Parametric Effects of Debris Source, Environments, and Design Options on the Overall Performance of ECCS Recirculation Sump

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1. Introduction

A primary safety issue regarding long-term recirculation core cooling following a LOCA (Loss of Coolant Accident) is that LOCA-generated debris may be transported to the recirculation sump screen, resulting in adverse blockage on the sump screen and deterioration of available NPSH (Net Positive Suction Head) of ECCS (Emergency Core Cooling System). USNRC identified this as Generic Safety Issue (GSI) 191 [1] and issued the Generic Letter 04-02 [2] to resolve the issue. The GL required that all PWR owners perform an engineering assessment of their containment recirculation sumps to ensure they will not suffer from excessive blockage. The guidance report (GR) [3] for PWR sump performance evaluation has been developed by NEI (Nuclear Energy Institute) and approved by the USNRC [4].

In Korea, Korea Hydro and Nuclear Power Company (KHNP) is performing the assessment of Kori unit 1 and planning for remaining plants in the near future. The objective of the assessment is to derive required plant modifications including insulation, sump screen, etc. To derive the cost-effective modification items, we have to get insight on the parametric effects of plant conditions and design. Therefore, the general effects of debris source, containment environments and debris interceptor on the performance of ECCS recirculation sump with respect to head loss are parametrically investigated.

2. Methods and Results

2.1 Effects of Debris Sources

The sump screen head loss calculations with various debris loadings on the sump screen are performed using USNRC's NUREG/CR-6224 correlation [5]. The screen area is assumed as 1,000 ft^2 with maximum ECCS flow rate of 7000 gpm. The sump pool temperature and pressure are assumed as 212°F and 14.7 psi, respectively. The debris source and their characteristics are summarized in Table 1. It is assumed that the particulate debris mixture consists of 85% of coatings, 10% CalSil and 5% of latent dust/dirt debris by mass.

Table 1 Debris Source and Characteristics [3, 4]

Debris Type	As-Feb. Density [lbm/ft^3]	Particle Density [lbm/ft^3]	Sv [ft^{-1}]
Fiber	2.4	175	171,700
Coatings	-	94	183,000
CalSil	-	115	600,000
Dirt/Dust	-	169	106,000

The head loss with various loadings of fiber and particulate mixture debris is shown in Fig.1. The head losses by fiber only debris beds are significantly lower than mixed debris beds of fiber and particulate. The head loss appreciably increases with the amount of particulate debris. Head loss drastically increases with the decrease of the amount of fiber debris because the mass ratio of particulate to fiber increases. The debris packing limit is shown in Fig.1, which is closely related to the maximum solidity limit. Above this limit, the particulate is the predominant ingredient and the fiber is embedded in the matrix. Such a condition of the debris bed is physically unacceptable. This situation can arise in the plant with a large particulate debris amount. The amount of particulate debris depends mainly on the amount of the unqualified coatings in the containment because the generation and transport of unqualified coatings are assumed to be 100% in the GR [3].

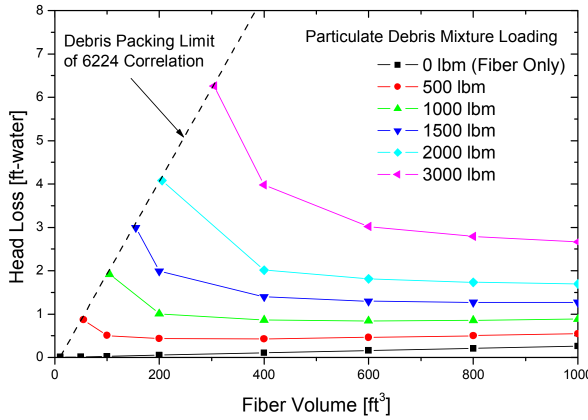

Fig. 1 Head loss with various mixed debris loading on the 1000 ft^2 sump screen (7000 gpm ECCS flow).

2.2 Effects of Containment Environmental Conditions

The materials inside containment may dissolve or corrode when exposed to the reactor coolant and spray solutions. This would produce oxide particulate corrosion products and a potential for formation of precipitates due to chemical reactions with other dissolved materials. These chemical products may become another source of debris loading to be considered in sump screen performance and downstream effects.

The prediction model for head loss by chemical products is currently not available and its effect on the head loss is evaluated only by the screen vendor's performance testing. In the present analysis, the amounts of the potential chemical precipitates in the various containment environments are evaluated using WCAP-16530-NP methodology [6]. The amount of three predominant types of precipitates, i.e., sodium aluminum silicate ($NaAlSi_3O_8$), aluminum oxyhydroxide ($AlOOH$), calcium phosphate ($Ca_3(PO_4)_2$) after 30 days of ECCS mission time are evaluated under various environmental conditions as shown in Table 2. The typical environmental conditions of a Westinghouse two loop nuclear power plant are used as the following input data in the present analysis:

- pH and temperature profiles of sump and containment during 30 days
- The maximum pool volume during the recirculation phase after LBLOCA
- Amount of metallic aluminum (submerged and unsubmerged)
- Amount of E-glass within ZOI (such as NUKON)
- Concrete surface area within ZOI (submerged and unsubmerged).

Table 2 Environmental Conditions in the Present Study

Amount of Cal-Sil insulation [ft^3]	0, 50, 100
Spray Termination Time [sec]	Short: 95,000 Long; 1,000,000
Buffer Agent	NaOH, TSP

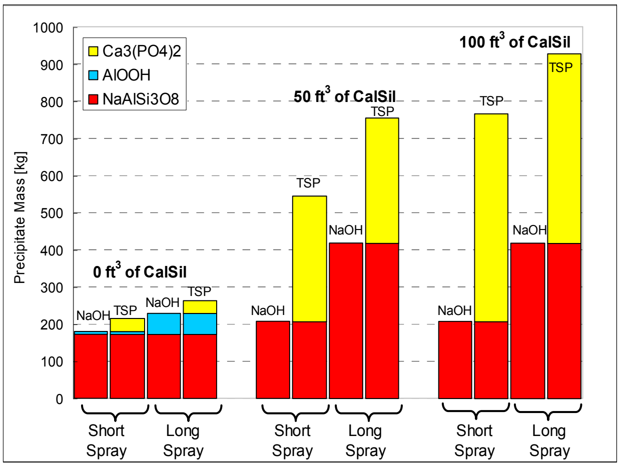

Fig. 2 Comparison of the chemical precipitates with various plant environments.

The presence of Cal-Sil insulation increases the releases of Calcium and Silicate. For plants with sodium hydroxide (NaOH) buffer and long spray termination time, the precipitation of aluminum oxyhydroxide increases compared to that with short spray termination time because spray time increases aluminum release as shown in Fig.2. However, the effect is smaller than that of buffer agent type. The amount of sodium aluminum silicate also increases with spray termination time.

Therefore, both of the presence of Cal-Sil and long spray time could drastically increase the amount of sodium aluminum silicate precipitates. With the presence of Cal-Sil, the precipitation of aluminum oxyhydroxide is negligible because the initial amount of aluminum in the present study is about 10% of other 3-loop or 4-loop plants. The precipitation of sodium aluminum silicate and aluminum oxyhyroxide are competing chemical reactions depending on relative amount of aluminum and silicate.

For plants using trisodium phosphate (TSP), calcium phosphate is generated in addition to sodium aluminum silicate and aluminum oxyhydroxide. When CalSil and TSP co-exist, significant amount of calcium phosphate is generated with increasing amount of Cal-Sil as shown in Fig.2. It has been known that calcium phosphate has a significant impact on the head loss because its characteristics is like a gum.

Therefore, above-mentioned three parameters, i.e., the amount of Cal-Sil, spray termination time, use of TSP as a buffer agent has a big negative effect on the recirculation sump performance. Through the present study, the following recommendations are made:

- Reduce the amount of Cal-Sil insulation
- Replace TSP with alternate buffer agent
- Reduce spray time by operation

2.3 Debris Interceptor

There may be various design options to reduce the head loss across the sump screen such as an active strainer and a specially designed screen surface to prevent the thin bed effects. The adoption of a debris interceptor is another viable option for reducing particulate debris such as unqualified coatings. The detailed effects on the debris transport are dependent on the specific debris interceptor design. For example, if the debris interceptor can reduce the particulate debris from 3,000 lbm to 1,000 lbm, the head loss can be reduced form 3.98 ft to 0.87 ft for 400 ft^3 fiber debris loading as shown in Fig.1.

5. Conclusions

A parametric study is performed on the effects of debris source, containment environments and debris interceptor on the overall performance of ECCS recirculation sump. The key parameters on each effect are deduced and the recommendations for reducing their adverse effects are made through the present analysis. Following conclusions can be made:

- The amount of unqualified coating debris has a great effect on the screen head loss by reducing porosity in the fiber-glass insulation,
- The amount of Cal-Sil insulation with TSP buffer significantly increases the amount of gum-like chemical precipitates,
- Spray time increases the chemical byproducts but the effect is smaller than that of buffer agent type and unqualified coating.
- The debris interceptor, when verified, may play vital role reducing head loss generated by coatings and fiber mix.

The cost of reducing debris sources, removal of Cal-Sil insulation and installation of debris interceptor should be compared with the benefit of reducing number of suction strainers to select design change options for a particular plant. For this, the present parametric analysis method can be used.

REFERENCES

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