April 17, 2006

MEMORANDUM TO: Jared S. Wermiel, Deputy Director
Division of Safety Systems

FROM: Michael L. Scott, Chief **/RA/**
Safety Issues Resolution Branch
Division of Safety Systems

SUBJECT: STAFF OBSERVATIONS OF PLANT-SPECIFIC TESTING FOR GENERIC SAFETY ISSUE 191 DURING FEBRUARY 26, 2006, TRIP TO THE ALION HYDRAULICS LABORATORY

On February 24, 2006, the NRC staff traveled to the Alion Hydraulics Laboratory in Warrenville, Illinois, to observe plant-specific testing associated with the resolution of Generic Safety Issue 191 (GSI-191). The primary objective of the trip was to observe large-tank testing of a modular strainer array simulating the double top-hat replacement suction strainer design for Indian Point Unit 2. However, the staff also fulfilled a number of secondary objectives enumerated in the list below. The participating NRC staff member was John Lehning of NRR/DSS/SSIB. The staff interacted with licensee personnel and vendor personnel from Enercon Services and Alion Science and Technology.

In summary, the staff's observations and activities regarding the Indian Point strainer design and associated testing included the following:

- Discussion of the sump configuration
- Discussion of the double top-hat strainer module design
- A tour of the Alion Hydraulics Laboratory facilities
- Observation of a large-tank test intended to address the possibility of thin-bed formation
- Discussion of an earlier large-tank test intended to fill the interstitial areas of the strainer with debris
- Observation of the patented downstream filters used to interdict fibrous debris that passes through the strainer
- Discussion of planned flow channeling modifications for containment pool
- Discussion of recently completed calcium silicate dissolution testing

In addition to the staff's observations regarding Indian Point, the staff also held discussions and made observations concerning the planning and setup for a separate set of erosion tests to be performed for the Diablo Canyon Power Plant.

The trip report below provides additional detail regarding the staff's observations and activities.

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Indian Point Unit 2 Sump Configuration

Indian Point Unit 2 (IP2) is equipped with two sumps, the internal recirculation (IR) sump and the vapor containment (VC) sump. The IR sump supplies suction to two 100%-capacity IR pumps, which provide the preferred means of cooling during the recirculation phase of an accident. The VC sump provides an independent back-up capability. The VC sump supplies suction to two 100%-capacity residual heat removal pumps that are located outside containment. The VC sump is not placed into service unless the IR system is unavailable.

Double Top-Hat Strainer Module Design

The IP2 replacement strainer design employs double top-hat modules, as opposed to other plants' single top-hat designs that had been previously observed by the staff. The diagram below provides the basic concept of this strainer module design (note that the connection to the suction plenum is not pictured).

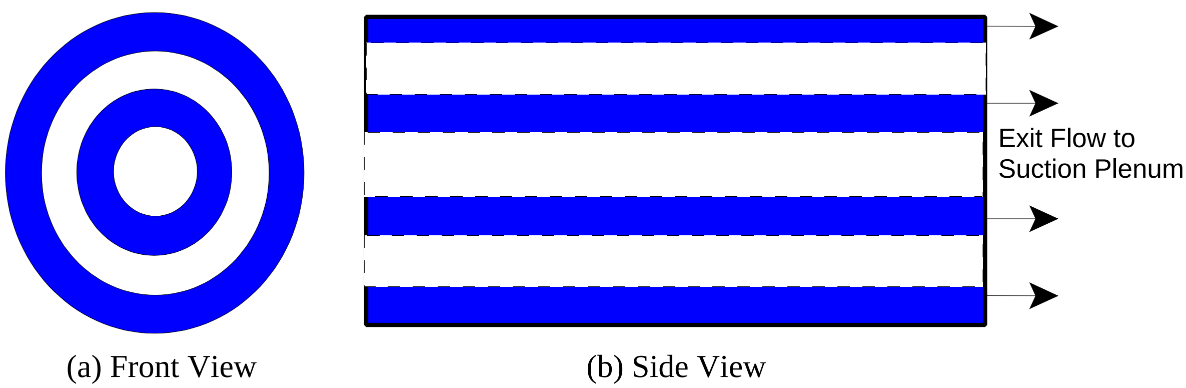

Figure 1: Double Top-Hat Strainer Module (not to scale)

On the front view, the shaded annular areas represent solid metal plate surface, and the white annular areas represent the interstitial volumes of the strainer. On the side view, the darker rectangular areas represent perforated plate surface, and the lighter rectangular areas represent internal interstitial volumes. Perforated strainer area exists on the outer cylindrical surface of the top hat module, as well as on the three inner cylindrical surfaces. Each double top-hat strainer module can accommodate two downstream filters, one inside each annular internal volume (i.e., inside the volumes represented by the dark shaded areas in the above diagram). Vendor personnel indicated that the IP2 strainer perforations will be 3/32 inch.

Vendor personnel informed the staff that a variety of aspects are considered in designing a strainer. An important consideration in determining whether a design should incorporate single top hats or double top hats is the desired ratio of total strainer surface area to strainer interstitial volume.

Facility Tour

The Alion laboratory has several hydraulic test apparatuses, including (1) a large tank for performing integral head loss testing of modular strainer arrays or strainer prototypes, (2) a small-scale vertical head loss test loop, (3) a small-scale multi-function test loop that is capable of being heated and operated with chemical solutions, and (4) a small-scale transport flume. The test apparatuses are somewhat flexible in function. The staff learned, for example, that debris erosion testing could be performed in the small-scale vertical loop and that qualification testing of the downstream filters could be conducted in the small-scale transport flume.

As described in detail subsequently, the staff's observations during the trip generally focused upon the integral testing of a strainer array conducted in the large-tank apparatus. However, the staff was also shown an informal flow test of a single strainer module in the small transport flume. The purpose of the test was to allow the staff to qualitatively observe the tendency for increased suction to occur at the base of the top-hat strainer module (which was nearest to the suction line) relative to its top (which was farthest from the suction line). The staff observed a pronounced variation in the suction force along the lengthwise axis of the top-hat strainer module, which appeared to provide an explanation for the subsequently described tendency of the top-hat strainers to load non-uniformly in the axial direction (i.e., with increased debris accumulation at the base of the strainer module).

<u>Large Tank Thin-Bed Testing</u>

The primary purpose of the staff's trip was to observe the integral testing of a 3×3 array of horizontally oriented, full-size double top-hat strainer modules in the large test tank. The test array was intended to simulate the IR sump. The modular array was housed in a chamber constructed of sheets of plexiglass. The purpose of the plexiglass chamber was to simulate the presence of a sump pit and/or other nearby strainer modules. The staff noted that the chamber did not appear to present a barrier to debris reaching the strainers due to the turbulence that was intentionally maintained in the test tank. On one side of the tank, the discharge pipe maintained sufficient turbulence to prevent debris settling; on the other side, a motorized stirring device served a similar function. A small "dead" area existed near the front of the tank, where small accumulations of debris were noted during the observed test. However, these accumulations were periodically resuspended by manual stirring.

Before the test, vendor personnel added a handful of fibrous test debris to the tank to demonstrate the flow pattern prior to the tank's becoming opaque due to the addition of suspended particulate debris. For approximately 15 minutes, the fibrous debris was allowed to circulate through the tank. During this time, the staff observed that the preparation of the fibrous debris had generated relatively small, transportable fragments. The staff also observed fibrous fragments entering the plexiglass chamber and accumulating upon the strainer surfaces. The effectiveness of the test setup in preventing debris settling was noted.

Following this demonstration, all of the particulate debris was added to the test tank. The particulate debris included calcium silicate, ground silica (a surrogate for inorganic zinc and non-inorganic zinc coatings debris), and a blend of silicate sand (a surrogate for latent dirt and dust). Upon the addition of this debris, the tank water assumed a milky color, which prevented further visual observation for the duration of the test. The test debris appeared to be well prepared into sufficiently small fines.

Along with the particulate debris described above, the first debris batch included an amount of fibrous debris that was calculated as providing a 1/8-inch equivalent uniform bed thickness. Once the debris was added to the test tank, the test was run for approximately 1 hour to satisfy applicable criteria in the test procedure (less than a 1% increase in head loss in a 10-minute period and at least 5 pool turnovers). The head loss remained steady at a very low value throughout this period, which was indicative that a uniform thin-bed accumulation had not formed. The staff did not examine in detail the acceptability of the test termination criteria.

Five additional batches consisting only of fibrous debris were subsequently added to the tank at intervals spaced in accordance with the above procedural criteria (i.e., approximately 1 hour intervals). The amount of fibrous debris in three of the batches was equivalent to a 1/8-inch uniform bed thickness; the amount in the other two batches was equivalent to a 1/4-inch uniform bed. All of the fibrous debris was simulated using Nukon low-density fiberglass insulation. From the IP2 Generic Letter 2004-02 response, the staff noted that high-density fiberglass was also present in the containment. The acceptability of this substitution was not investigated during the staff's trip.

After each batch of fiber was added to the test tank, the head loss gradually increased prior to eventually reaching a quasi-stable value (i.e., not increasing more than 1% in 10 minutes). A sharp head loss peak was not observed, as would have been expected for a uniform thin-bed accumulation of debris on a flat plate strainer. At the conclusion of the test, sufficient fibrous debris had been added to have created a uniform bed with a theoretical thickness of 1 inch. The measured head loss at the test's conclusion was approximately 0.42 foot, which was essentially the maximum value achieved during the test. The test was conducted in tap water at approximately 57 °F. Vendor personnel indicated that the head loss versus time data from the observed test was similar to an earlier thin-bed test performed under equivalent conditions.

Once the recirculation pump had been secured, the staff observed that a significant portion of the debris bed on the upper surfaces of the strainer was forcibly dislodged by the release of trapped gas. This gas had apparently come out of solution with the tank water after passing through the strainer debris bed, and been held inside the strainer by the flow of water through the strainer surface.

After the test tank was drained, the staff observed that a substantially non-uniform debris loading had occurred. The double top-hat modules nearest the suction pipe were nearly engulfed with debris, whereas those farthest from the suction pipe were significantly less obstructed. The staff observed that minimal residual debris was found to have settled onto the tank floor after the tank was drained.

A post-test examination of the double top-hat modules showed that debris accumulation had occurred upon all of the perforated strainer surfaces. The interstitial areas of the strainer modules nearest the suction pipe appeared to be completely filled with debris. As debris was scraped away from the strainer modules following the test, it seemed that some degree of stratification had occurred in the debris bed. In particular, based upon visual observation, a higher particulate-to-fiber mass ratio appeared to have been achieved near the surface of the strainer as opposed to the outer layers of the debris bed. This observation may have been the result of the timing of debris addition specified in the test procedure; however, such an explanation may not be convincing in itself, since a significant quantity of fine particulate debris remained suspended in the tank volume throughout the test. The staff speculated that another explanation for the observed stratification could be the apparent variation in porosity along the thickness of the debris bed. The outer layers of the fibrous debris bed may have been sufficiently porous to allow a significant fraction of the fine suspended particulate to pass through. The inner layer of the debris bed, in contrast, appeared significantly less porous, and may have been more effective at trapping fine particulate. However, the staff notes that this observation may have been an anomaly and, in any case, a definitive explanation was lacking.

Downstream filters had been installed in the strainer module internal volumes during the observed test to simulate the planned installation of these filters inside the IP2 replacement strainer modules. One of the double top-hat modules was removed from the test tank after drain down was completed to allow the extraction and examination of the filters. A post-test examination showed a mixture of fine fibrous and particulate debris on the filters' outer surfaces (as with the top-hat modules, the loading on the filters tended to be biased toward the bottom, nearest the suction pipe). The filters appeared to be clean at the point of exit from the top-hat module. Another indication of the downstream filters' effectiveness at interdicting fibers was the observation of a high-purity (i.e., apparently fiber-free) silt of particulate debris that was deposited at a low-flow area near the exit of the top-hat module.

Large Tank Interstitial Volume Test

The interstitial volume test, intended to simulate the VC sump, was conducted prior to the staff's trip. However, this test was discussed in the test plan provided to the staff, and photographs and results from this test were shared with the staff.

The purpose of this test was to examine the strainer performance limit opposite to that of the thin-bed test observed by the staff: namely, engulfing the strainer with debris in an attempt to completely fill the interstitial volumes of the strainer. Once a complex strainer's interstitial volumes have been filled, it may tend to lose the advantage of its complex geometry, transitioning to a circumscribed debris accumulation pattern. This phenomenon was apparently observed during the VC strainer test, the resultant head loss for which was substantially higher than the IR sump thin-bed test.

The staff understood that completely filling the strainer interstitial volumes with debris is possible for the VC sump replacement strainer (with a surface area of 1,200 ft^2), but not for the IR sump replacement strainer (with a surface area of 3,200 ft^2).

Downstream Filter Testing and Observations

As already noted, downstream filters were installed in the double top-hat strainers used for the thin-bed test observed by the staff. In addition to the qualitative observations made above, vendor personnel stated that previous results have indicated that approximately 8% bypass of fibrous debris may occur without the filters in place. With the filters, the fibrous debris bypass fraction was stated as having been reduced to approximately 0.5%. Vendor personnel further discussed criteria for estimating fibrous debris bypass, indicating that the most reasonable approach may be to consider the ratio of the volume of transported fibrous debris to the total screen surface area (as opposed to, for example, a flat concentration or filtration efficiency). The approach discussed by the vendor would account for the phenomenon of the "first wave" of fibrous debris being more likely to pass through the screen (being at that time essentially clean), whereas, once a certain volume of fiber has approached the screen, few additional fibers will be likely to pass through, since a fibrous bed with a high filtration efficiency will almost certainly have formed.

Vendor personnel indicated that formal testing of the downstream filters would soon be conducted in the small transport flume. Filter banks had been added to the test setup to quantify the downstream filters' performance.

Flow-Channeling Transport Modification

In the licensee's response to Generic Letter 2004-02, the staff noted that extensive activities had been considered to channel containment recirculation flows through the reactor cavity/ in-core tunnel area. The staff requested that the licensee discuss the status of these activities.

The licensee described the unique flow channeling modifications that were planned to increase the opportunity for small and large pieces of debris to settle in the reactor cavity/in-core tunnel area, where the flow has a relatively low velocity and is without significant turbulence. The debris interceptors/obstructions used to channel the containment flow were described, and diagrams of the containment floor elevation were presented to facilitate discussion. Computational fluid dynamics (CFD) had been used to validate the licensee's understanding of the flow pattern created by the flow channeling modifications.

Calcium Silicate Dissolution Testing

During a public meeting on February 9, 2006, the licensee had referred to plant-specific calcium silicate testing that had indicated essentially no dissolution or precipitate formation. Although procedural differences were apparent, these results appeared somewhat contrary to the staff's expectations based upon NRC-sponsored chemical effects testing. The staff requested further details regarding this testing.

The licensee stated that a test report had not been completed and details were not readily available. However, the staff was informed that the calcium silicate tested was actual plant material that contained asbestos and radioactive contamination. As such, the test had been conducted in a specialized laboratory facility. During the February 9^{th} public meeting, the licensee had also stated that the calcium silicate insulation at Indian Point was "compacted."

The calcium silicate insulation was prepared for testing by being separated into cubes of approximately 1 inch in size. Tests were performed for several hours in three environments: (1) hot (roughly 200 °F) borated water with sodium triphosphate (TSP), (2) pure hot water, and (3) pure cold water. Although formal results were not available, the conclusion was reiterated that minimal dissolution had occurred and no precipitate formation had been identified.

Diablo Canyon Erosion Testing

In addition to the above testing and analysis regarding IP2, the staff also observed preparations for a series of erosion tests planned for the Diablo Canyon Power Plant (DCPP).

Prior to the trip, the staff held a phone call with the DCPP licensee to discuss the test purpose and plan. The licensee noted that the Nuclear Energy Institute sump evaluation methodology adopted a highly conservative position (i.e., 100% destruction into small fines) with respect to unjacketed debris sources in containment outside the zone of influence of the pipe break. Through erosion testing, the licensee intended to obtain data to support a more realistic treatment of materials used for fire barriers, including Marinite and Kaowool. The licensee also stated that erosion testing would be performed for Temp-Mat and Cerablanket high-density fiberglass insulation materials.

At the test facility, the staff observed vendor modifications to the small-scale vertical loop to accommodate the testing of the debris source coupons provided by the licensee. During the staff's visit, a shipment of samples arrived, and the staff viewed them. The coupon samples were approximately 2-inch squares of material wrapped in a loose wire mesh. In addition to the coupon samples, a realistic mock-up of a cable tray 2 to 3 feet in length was also shipped to the laboratory. The staff noted that the mock-up included cables, structural material, fire barrier, and damming. As the test plan had not been finalized, it was not clear whether and how erosion testing of the mock-up would be conducted.

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