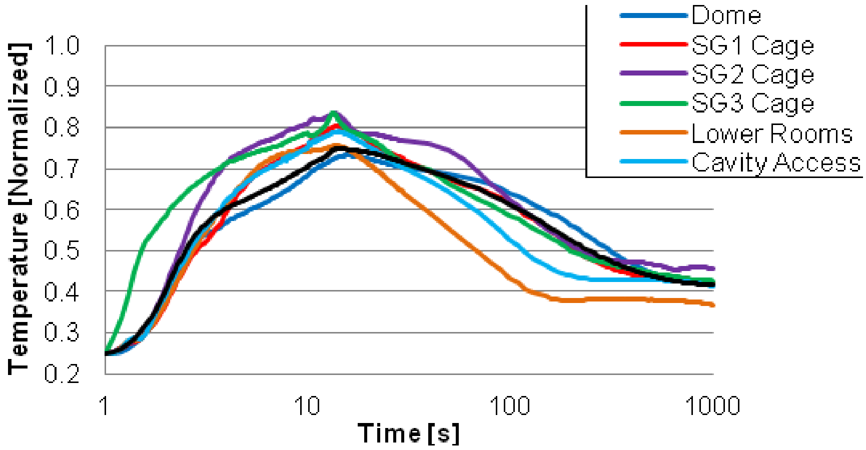

Figure 7: CNA-DIM Compartments Temperature

The steam travelling time causes a delay in the temperature increment between different compartments. The differences in temperature evolution between lower rooms (Figure 8) depends on the steam residence time and the heat structures capacity to absorb the released energy. This capacity is also influenced by the temperature distribution over the whole volume, and therefore by the geometry.

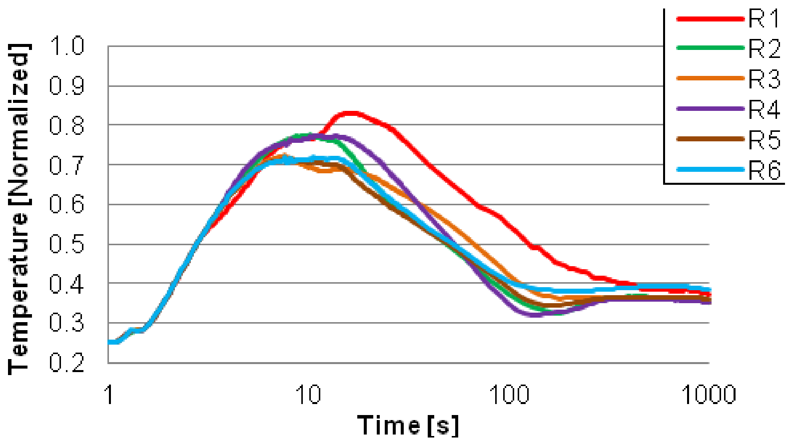

Figure 8: CNA-DIM Lower Rooms Temperature

4.2. CNA Model Comparison

As was commented above, the same accident sequence has been simulated using the other model approaches: MZMA and MZMB. During the CNA-DIM analysis, it was observed that the M&E release produces a containment heat up and increases the pressure drastically. The temperature increment over the compartments was not homogeneous due to the steam flow currents. However, the pressurization occurred at sonic velocity and is dependent on the mass released, the free volume and the temperature. Furthermore, it is not necessarily dependent on the flow currents. The alternative models results show a homogeneous pressurization over all the compartments (Figure 9). While the free volume is almost the same in all the models, the pressure difference is mainly produced by the energy absorbed by the heat sinks. Therefore, the main parameter that could affect the pressure in the models analyzed is the temperature, and as a result, it could be assumed that the higher pressure resulted in the MZMA and MZMB models is due to a lower heat transfer.

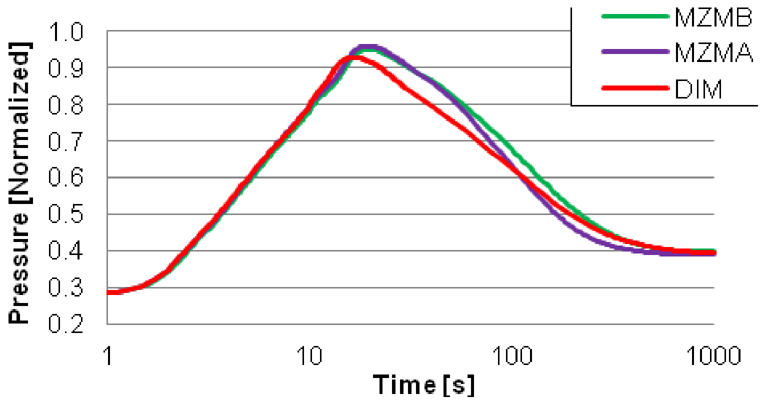

Figure 9: CNA Average Pressure

Comparing the average temperature between models (Figure 10), can be observed that the evolution is quite similar. However, as it was observed in the CNA-DIM Analysis, the temperature distribution is not homogeneous over all the building.

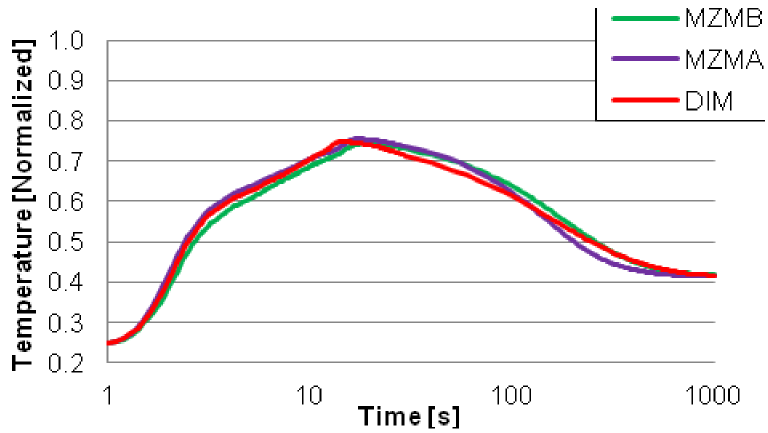

Figure 10: CNA Average Temperature

Therefore, comparing the different models results, is observed that in all the models analyzed, the higher temperature is registered in the SG1 control volume (Figure 11), where the break is located. The higher peak resulted in the MZMB.

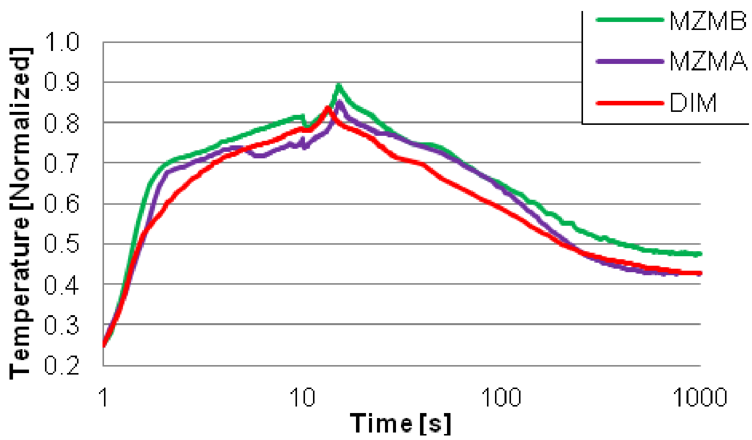

Figure 11: CNA SG1 Cage Temperature

5. FINAL REMARKS

The methodology used in [6] has been applied in order to develop GOTHIC 3D containment models for Almaraz NPP.

Different model approaches were used for each containment: a Detailed Integral Model (DIM), where the whole containment is represented in a unique subdivided control volume; Multi-Zone Model (MZM), where containment is divided in 7 control volumes using a coarser mesh.

A LBLOCA was simulated in order to compare the thermal-hydraulic behavior of each model approach. The MZMB registers the highest temperature peak.

Can be conclude that there are several parameters in competence which highly affect the results in a containment accident analysis:

- The characteristic length used in the GOTHIC code heat transfer coefficient calculation is based on the volume (or cell) hydraulic diameter (D_h) [12], depending on it is a lumped or a subdivided volume. In subdivided models, the D_h is only calculated in cells where a blockage (surface) is present. Free cells use a default value (1.0E+06) for the D_h. Since the multi-zone models have bigger cells than the DIM, the convective HTC calculated for the MZM is smaller.

- Big cells have a bigger volume, therefore the thermal conductor can interchange heat with a bigger air–steam mixture mass and as a result this leads to a heat flux increase.

- The temperature behavior is also influenced by the building geometry. Different buildings with different geometric distribution will produce different flow currents and different steam residence time in compartments [6].

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