FULL SCALE CFD MODELING OF THE CONTAINMENT BEHAVIOR DURING A TLAP SEQUENCE IN A GENERIC KWU PWR WITH CONTAINMENTFOAM

Stephan Kelm[1], Carlos Vázquez-Rodríguez[1], Michael Klauck[1], Luis Serra-Lopez[2], Gonzalo Jimenez[2]

[1] *Forschungszentrum Jülich GmbH, Jülich, Germany*
[2] *Universidad Politécnica de Madrid, Madrid, Spain*

Abstract

The European AMHYCO project (Euratom 2019-2020, GA 945057) aimed at enhancing the understanding of H_2/CO combustion risk within the containment of a nuclear power plant during a severe accident. Its ultimate goal has been to incorporate this knowledge into recommendations for the severe accident mitigation guidelines (SAMGs) and long-term operation upgrades. The analytical work comprised a consecutive analysis chain, consisting of three levels with increasing detail (system codes, 3D GOTHIC, and CFD) to assess containment pressurization and heat up, and/or options of individual mitigation measures regarding H_2/CO combustion risk and equipment and instrumentation survivability for three generic European PWR containment designs, namely KWU, Western (Westinghouse and French), and VVER [1].

The presentation focuses on the *containmentFOAM* modeling of a PWR KWU containment. Along with a brief introduction of the *containmentFOAM* CFD package built on OpenFOAM-11, the modeling assumptions and simplifications of the full-scale model are discussed. On this basis, the condensable and non-condensable gas distribution in the containment is presented, and the effect of PAR operation on the containment atmosphere mixing process is elaborated for a Total Loss of Auxiliary Power (TLAP) sequence. The results are discussed in comparison with the system code COCOSYS and the 3D code GOTHIC^{TM}. To conclude, the presentation summarizes the lessons learned from the full-scale application and needs for further CFD model development.

Keywords

Containment mixing, H_2 risk, CFD, containmentFOAM

1 Scenario and Modeling Approach

A generic German PWR 1300MW$_{el}$ is selected for this study. Its containment (see Figure 1 left) is compartmentalized into the equipment rooms, housing the Reactor Cooling System (RCS), and the operating compartments. They are separated by the cylindrical missile shield and burst foils on top of the steam generator towers.

In the investigated TLAP scenario, a delayed depressurization of the RCS is considered, which results in a large amount of hydrogen being released in a short period of time from the pressurizer relief tank (PRT) into the equipment rooms. The released hydrogen cloud first stratifies in the equipment room before ascending through the open SG tower rupture foil into the upper containment dome. It is assumed that the rupture foil on the second steam generator tower remained closed and thus impaired containment mixing.

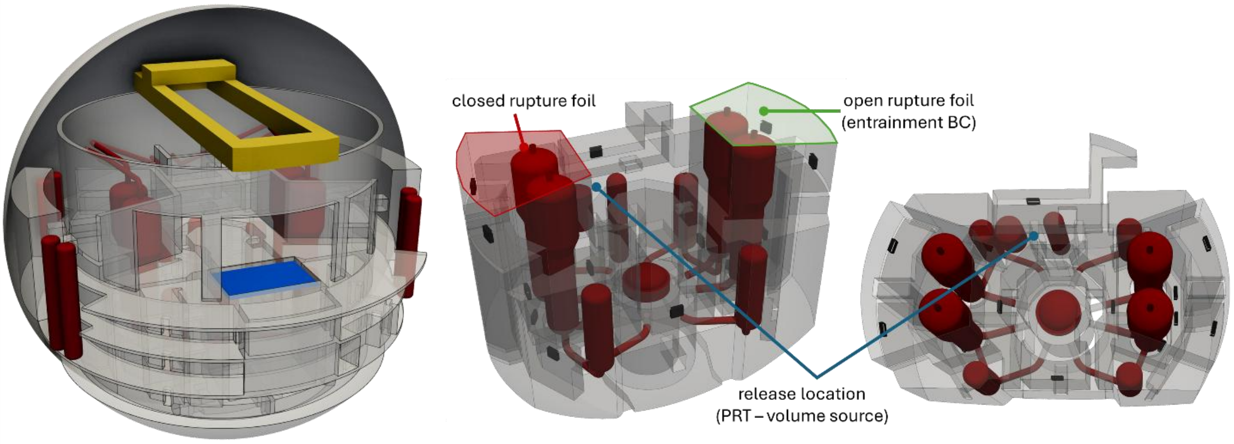

Figure 1: Full containment geometry (left), separated equipment rooms (right). Black boxes represent PARs

To investigate the rather transient stratification and mixing process, four simulations were conducted with *containmentFOAM* [2], [3]. The first two considered the full containment with and without H_2 mitigation employing passive auto-catalytic recombiners (PARs). This work provides a detailed description of two of the four sequences —focused on the equipment rooms— including a one-way coupling to UPM's GOTHIC^{TM} 3D model providing an entrainment boundary condition for containmentFOAM. (see Figure 1 right).
The computational domain was discretized using the commercial grid generator CFMesh+, featuring hex-dominant cells, including boundary layers, resulting in 4.5M cells in the gas space and 3M cells in the concrete structures. *ContainmentFOAM*'s validated baseline modeling approach was employed. The simulations were initialized using GOTHIC 3D field data at t=8000 s, before the initial strong release of H_2 and steam.

2 Results

The simulations were performed using up to 1024 cores of FZJ's JUCRECA HPC facility. The evolution of the gas composition in the southern steam generator compartment (SG-N) is compared for the CFD, 3D-GOTHIC^{TM}, and COCOSYS (LP) analyses in Figure 2, for the case without PARs. Considering the H_2 distribution (left), it becomes obvious that the momentum of the release at a high elevation cannot mix the entire equipment rooms. Comparing the initial mixing process (see the avg. CFD results on the graphs), the CFD model reveals a different transport mechanism: The continuous steam release replaces the initially H_2 richer gas mixture in the upper parts while the lower sump region remains at an increased H_2 concentration. Thus, e.g. in SG-N, the O_2 concentration drops faster in both 3D approaches than for COCOSYS model, which in contrast reveals a stronger dilution of the atmosphere.

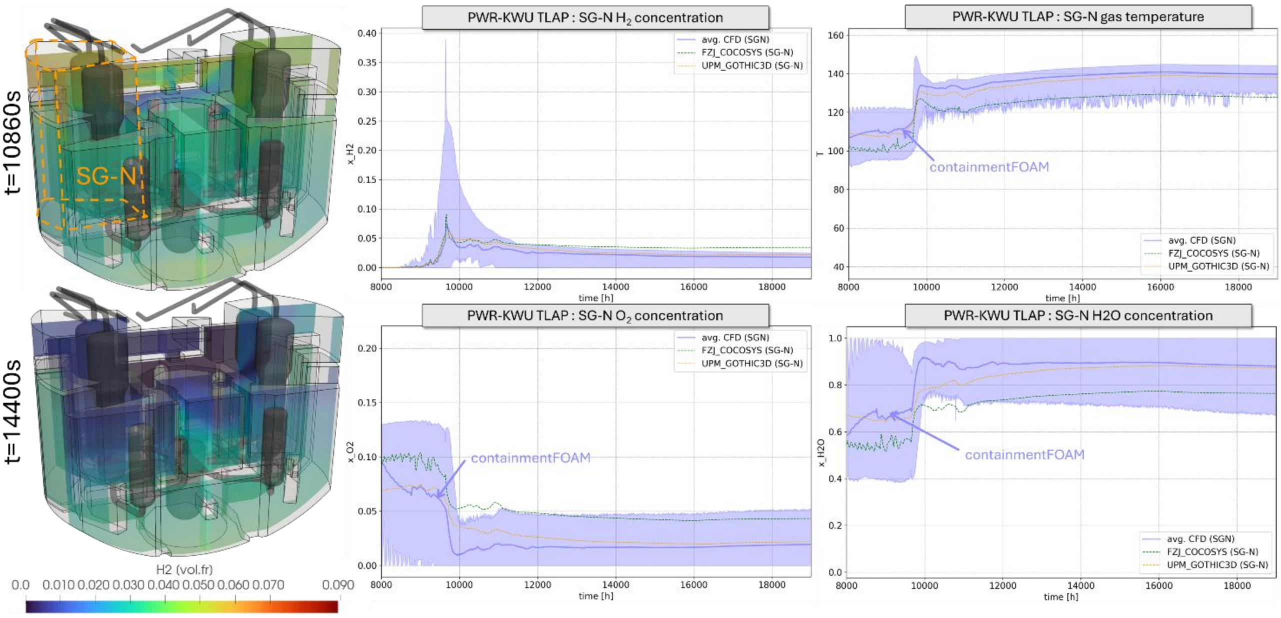

Figure 2: Evolution of the gas composition in the SG-N compartment. The bands represent CFD min/max values.

While the simulation results demonstrate the added value of a 3D CFD simulation, also the limitations of the employed single-phase approach also become apparent and require further work, e.g. for condensation of (nearly) pure steam (in the upper regions) or heat and mass exchange with the sump driving the flammability in the lower region.

REFERENCES

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