Options of Resolving Post-LOCA Recirculation Sump Blockage Issue for Operating PWRs

Jong Woon Park, Byung Hwan Bae, Jae Sung Lee

Korea Hydro & Nuclear Power Co., Ltd., 103-16, Munji-Dong, Yuseong-Gu, Daejeong, 305-380, Parkjw@khnp.co.kr

1. Introduction

Responding to the ECCS (emergency core cooling system) recirculation sump (screen) blockage events of the BWR plants, an USNRC information notice revealed that the amount of debris generated by a loss of coolant accident (LOCA) could be greater and more easily transportable to the sump than assumed in the previous designs to deteriorate the available NPSH (Net Positive Suction Head) of the ECCS under recirculation mode [1].

After the issue resolutions for the BWR plants, the USNRC opened the Generic Safety Issue (GSI) 191 [2] for the PWR plants, and the PWR utility guidance report (GR) [3] has been developed and recently approved by the USNRC [4]. The USNRC issued the Generic Letter 04-02 guiding the PWR utilities and the Korean regulatory body is also developing regulatory positions for the domestic plants regarding the issue.

This paper reviews and summarizes the sump blockage phenomena and the issue resolution options.

2. Sump Blockage Phenomena

The phenomena from the blowdown phase of a LOCA to the potential sump blockage are very complicated phenomena consisting of break-jet, debris generation phenomenon, airborne/Washdown transport, pool transport, debris accumulation, and head loss, and chemical effects [5].

Break-jet phenomenon

Dynamic (shock) forces and erosion caused by steam/water jet impingement from the break on neighboring insulation, coatings, and other structures are dominant mechanisms for LOCA-generated debris. Break-jet phenomenon determines the shape of the Zone of Influence (ZOI) defined as the zone within which the break jet has sufficient energy to generate debris of transportable size and form.

Debris generation phenomenon

Debris, mainly from insulations, is generated from the break-jet dynamic pressure. The amount and type of the debris depend on the location and orientation of the jet, type (such as fiberglass and reflective metal, RMI) and jacket design of the insulations.

Airborne/Washdown transport phenomenon

The transport of debris within the containment down to the containment sump pool is first a result of a high-energy effluent that destroys insulations and transports throughout the containment (airborne transport). The transport is also driven by containment spray water (washdown transport).

Pool transport/Accumulation on the Sump Screen

Debris washed down to the containment floor pool is transported to and accumulated on the sump screen. This transport is influenced by such processes as tumbling, floating, settling and by containment design and accident scenarios. The amount, composition, porosity and uniformity of the debris accumulated on a screen are so uncertain that they are assumed in a manner to maximize the head loss.

Head Loss phenomenon

The accumulation of debris onto a sump screen causes a head (pressure) loss. The head loss across the debris bed depends on the debris bed composition, i.e., its constituents and its morphology.

Chemical phenomenon

The materials inside containment susceptible to chemical reactions with the post-LOCA solution are aluminum, zinc, carbon steel, copper and non-metallic materials such as paints, thermal insulation (e.g., Cal-Sil, fiberglass), and concrete. The studies on these chemical effects are still underway.

3. Resolution Options

There are two options that utilities have in resolving the GSI-191:

Option 1: The first option is to prepare alternative long-term cooling water sources and procedures to prevent and mitigate sump blockage when unacceptable head loss renders the sump inoperable.

Option 2: The second option is to perform deterministic, plant-specific sump performance evaluation considering debris transport, interceptor blockage, and head loss to ensure that long-term recirculation cooling can be accomplished following a LOCA without operator actions.

When the second option stated above is chosen for a particular plant, we need a new sump performance evaluation according to the section C.3 of the revised regulatory guide [6] and subsequent analytical and/or design refinements if and only if additional ECCS NPSH margin is to be sought. The baseline sump performance evaluation consists of following steps [3]:

Selection of the Break Size/Location

To identify the break size and location that result in debris generation to produce the maximum head loss across the sump screen.

Determination of Type/Quantity of Debris Generated

To determine an appropriate spherical zone of influence (ZOI) within which the resultant break jet has sufficient energy to generate debris. This is a two-step process: evaluate an appropriate ZOI and the characteristics of the debris generated.

Estimation of Debris Transport Fraction to the Sump
To estimate the fraction of debris that is transported from debris origin to the sump screen. The four major modes are blowdown transport, washdown transport, pool fill-up transport and recirculation transport. Transport logic charts are generally used on this purpose.

Calculation of the Head Loss
To calculate the head loss from a debris bed using the plant design inputs such the sump screen parameters, thermal-hydraulic conditions of the sump, and the types, total quantities, and characteristics of the debris.

Consideration of Chemical Effects
To evaluate the sump screen head loss consequences from the chemical effect in an integrated manner with other postulated post-LOCA effects.

4. Analytical and Design Refinements

When the sump performance evaluation for a particular plant does not provide a sufficient NPSH margin, next step is to refine the analytical method and/or design for the issue resolution. Following sections review the refinement options.

4.1 Analytical Refinements

The analytical refinements are to incorporate more detailed and realistic evaluations. We have two options: refine the analysis method of debris generation and transport.

Refinement of Debris Generation Analysis
One way is to define debris-specific ZOIs where multiple ZOIs are assigned to each break, each corresponding to the destruction pressure of a particular insulation species to realistically model the insulation. Another way is to apply rigorous three-dimensional direct jet impingement model to determine the jet geometry, not a simple spherical ZOI.

Refinement of Debris Transport Analysis
A nodal network methodology (NNM) and computational fluid dynamics (CFD) can be considered. NNM provides the transport velocities in the channels between large compartments but compares favorably with the CFD, with an error less than 10%. The CFD method more sophisticatedly calculates transport velocities and turbulent parameters but it requires plant-specific experimental verification and is very costly. Also, it has limitations that it can be applied only to the containment floor pool transport and washdown/pool fill-up processes cannot be appropriately modeled.

4.2 Plant Design Refinements

Reduction of Debris Sources
This is to remove problematic (e.g., fiber-glass) insulations and replace them with RMI. Also, reinforcement of existing insulation such as jacketing can reduce the debris source by increasing the destruction pressure. However, this method may need a new testing for destruction pressure and design basis analyses such as seismic analysis, heat load, etc.

Floor Intermediate Obstacles
The introduction of physical barriers on the floor can reduce total debris movement toward the sump. New barriers such as curbs can stop or redirect floor debris to reduce the debris loading on the sump.

Screen Modification
It may be determined that it is desirable to modify existing sump screen design if the previous refinements, are not successful. There are several options: simply passive screens (simply enlarged or innovative), backwash and active systems.

5. Conclusions

The generic Safety Issue 191 regarding the containment recirculation sump blockage after LOCA and the resolution options considered are reviewed. The baseline and nodal network methodologies are mature and reliable but some technical issues still need to be resolved for realistic evaluation of the sump performance: uncertainty of the chemical effects and limitations of the CFD methodology.

REFERENCES

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