MULTI-SCALE MULTI-PHYSICS SIMULATION OF GAS INJECTION INTO THE LIQUID USING DNS/LSM

By

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ABSTRACT

One possible accident scenario in a hexagonal fuel assembly of a Gen. IV sodium-cooled fast reactor (SFR) is associated with local heat transfer decrease around the hottest fuel rod due to the coolant flow blockage by foreign objects and/or mechanical failure of the hottest fuel rods. As a result, pressurized fission gases would be released into the liquid sodium coolant as a high speed two-phase cross-flow jet.

A model for gas jet evolution in liquid-sodium flow was formulated using the Parallel Hierarchic Adaptive Stabilized Transient Analysis (PHASTA) software. This new model of the turbulent, unsteady, three-dimensional two-phase flow uses unstructured grids and massively parallel computers. The PHASTA code uses a direct numerical simulation (DNS) method and is capable of capturing the shape of gas/liquid interfaces using the level set method.

An intrinsic flaw in the standard approach to the modeling of gas-liquid interfaces using the level set method was found and analyzed. It has also been demonstrated that the pressure outflow boundary conditions (BCs) commonly used in single-phase flow simulations are not applicable to two-phase flows with resolved gas/liquid interfaces, since they cannot handle the surface-tension-induced sharp pressure gradients across the interface. A new approach to treating the outflow BC in two-phase flow problems has been proposed.

PHASTA capabilities had been validated thoroughly before, but it was still helpful to validate two-phase flow models using experiments related to the problem of interest. A series of experiments measuring the velocity of the rising bubbles in narrow channels (inclined and vertical channels) were chosen to validate the two-phase flow models.

It has been shown that a very thin liquid film should be introduced between the

solid walls and the bubbles to achieve a better agreement with experimental data. A number of simulations were performed for different inclination angles. It was shown that properly introducing such a liquid film, PHASTA simulation results have shown a very good agreement with experimental data.

A new capability was added to the code to change the geometry of the cladding failure based on the analytical, numerical or experimental data from external sources. This method provides the option to simulate an expanding crack on the cladding by changing both gas release velocity profile and the crack shape while PHASTA is running. The new model was tested and verified.

Another development dealt with the capability to adjust the gas flow rate as a function of time based on the difference between the pressure of the gas inside cladding and the pressure at the crack. A simulation was performed and the results were studied to prove that the introduced method works properly and is stable.

Selected gas release scenarios using different geometries and gas release flow rates with laminar and turbulent liquid coolant flows were numerically simulated and studied using both constant and time-varying gas release flow rates.

A multi-stage method was developed to record, interpolate and average PHASTA results and then post-process them and feed into an ensemble-averaged code (NPHASE-CMFD). The NPHASE-CMFD numerical simulation results using PHASTA results as inflow have been studied for laminar and turbulent liquid coolant flows.

Finally, a brief summary of the achievements and their significance is discussed and novel ideas are suggested for the future work.