CFD Analysis of LOCA Blow-Down Transport for OPR-1000 Plant

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1. Introduction

In 1992, a spurious opening of a safety valve at Bardebäck-2, a Swedish Boling Water Reactor (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 Generic Safety Issue 191 (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. As a response of these activities, Nuclear Energy Institute (NEI) performed evaluation for PWR sump performance. The methodology of debris transport is evaluated based on debris transport logic chart. This chart is composed of blow-down, wash-down, pool-fill up, and recirculation transport. According to this methodology, 0.25 of small pieces transport to upper containment during LOCA blow-down transport. Also, NEI 04-07 suggest two method of evaluation for debris transport. one is a open channel network model, the other is a Computational Fluid Dynamics (CFD) model. The analysis for recirculation transport is performed using CFD code.

The present work aim to evaluate the fraction of debris transport during LOCA blow-down based on CFD. Reference plant is OPR-1000 plant (Optimized Power Reactor 1000MWe), Ulchin nuclear power plant unit 3&4 (UCN3&4). This result will give a clear figure about flow pattern during LOCA blow-down, and fraction of debris transport to upper containment, which is one of major safety issue. The real geometry of OPR-1000 plant was used in the analysis. The FLOW-3D version 9.2, a commercial CFD code, was used in the present work.

2. Numerical Model

2.1. Geometry and Mesh

In this work, the calculation domain is selected part of full containment (75 ft-302 ft), from bottom of sump floor (75 ft) to bottom of hemisphere dome (230 ft). There are main components of the nuclear power plants (NPPs), one reactor vessel, two steam generators, four reactor coolant pumps, and pipes, etc. The flow patterns during LOCA blow-down is strongly affected these components, so it is very important to make non-simplified real geometry for debris transport evaluation during LOCA blow-down.

The 3D geometric CAD model is imported into mesh generator of FLOW-3D. Then, the geometry was split 4 blocks according to 4 floor level. The elevation of each floor level is 75-100 ft, 100-122 ft, 122-142 ft, and 142-230 ft. The second block (100-122 ft) is spilt 5 block for make inlet region. Fig. 1 shows that 11 blocks and generated mesh. Fine mesh is generated to block include hot-leg, steam generator, RCPs, and pipes where higher coolant velocity is expected and complex flow pattern is generated. The average mesh size of these blocks is about 0.5 inch, another blocks is about 0.8 inch. These criteria generated about 7.0 million structured meshes.

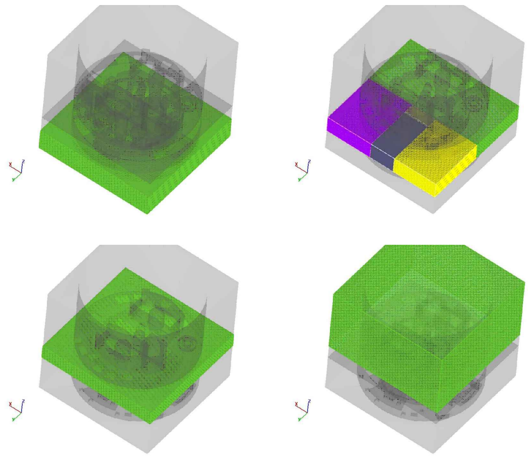


Fig. 1. Mesh blocks and structured mesh for calculated domain

2.2. Boundary conditions

According to NEI 04-07, a double ended guillotine break (DEGB) of piping around steam generator cause the maximum head loss across the sump screen. In this simulation, the break selection is selected DEGB of hot-leg. Total mass of jet flow is expelled from reactor. The second step, working fluid is selected. The jet flow during LOCA blow-down is saturated liquid-vapor mixture. In this simulation, the jet flow was assumed 100% compressed liquid, water. The third step, inlet boundary velocity is calculated based on mass flow rate during LOCA blow-down introduce by table 6.2-8 in FSAR (Final Safety Analysis Report). And then, initial condition of containment is decided. Containment is filled up air. According to table 6.2-20 in FSAR, the air pressure in containment is 16.8 psi. The assumptions of simulation for debris transport during LOCA blow-down are summarized in Table 1.

Table 1: Modeling assumption

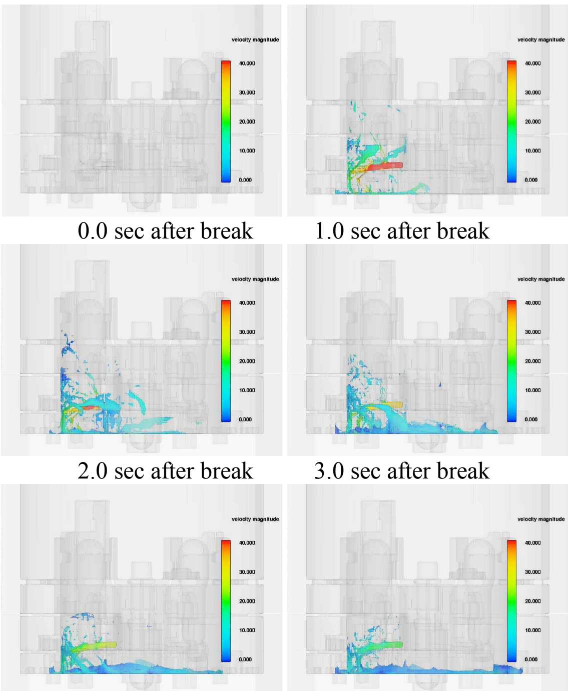
Items	Assumption
Break location	Hot-leg break
Break size	Double ended guillotine break
Jet flow	Total mass of coolant is expelled from reactor
Working fluid	100% Compressed liquid, Water
Inlet velocity	V = $\dot{m}$ /ρ2A
Initial condition of containment	16.8 psi

2.3. Numerical Simulation

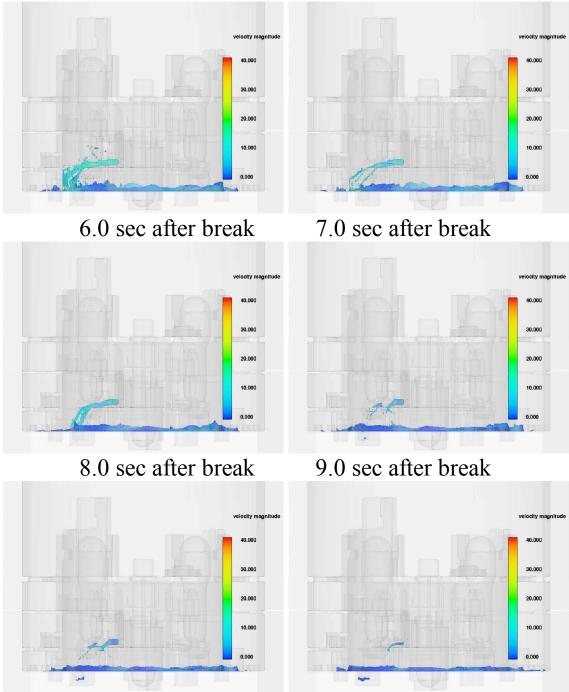
In the present work, a commercial CFD code FLOW-3D Version 9.2 is used. This essentially solve the full set of the conservation of mass and momentum equations, Navier-Storkes equations, as well as turbulence equations for each of the computational elements in the domain. Renormalization-group (RNG) k-ε model and Volume of Fluid (VOF) method were selected in the present simulation.

3. Analysis Results

The elevation of upper containment is the region from 100 ft to 302 ft, top of hemisphere dome, and lower containment is the region below 100 ft. The center of hot-leg, break location is about 103 ft. The results of debris transport to upper containment are shown in Fig. 2. Fig. 3 shows that volume of coolant in upper containment, and lower containment.



0.0 sec after break　1.0 sec after break
2.0 sec after break　3.0 sec after break
4.0 sec after break　5.0 sec after break



6.0 sec after break　7.0 sec after break
8.0 sec after break　9.0 sec after break
10.0 sec after break　11.0 sec after break

Fig. 2. Debris transport to upper containment

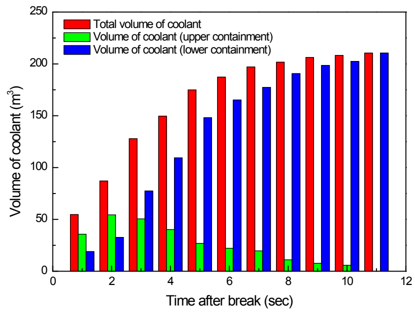


Fig. 3. Volume fraction of coolant in containment

4. Concluding Remarks

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.

REFERENCES

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[3] A. K. Maji, B. Letellier, K. W. Ross, D. V. Rao, L. Bartlein, Experimental Validation of CFD Analysis for Estimating the Transport Fraction of LOCA-Generated Insulation Debris to ECCS Sump Screens, Nuclear Technology, Vol. 146, pp. 279-289, 2004.