August 25, 2005

MEMORANDUM TO: John N. Hannon, Chief
Plant Systems Branch
Division of Systems Safety and Analysis

FROM: David L. Solorio, Chief /***RA***/
Balance of Plant Systems Section
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SUBJECT: TRIP REPORT REGARDING STAFF OBSERVATIONS OF TESTING PERFORMED ON DIABLO CANYON PLANT-SPECIFIC SUMP STRAINER DESIGN

On July 28, 2005, the NRC staff traveled to Chicago, Illinois to observe testing of a suction strainer design specific to Diablo Canyon Power Plant (DCPP) at the test facility operated Alion, Inc. Participating staff included Ralph Architzel, John Lehning, and Section Chief David Solorio of NRR/DSSA/SPLB.

In summary, the staff observed debris accumulation and head loss testing on a segment of the DCPP suction strainer design in a large test flume. The debris mixture used for the testing was intended to represent the plant condition following the removal of the calcium silicate insulation currently covering the steam generators, which is planned for 2008-9. Halfway through the addition of the debris into the test flume, a thin bed of approximately 1/8 inch in thickness had formed upon the suction strainer, resulting in a head loss that approached the design constraints of the flume. Therefore, the test was terminated prematurely. Subsequently, experiments were also performed to determine the effects of (1) stopping and subsequently restarting flow through the strainer and (2) stopping and subsequently restarting flow through the strainer with backflushing. As described subsequently in further detail, the backflushing procedure appeared to be effective. The staff also observed an unrelated informal experiment regarding the erosion of calcium silicate insulation. Finally, a DCPP representative discussed with the staff a possible phenomenon whereby cavitation-induced flow erosion could create a downstream effects concern within the emergency core cooling system (ECCS). Further details concerning the staff's observations are provided below.

The primary purpose of the staff's visit was to observe debris accumulation and head loss testing on a full-scale test segment representative of the DCPP suction strainer design (representing 1/12 of the total suction strainer area) that was placed into the test flume. To increase the available flow area, the strainer design employs a box-like structure of folded plates with 1/8-inch diameter flow holes.

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To accurately model the water level predicted by the DCPP accident analysis, the suction strainer was mostly, yet not completely, submerged. Structures simulating the DCPP debris curb and trash rack were also placed in the flume, in an attempt to model actual flow conditions along the approach to the strainer surface. The test flume flow velocity at the strainer surface was calculated to be approximately 0.02 feet per second (ft/s) and approximately 0.06 ft/s through the trash rack. The flow conditions for this test were intended to simulate an actual flow rate of approximately 3000 gallons per minute (gpm), which is the assumed flow rate approximately 10 minutes after the switchover to sump recirculation, once operators have throttled the low-pressure safety injection pumps. The test observed by the staff did not explicitly account for the larger flow rates (approximately 7000 gpm) that are assumed to be present immediately following the switchover to recirculation. The stated reason for not considering this larger flow rate was that, based upon the licensee's procedures, the throttled flow of 3000 gpm would realistically be expected. The reduced flow rate is apparently not assumed in the safety analysis immediately after switchover to avoid crediting an operator response (i.e., flow throttling) within the first 30 minutes following a transient.

Once the flume had been filled and representative flow conditions established, a plant-specific debris mixture was added. The composition chosen for the debris mixture was based on the expected condition of the plant once existing calcium silicate insulation on the steam generators is replaced (currently planned for 2008-9). The staff did not assess in detail whether the surrogate debris mixture used for the observed test conservatively represents the head loss and transport characteristics of actual debris mixtures that could potentially occur during an accident.

The debris mixture was added to the test flume in batches that the staff observed to have been thoroughly mixed together in a bucket prior to their addition. Turbulence was intentionally created by the test technician in the process of gradually adding each batch of debris into the flume. This turbulence was created to facilitate the formation of a thin debris bed, and the licensee considered it a conservatism, since such turbulence would not be expected in the vicinity of the sump under actual accident conditions. Each batch was sized such that it would create a 1/8-inch-thick thin bed, presuming that the entire batch were to accumulate uniformly upon the suction strainer. The test had originally planned for the addition of 8 batches of debris; however, due to head loss constraints inherent in the test flume design, debris addition was terminated after 4 batches were inserted. The specific constituents of the debris mixture used for the observed test are listed in the table below.

Debris Type	Amount Per Batch (lbm)	Total Mass Added (lbm)
Calcium Silicate	0.375	1.50
Marinite	0.429	1.72
Nukon	0.6375	2.55
Inorganic Zinc	4.356	17.4
Total	5.80	23.2

The staff did not record specific sizes or other characteristics of the debris used in the observed test; however, the debris generally seemed to have been prepared in an appropriate manner that created relatively fine fragments. The staff further observed that, prior to being mixed with the other debris sources, the Nukon fibrous insulation had been boiled to remove the binder material and thoroughly soak the insulation with water to minimize floating.

Each batch of debris was introduced to the test flume roughly 6 feet upstream of the suction strainer. Sufficient time was allowed between the addition of successive batches of debris to allow the water in the flume to make an average of 5 passes through the suction strainer. The rationale for circulating the flume water through the suction strainer 5 times was to allow debris particles ample opportunity to be intercepted by the strainer. To provide an idea of the test scaling, the staff understood that, at DCPP, a containment pool volume is cycled through the suction strainer in roughly one hour.

After the first batch of debris had circulated 5 times, the water in the flume remained rather opaque. However, as successive debris batches were added, additional debris accumulated on the suction strainer surface, increasing the filtration efficiency. As a consequence, by the end of the test, the water in the flume appeared quite clear. The staff observed that measurements of turbidity were taken regularly throughout the test.

The staff observed that the test conditions resulted in the formation of a thin debris bed. Although a measurement was not performed, the bed thickness following the addition of 4 batches of debris was estimated as being roughly 1/8 inch. The staff observed, however, that the thin bed was not completely uniform, in that, sporadically, hydraulic forces would poke holes in the thin bed and proceed to push water through these open holes. Following the addition of the fourth batch of debris, a head loss exceeding 16 inches was experienced. At this point, the debris addition was terminated prematurely due to the head loss constraint of the flume being approached.

The staff noted that the debris curb appeared to have been effective in interdicting a significant fraction of the added debris. The precise amount of debris was not quantified during the staff's observation. As expected from the small size of the debris fragments, the trash rack remained essentially clear of debris during the test.

Subsequently, a measurement of head loss was made at reduced flow. The flume flow rate was reduced to simulate a flow of approximately 2200 gpm, which could occur with a single train of ECCS operating. Under this condition, the head loss was reduced by approximately 4 inches to roughly 12-13 inches.

Following this flow reduction experiment, the pump driving the flow through the flume was secured and a valve was closed to prevent backflow through the suction strainer. The pump was kept secured until the upstream and downstream flume levels equilibrated (approximately 30 seconds to 2 minutes). The valve was then re-opened and the pump restarted. The staff observed that the debris bed essentially remained intact throughout this transient, and that the previously observed head loss returned once steady flow was reestablished.

Subsequently, from a steady flow condition, flow was again terminated by stopping the pump. However, for this experiment a valve remained open to allow an apparently small (but unquantified) backflow through the pump and the suction strainer. The backflow through the

suction strainer appeared effective in returning a significant fraction of the suction strainer surface to an essentially clean condition. However, simultaneously with the backflushing action, a considerable amount of turbulence was introduced as a result of the uncovering of a pipe returning water to the upstream section of the flume. As this turbulent condition was not present during the previous experiment, which involved pump stoppage without backflow, it was not clear to the staff how much the artificially induced turbulence contributed to the clearing of a large fraction of the debris bed. Subsequently, normal pumped flow was resumed through the flume. Essentially no head loss was experienced, due to the availability of a large fraction of open area on the strainer surface. Although the flume water was circulated through the suction strainer several times and a very thin coating of debris eventually formed on the cleaned area of the strainer, the head loss remained essentially zero.

The staff also observed an informal experiment unrelated to the DCPP suction strainer testing. This test was performed in a small-scale vertical head loss test loop and concerned the erosion of calcium silicate. Several large pieces of calcium silicate were placed into the test loop, and exposed to cascading flows of water at a temperature of approximately 90 EF. The water fell upon the calcium silicate from a height of approximately 6 feet and with a flow velocity of approximately 0.34 ft/s. After a period of roughly an hour, the staff observed that the pieces appeared noticeably smaller and had well-rounded edges. Measurements showed that approximately 70 percent of the calcium silicate insulation had remained in large pieces. As is clear from the test conditions specified above, the experiment was not intended to be representative of the erosion conditions in a quiescent containment pool. Rather, the experiment may more closely simulate a situation where calcium silicate insulation is trapped in a location that is continuously exposed to break flow. In the future, other tests may be performed formally under controlled and qualified conditions to estimate erosion rates that may occur in a quiescent pool.

Following the tests, the licensee explained how the design of the ECCS at DCPP accounts for the phenomenon of cavitation-induced flow erosion through uniquely designed flow orifices. The licensee stated that plant-specific testing had been performed to show that the DCPP orifice design was effective at mitigating the effects of cavitation-induced flow erosion over the ECCS mission time through the use of opposing flows across the pressure drop. The licensee further stated that other plant-specific tests had shown that certain orifice and throttle valve designs that were not properly engineered with respect to cavitation had experienced significant material degradation following exposure to cavitating flow over the course of several weeks. The NRC staff understands that many licensees are planning to use a report produced by the Westinghouse Owners Group (WOG), WCAP-16406-P, entitled “Evaluation of Downstream Sump Debris Effects in Support of GSI-191,” to evaluate ECCS downstream effects such as material erosion. The staff has obtained a proprietary copy of this report and plans to offer comments either to the WOG or to individual licensees that may reference this report if the staff determines that the report does not provide adequate guidance concerning the potential for material degradation due to cavitating flows.

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