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CFD Analysis on Debris Transport to the IRWST for APR1400

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1. Introduction

US NRC studied the effect of recirculation sump blockage in PWR and issued Regulation Guide 1.82 Revision 3 in 2003 [1]. Next year, NEI fully incorporated the NRC position for the sump blockage issue and developed a methodology of recirculation sump blockage analysis through NEI 04-07 [2] approved by USNRC. One of main methodologies in NEI 04-07 is to evaluate the quantification of debris transport by using a transport logic tree with proposing other methods of refined analysis which are CFD and nodal net work. The basic methodology, however, gives a general guideline regardless of characteristics of a particular Nuclear Power Plant (NPP). An augmented regulation guide has strongly argued about a qualified system to maintain the long-term recirculation cooling operation. In order to apply for the regulation guide in a particular NPP, the development of a specific method has been required.

Since the debris transport strongly depends on engineering judgment, characteristics of a NPP and accident scenarios, a quantitative study on fluid dynamic analysis has to be performed. In this study, a new deterministic methodology for the debris transport has been developed based on NEI 04-07 and NUREG reports [3,4]. Applying the transport logic tree in NEI 04-07, this study presented a fraction of debris transport to sump.

2. Methods and Results

APR 1400 consists of 4 recirculation sumps inside an IRWST. In a LOCA, the RCS coolant moves to IRWST through spillways after collecting in Holdup Volume Tank (HVT). Debris generated by a large RCS pipe break is likely to be transported to recirculation sumps via the same path as RCS coolant. This study focused on the fluid dynamic behavior of RCS coolant on the containment floor to HVT. Then it is assumed that all debris collected in HVT is transported to the IRWST via spillways. Thus a final volumetric fraction of debris transport to the IRWST is determined.

2.1 Methodology for Recirculation Transport

In a large break LOCA, the evaluation of debris transport is carried out for following (1) Break location selection, (2) Determination for initial condition & boundary condition, (3) CFD analysis (4) Determination for tumbling velocity according to debris size, (5) Calculation for flow area above tumbling velocities (6) Evaluation for debris transport fraction. In the break selection, 42-inch hot leg double ended guillotine break could be assumed because the hot leg break produces a maximum amount of debris. The inlet boundary of break point was determined to be the same elevation as a minimum flooding level. HVT is modeled as an exit boundary in the CFD analysis. Table 1 shows all initial and boundary conditions of temperature, flow rate, minimum water level, wall condition and free surface condition for the APR 1400 plant. A steady-state CFD analysis was simulated to find a long-term flow velocity field. NUKON insulation material was selected as a type of debris in the study. In accordance with NUREG/CR-6808 and NUREG/CR-6772, tumbling velocities for large and small sizes of debris groups are determined to be 0.30 and 0.12 ft/s, respectively. Thus, a fraction of debris transport was evaluated by obtaining the ratio of the sectional flow area higher than the tumbling velocity to the total flow area.

Table 1: Initial & Boundary Condition for CFD Analysis

Initial condition & Boundary condition	APR1400 plant
Temperature	140 °F
Flow rate	6,600 gpm (SI+CS)
Minimum water level for flooding	8 inch
Wall condition	No-slip
Free surface condition	Slip

2.2 Numerical Simulation

The calculation domain for CFD analysis was selected to be 8-inch volume from the containment floor of EL. 100 ft excluding HVT and IRWST. Inside domain apart from wall boundary, unstructured mesh was generated, where four-layer structured mesh was applied in the wall boundary. For a turbulent simulation, RNG k-epsilon model was used and a standard wall function was applied on wall boundary. SIMPLE algorithm was used to solve the continuity and momentum equations.

2.3 Analysis Results

As a result of CFD analysis, Figures 1 and 2 show velocity profiles at the elevation of 100'-7" for large and small sizes, respectively. The red-colored regions represent the flow area formed above the tumbling velocities, 0.3 ft/s for large size debris and 0.12 ft/s for small size debris. In Table 2, fractions of debris transport for large size are summarized indicating velocity profile areas in each elevation. At the elevation of 100'-7", the maximum fraction, 0.3558, among all elevations was evaluated. In Table 3, fractions of debris transport for small size are summarized indicating velocity profile areas in each elevation. At the same elevation of 100'-7", the maximum fraction, 0.7031, among all elevations was calculated. The maximum fractions were incorporated into the NEI 04-07 transport logic tree for conservatism. The NEI logic tree, however, is adequate to NPP which have sequentially-separated operation modes after a LOCA. All small-sized debris in the upper containment is assumed to be moved down to the lower containment floor in the washdown mode. In the case of APR1400, debris can be directly transported to IRWST in the blowdown mode. Therefore, the NEI logic tree was modified as shown in Figure. 3. Two red-colored lines represent direct blowdown transport stages to sump. The debris transport can occur with blowdown water through the RCS break area. There are two direct blowdown transport modes for small and large debris sizes indicating the same fraction of 0.443 in Fig.3. In the short period of the initial blowdown mode, the fraction of debris transport can be defined as the ratio of an initial full of water in HVT to the total blowdown. It was evaluated to be 0.443. Combining all transport modes, the total transport fraction was calculated to be 0.736.

Table 2: Evaluation for Debris Transport Fraction
(Large size, 0.30 ft/s, 0.0914 m/s)

Elevation	Flow area (m^2)	Excessive area (m^2)	Fraction (%)
100' 1"	1132	364	32.14
100' 3"		375	33.16
100' 5"		388	34.27
100' 7"		403	35.58
100' 8"		398	35.15

Table 3: Evaluation for Debris Transport Fraction
(Small size, 0.12 ft/s, 0.0366 m/s)

Elevation	Flow area (m^2)	Excessive area (m^2)	Fraction (%)
100' 1"	1132	719	63.56
100' 3"		747	65.97
100' 5"		773	68.33
100' 7"		796	70.31
100' 8"		787	69.58

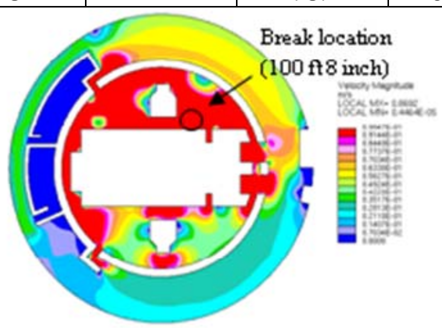

Fig. 1 CFD analysis result for large size debris – 0.30 ft/s, 0.0914 m/s (EL. 100 ft 7 inch)

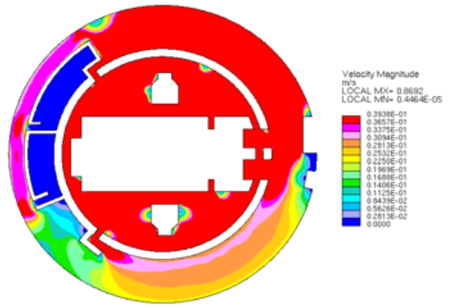

Fig. 2 CFD analysis result for small size debris – 0.12 ft/s, 0.0366 m/s (EL. 100 ft 7 inch)

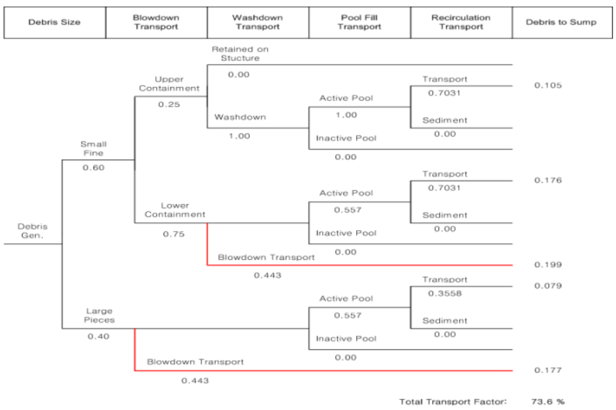

Fig. 3 NUKON transport logic tree for APR1400 plant

3. Conclusions

This study shows a modified transport logic tree reflecting unique features of APR1400's long-term cooling modes after a LOCA compared to a transport logic tree proposed by NEI 04-07. Combining debris transport fractions of two direct blowdown transport mode with other debris transport fractions by CFD analysis, the total transport fraction was evaluated to be 0.736. In conclusion, the developed methodology for APR1400 sump blockage analysis is proposed to calculate NPSH for a long-term cooling performance.

REFERENCES

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