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CHEMICAL EFFECTS ON PWR SUMP STRAINER BLOCKAGE AFTER A LOSS-OF-COOLANT ACCIDENT: REVIEW ON U.S. RESEARCH EFFORTS

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Industry- or regulatory-sponsored research activities on the resolution of Generic Safety Issue (GSI)-191 were reviewed, especially on the chemical effects. Potential chemical effects on the head loss across the debris-loaded sump strainer under a post-accident condition were experimentally evidenced by small-scale bench tests, integrated chemical effects test (ICET), and vertical loop head loss tests. Three main chemical precipitates were identified by WCAP-16530-NP: calcium phosphate, aluminum oxyhydroxide, and sodium aluminum silicate. The former two precipitates were also identified as major chemical precipitates by the ICETs. The assumption that all released calcium would form precipitates is reasonable. CalSil insulation needs to be minimized especially in a plant using trisodium phosphate buffer. The assumption that all released aluminum would form precipitates appears highly conservative because ICETs and other studies suggest substantial solubility of aluminum at high temperature and inhibition of aluminum corrosion by silicate or phosphate. The industry-proposed chemical surrogates are quite effective in increasing the head loss across the debris-loaded bed and more effective than the prototypical aluminum hydroxide precipitates generated by in-situ aluminum corrosion. There appears to be some unresolved potential issues related to GSI-191 chemical effects as identified in NUREG/CR-6988. The United States Nuclear Regulatory Commission, however, concluded that the implications of these issues are either not generically significant or are appropriately addressed, although several issues associated with downstream in-vessel effects remain.

KEYWORDS : GSI-191, Sump Strainer, Chemical Effects, Head Loss, Fibrous Debris, Colloidal Particles, Aluminum Solubility

1. INTRODUCTION

The United States Nuclear Regulatory Commission (NRC) established Generic Safety Issue (GSI)-191 to determine whether the transport and accumulation of debris in pressurized water reactor (PWR) containments following a loss-of-coolant accident (LOCA) could impede the operation of PWR emergency core cooling systems (ECCSs) or containment spray systems (CSSs) [1]. In the event of a LOCA, the materials in the vicinity of the break (e.g., thermal insulation, coatings, and concrete) could be damaged and dislodged. The material could then be transported to the recirculation sump and may accumulate on its strainer (or screen). Debris transported to the sump strainer has a tendency to form a bed, which, much like a filter, could increase head loss across the sump strainer. The flow restriction at the sump strainer can threaten the safety margin required to assure the successful operation of ECCS and CSS pumps after the LOCA. In addition, chemical precipitates, which mean solid particles formed by chemical reactions between dissolved chemical species in solution, can form, interact with fibrous debris bed, and aggravate the sump strainer blockage possibly to an extreme condition, i.e., no water flow through the fibrous debris. This phenomenon is called "chemical effects." The formation of the chemical precipitates in the post-LOCA ECCS recirculation water is a reasonable assumption. High concentration of boron is present in the primary water, and containment spray solutions may be injected at high pH values depending on the plant design. The containment spray water can cause the corrosion of metallic components and the release of metallic ions into the post-LOCA cooling water. Even after the cease of the CSSs, submerged surfaces of metallic components, insulations, concrete, coating etc. in the ECCS recirculation water would still be subject to corrosion or chemical reactions over a long period of time (typical mission time is 30 days).

If the sump pump cannot provide enough cooling water to a reactor core because of the strainer blockage, this can lead to a serious consequence like core damage. To help resolve the NRC GSI-191, the NRC issued Generic Letter (GL) 2004-02 outlining schedules for licensees to complete PWR sump performance evaluations and if necessary, sump modifications and procedure changes [2]. The PWR sump performance methodology requires an evaluation of chemical effects, including the potential consequences of chemical precipitates on head loss across the sump strainer, on plant-specific basis. Since then, various industry- or NRC-led researches have been performed in the U.S., specifically on the chemical effects.

The objective of the current article is to review the research efforts in the U.S. to resolve the GSI-191 chemical effects. This review is limited to the PWR sump strainer works. The downstream in-vessel chemical effects are excluded in this review, which are still on-going efforts by plant licensees and NRC. The efforts in the other countries related to the chemical effects on the sump strainer blockage are also excluded (for examples, see references [3-6]).

2. RESEARCH EFFORTS PRIOR TO INTEGRATED CHEMICAL EFFECTS TEST

The NRC initiated a small-scale chemical effects test in response to a concern raised by the Advisory Committee on Reactor Safeguards (ACRS) during its review of staff activities related to the resolution of GSI-191 in February 2003 [7]. Specifically, the NRC ACRS raised the concern that chemically induced corrosion products have the potential to impede ECCS recirculation after a LOCA. Under this study, several small-scale head loss tests were conducted to determine whether debris generation and sump strainer head loss can be affected by chemical interactions between the ECCS recirculation water and exposed metal surfaces [7-8]. The principal conclusions are that it is possible for gelatinous materials, if formed, to transport to PWR sump strainers, and that such materials can increase head loss across a fibrous debris bed. These results lend credibility to the concerns raised by the ACRS. Figure 1 shows the ratio of the measured head loss as a function of metal ion concentration. The head loss with chemical precipitates was normalized by the head loss without chemical precipitates. In the case of aluminum, the head loss with chemical precipitates is almost two orders of magnitude higher than that without chemical effects.

Even though this study showed the significance of chemical effects, the scope of the work was limited; only

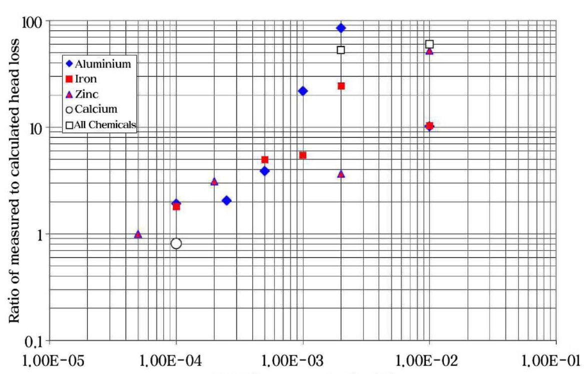

Fig. 1. Ratio of Measured Head Loss with and without Chemical Precipitates as a Function of Metal ion Concentration [7].

sodium hydroxide (NaOH) was used as a pH buffering agent, and metal salts (as nitrate forms) were added to the test loop. Only separate-effects tests were performed for each potential stage of the progression. As a result, the study did not include integrated tests to demonstrate the complete progression of chemical effects from metal corrosion to the ultimate formation of precipitation products. Three NRC-sponsored research activities described in the following sections are follow-on studies to implement the findings in this study.

3. INTEGRATED CHEMICAL EFFECTS TEST (ICET)

The Integrated Chemical Effects Test (ICET) project was a joint effort by the NRC and the nuclear power industry [9-10]. The ICET attempted to simulate the chemical environment in a containment water pool after a LOCA and monitored the chemical system for 30 days to identify the presence, composition, and physical characteristics of chemical products that formed during the tests. The primary objectives were to determine, characterize, and quantify chemical-reaction products that may develop in the containment sump under a representative post-LOCA environment, and identify and quantify any chemical precipitates that might be produced during the post-LOCA recirculation phase [9]. No measurements of head loss were made in the tests. The head loss testing conducted by Argonne National Laboratory (ANL) is discussed in a later section of this article.

3.1 Test Conditions

All of the ICETs were conducted in an environment that attempted to simulate containment pool conditions during recirculation. The tests included an initial 4-hr spray phase to simulate containment spray interaction with the non-submerged materials. The materials present in this environment included representative amounts of submerged and non-submerged aluminum, copper, concrete, zinc, carbon steel, and insulation samples. Representative amounts of concrete dust and latent debris (dirt) were also added. Insulation samples consisted of NUKON fiberglass and calcium silicate (CalSil). Water was circulated through the bottom portion of the test chamber during the entire test to achieve representative flow rates over the submerged specimens. The amounts of material in the test were scaled to the liquid volumes of the test chamber and the containment sump volume. Detailed plant survey information was available after testing, and indicated the amount of insulation (e.g., CalSil) in these tests may have been too high to be representative.

The physical and chemical parameters that defined the tank environment are summarized in Table 1. The pH of the initial test solution was different for each test because three different pH control agents were used: NaOH, trisodium phosphate (TSP), and sodium tetraborate (STB). The