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Debris Transport Evaluation during LOCA Blow-down using CFD Methodology for OPR-1000 Plant

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1. Introduction

The emergency core cooling system (ECCS) provides water to cool the core of the nuclear reactor in case of a loss of coolant accident (LOCA) that would result, for example, from a reactor coolant system pipe break. The water supplied by the ECCS comes from the refueling water tank (RWST) and safety injection tanks. When the low level limit is reached in the RWST, the water that has accumulated in containment sump will be recirculated through the reactor core using the ECCS system. This process provides long-term cooling for the core. Therefore, the accumulation of debris generated during a LOCA will result in an increase in head loss across the sump screens and if the head loss across the screen becomes too large, the pumps will no longer have adequate net positive suction head (NPSH), which could result in cavitation and failure of the pumps to deliver the amount of water needed.

In 1992, a spurious opening of a safety valve at Bardebäck-2, a Swedish BWR, resulted in clogging of two ECCS pump suction strainers leading to loss of both containment sprays within 1 hour after the accident. This issue is classified as GSI-191 in United States. The U.S. Nuclear Regulatory Commission (NRC) published regulatory guidance on the performance of pressurized water reactor (PWR) containment sump screen in 2002 in Regulatory Guide 1.82 Revision 3.

The present work aims to evaluate debris transport LOCA blow down for OPR-1000 plant based on CFD methodology. This analysis result can be used to develop the regulatory capability to evaluate the safety related to the issue in the nuclear power plants (NPPs).

2. Numerical Model

2.1. Geometry and Mesh

Fig. 1 shows the 3D CAD drawing of OPR-1000 plant. The containment has a diameter of 152 ft and has structures in the pool as shown. There are four reactor coolant pump (RCP) supported structures, two steam generator (SG) supported structures, two recirculation sumps, two sump cuds surrounds recirculation sumps, two normal sumps, and one elevator pit. These structures affected flow paths during LOCA.

The 3D geometric CAD model was imported into the mesh generator of FLOW-3D. Then, the geometry was split ten blocks. The average size of cells is about 10 inch each block. These criteria generated about 5 million structured cells. Fig. 2 shows that ten blocks for mesh generation and structured mesh for fluid domain of OPR-1000 plant.

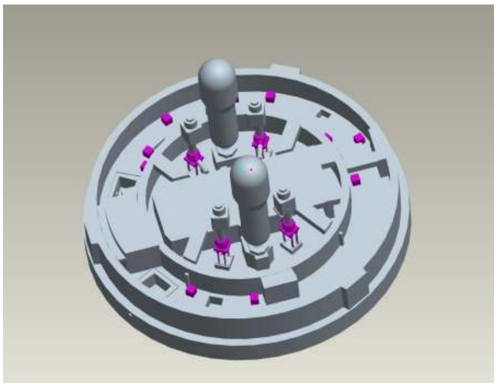

Fig. 1. CAD drawing of OPR-1000 plant.

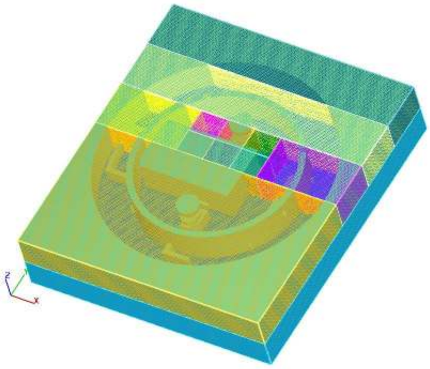

Fig. 2. Mesh blocks and structured mesh for OPR-1000 plant.

2.2. Turbulence Model

The main options currently available in FLOW-3D for general applications are variants the well known standard k-ε model, comprising transport equations for turbulence kinetic energy k and its dissipation rate ε. In standard k-ε model, k and ε are chosen as typical turbulent velocity scale and length scale, respectively. Standard k-ε model assume that turbulence Reynolds stresses and scalar fluxes are linked to the averaged flow variables in an analogous fashion to their laminar flow counterpart. The transport equations for turbulence kinetic energy and turbulence dissipation rate of Standard k-ε model are as follows:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}\left[\rho u_j k-\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]=$$

$$\mu_t(P+P_B)-\rho\varepsilon-\frac{2}{3}\left(\mu_t\frac{\partial u_i}{\partial x_i}+\rho k\right)\frac{\partial u_i}{\partial x_i}+\mu_t P_{NL} \quad (1)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_j}\left[\rho u_j \varepsilon-\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial k}{\partial x_j}\right]=$$

$$C_{\varepsilon 1}\frac{\varepsilon}{k}\left[u_t P-\frac{2}{3}\left(\mu_t\frac{\partial u_i}{\partial x_i}+\rho k\right)\frac{\partial u_i}{\partial x_i}\right]+C_{\varepsilon 3}\frac{\varepsilon}{k}\mu_t P$$

$$-C_{\varepsilon 2}\rho\frac{\varepsilon^2}{k}+C_{\varepsilon 4}\rho\varepsilon\frac{\partial u_i}{\partial x_i}+C_{\varepsilon 1}\frac{\varepsilon}{k}\mu_t P \quad (2)$$

Where σ_ε is the turbulent Prandtl number, $C_{\varepsilon 1}$, $C_{\varepsilon 2}$, $C_{\varepsilon 3}$, and $C_{\varepsilon 4}$ are coefficients whose values are given in experimental data.

2.3. Numerical Simulation

In the present work, a commercial CFD code FLOW-3D Version 9.2 was used. The simulation was performed that debris transport analysis during LOCA blow-down. Time dependent break flow rate is calculated by RELAP on condition of double ended guillotine break, that is, large break LOCA (LBLOCA). These analyses have continued for 200 seconds.

3. Analysis Results

The results of unsteady blow-down transport on containment are shown in Fig. 3, Fig. 4, and Fig. 4. Break jet impinges onto SG and flows spread. Then, the coolant flow downward and fill up containment pool.

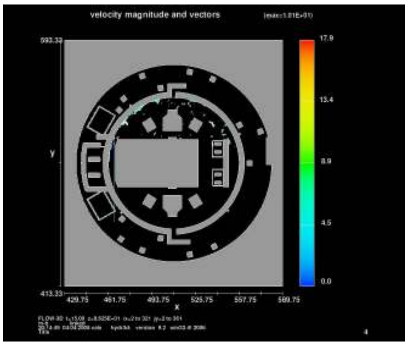

Fig. 3. Break flow fill up containment on t = 1 [s]

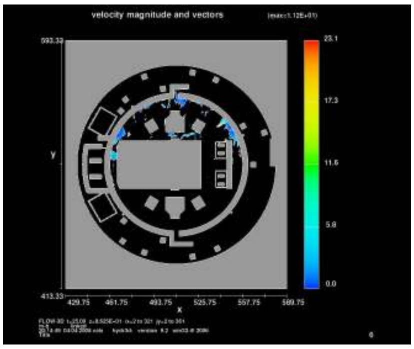

Fig. 4. Break flow fill up containment on t = 3 [s]

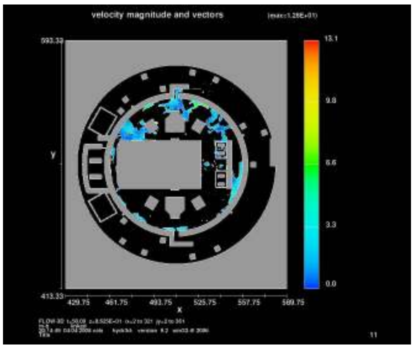

Fig. 5. Break flow fill up containment on t = 5 [s]

4. Conclusion

The understanding of debris transport during LOCA is very important in NPP safety analysis. The results of present work give a clear figure about debris transport for blow-down LOCA, which is one of major safety issue.

ACKNOWLEDGMENTS

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