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Flow Characteristic Evaluation during LOCA Recirculation Transport based on CFD Analysis for OPR1000 Plant

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1. Introduction

Discharged coolant jets during LOCA affects the structures around break location and generate debris, such as insulations and paint chips. And then, these generated debris moves to the containment floor with coolant flow during LOCA. During LOCA long term cooling, Nuclear power plants(NPPs) supplements coolant form recirculation sump on the containment floor for cooling. Therefore, if debris generated during the accident accumulates on recirculation sump screen by coolant flow, cooling water is not supplied sufficiently for long term cooling. Recirculation sump screen clogging accident happened in BWR in USA and Sweden in 1990. So, US NRC judged PWR under the possibility of the same accident. US NRC started studies on recirculation sump blockage issue, which is GSI-191(Generic Safety Issue-191). According to the analysis results of GSI-191, US NRC published Regulatory Guide 1.82 Rev.3. NEI developed the methodology for recirculation sump blockage analysis in PWR, that is NEI 04-07 which was obtained approval from USNRC through SER(Safety Evaluation Report). NEI 04-07 is composed of the five main subjects, break selection, debris generation, latent debris, debris transport and head loss. Debris transport was estimated using transport logic chart as baseline analysis, and CFD and nodal net work methodology was proposed as refined analysis. However, these results of research were highly dependent on engineering judgments, characteristics of nuclear power plant and accident pattern. Hence additional research reflecting characteristics of nuclear power plant is necessary to apply the strengthened regulation guideline to power plants in Korea. This research assessed the characteristic of coolant flow during OPR1000 plant LOCA recirculation transport by using CFD analysis after examining NEI 04-07. Transport of debris is dominantly influenced on the coolant flow during LOCA, so that this research will make it possible to estimate the rate of debris transport.

2. Methodology and Numerical Models

The object of analysis in this research is UCN 3&4 which is a type of OPR1000 plant. The containment is 144ft in diameter, 219ft in height and 2.717e6 ft^3 in free volume. Figure 1 shows the design drawing of plant containment floor. The structures, such as recirculation sumps, normal sumps and elevator pit etc, undergo influence coolant flow on containment floor are existed. In CFD analysis, these must be reflection of rear form.

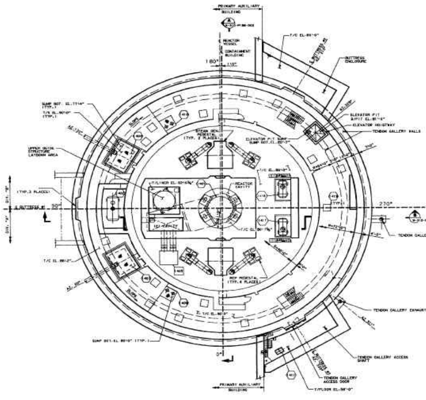

Fig. 1. OPR1000 Plant containment floor

2.1 Methodology

CFD analysis in LOCA recirculation transport was achieved stage by stage as follow:

(1) Break selection
(2) Determination of Initial conditions and boundary conditions
(3) 3D geometry generation
(4) Calculation domain generation and Mesh generation
(5) CFD analysis
(6) Flow characteristic evaluation

Hot leg DEGB(Double Ended Guillotine Break) near the steam generator, the place where the maximum thermal insulating material debris(Nukon) is created during accident, was assumed as break selection(1) according to NEI 04-07. Initial condition and boundary condition(2) for CFD analysis is shown at Table 1. We assumed that during recirculation transport flux(HPSI + LPSI) flowing into containment floor flows to the whole break part. And four recirculation sump suction pipes were assumed as outlet. We drew OPR 1000 plant 3D CAD geometry(3) based on the design drawing(see Figure 2). Recirculation sumps, normal sumps and elevator pit etc. are same form of a real drawing. About 5 million of structured meshes(4) were created after calculating domain from 3D CAD data as shown in Figure 3 .

Table I: Initial & Boundary Condition for CFD Analysis

Initial condition & Boundary condition	OPR1000 plant
Temperature	140 °F
Mass flow rate	6,600 gpm (HPSI+LPSI)
Minimum water level for flooding	3.13 ft

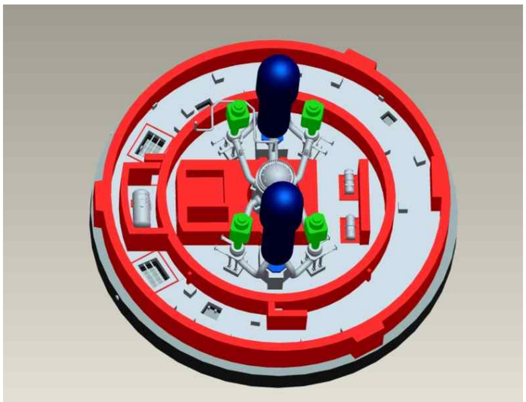

Fig. 2. 3D CAD drawing of OPR-1000 plant containment floor (EL. 86 ft)

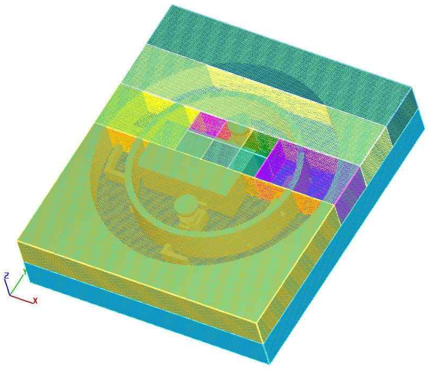

Fig. 3. Calculation domain and mesh generation

2.2 Numerical models

Unsteady state transport analysis was performed concerning coolant flow on the floor of containment during LOCA recirculation mode. Turbulence model used k-ε model, and wall boundary used standard wall function. k-ε model is assumed that the turbulence Reynolds stress and scalar flux are linked to the averaged flow variables in an analogous fashion to their laminar flow counterparts. The transport equations for turbulence kinetic energy of k-ε model are as follows:

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

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

The transport equations for turbulence dissipation rate are as follows:

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

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

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

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

2.3 Analysis Results

Transport analysis result, annulus opening of transport form from break area and Transport in annulus inside of right and left narrow area appears high phenomena.

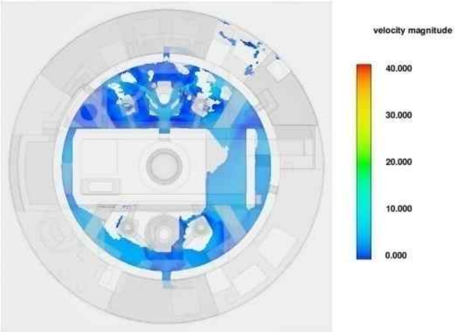

Fig. 4. Flow pattern during LOCA recirculation transport for OPR1000 plant

3. Concluding Remarks

Coolant flow characteristic was understood when LOCA recirculation takes places through this analysis. The result of this research will be utilized for debris flow rate considering characteristics of power plant.

REFERENCES

[1] USNRC, Regulatory Guide 1.82, Revision 3, "Water Sources for Long-term Recirculation Cooling Following a Loss-of-Coolant Accident", Washington D.C., November 2003.

[2] NEI, "Pressurized Water Reactor Sump Performance Evaluation Methodology", NEI0 4-07, May 2004.