March 23, 2007

MEMORANDUM TO: Jared S. Wermiel, Deputy Director
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: Michael L. Scott, Chief ***/RA/***
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SUBJECT: STAFF OBSERVATIONS OF DIABLO CANYON POWER PLANT STRAINER TESTING FOR GENERIC SAFETY ISSUE 191 DURING DECEMBER 14–15, 2006, TRIP TO CONTINUUM DYNAMICS, INC.

On December 14–15, 2006, the NRC staff traveled to the Continuum Dynamics, Inc. (CDI), test facility in Ewing, NJ, to observe containment sump strainer testing for the Diablo Canyon Power Plant (DCPP) associated with the resolution of Generic Safety Issue 191 (GSI-191). The participating NRC staff members were John Lehning of NRR/DSS/SSIB and Paul Klein of NRR/DCI/CSGB.

The primary objective of the trip was for the staff to observe head loss testing performed on a rear strainer sector. As described further in the following trip report, a sector represents one interstitial segment of the DCPP replacement strainer design. The debris loading used in the observed test assumed an alternate break size of 14 inches and included surrogate chemical precipitates. In addition to observing the head loss test of the rear strainer sector, the staff was also given a brief tour of the CDI facilities and briefly discussed other activities performed by the DCPP licensee to resolve GSI-191.

The following trip report provides additional detail regarding the staff's observations during the trip.

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Diablo Canyon Power Plant Replacement Strainer Configuration

The Diablo Canyon Power Plant (DCPP) licensee plans to install a replacement strainer designed by General Electric (GE). The strainer will be composed of a series of front modules connected by a suction plenum on one of their side faces and a series of rear modules connected by a suction plenum along their bottom faces. In this design, each of the front and rear strainer modules is basically composed of an array of flat, perforated plates.

Overall Test Program

The licensee has contracted with GE to complete a series of tests at the Continuum Dynamics, Inc. (CDI), facilities, including front and rear sector head loss tests, fiber bypass tests, fuel head loss tests, and rear module tests. Most of the tests are to be performed with the alternate break debris loading; however, several tests are to be performed with the projected debris loading following the steam generator replacement project, and one of the module tests is to be performed with the current baseline debris loading. A number of the sector tests in the licensee's test plan are intended to ensure acceptable test repeatibility.

Following insulation changes to be performed in conjunction with steam generator replacement modifications scheduled for 2008–2009, licensee representatives stated that the baseline plant debris loading will become comparable to the current alternate break debris loading. Licensee representatives stated that it was not clear whether the head loss resulting from existing baseline debris loading would be less than the acceptable debris bed head loss criterion. In any case, at the conclusion of the current baseline debris loading rear module test, the licensee stated that an experiment with backflushing the strainer would be conducted to simulate a potential piping alignment through the containment spray system that can provide reverse flow through the strainers. If successful, backflushing may be considered as an option for the licensee to address the current baseline large-break loss-of-coolant accident (LOCA) debris loading.

Rear Strainer Sector Design

The design of the rear sector test strainer was based upon the configuration of the perforated plates intended for the actual plant replacement strainer. A test sector is composed of two "half" plates (plates with the inner surface perforated and the outer surfaces solid) and a sufficient length of suction plenum to represent a single interstitial volume of the replacement strainer. A simplified schematic diagram of the rear test sector is provided below as Figure 1.

In this simplified figure, the two upright rectangles represent flat plates extending out of a suction plenum, which is represented by the parallelogram beneath them. The solid surfaces in the figure represent solid strainer surfaces, and the cross-hatched area in the figure represents the part of the flat plates that is perforated.

The front strainer sector design is conceptually similar to the rear sector design, but the suction plenum is located to one side of the flat plates rather than beneath them.

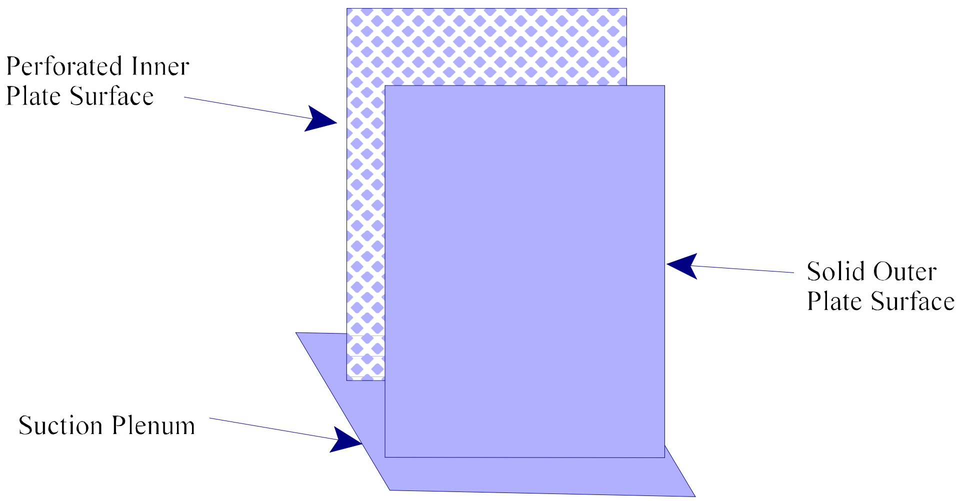

Figure 1: Schematic Diagram of Rear Strainer Test Sector

Test Observations

The debris preparation procedure was completed prior to the staff's arrival at the test site. However, while the test was running, the licensee showed the staff the debris that was being used for the test program. Among this test debris, the staff observed shredded Nukon, pulverized Marinite board, shredded rock wool, shredded Kaowool, pulverized calcium silicate, silica particulate, a mixture of sand/silica particulate, and paint chips.

The staff observed the addition of debris to the test tank. The non-chemical test debris was added to the tank first, with the test pump running and four stirrers operating to prevent debris settling. The turbulence induced by the stirrers was so strong that even the paint chips in the tank were unable to settle permanently. The staff observed that flurries of paint chips were continuously being driven back into suspension by the stirrers after temporarily coming to rest on the tank floor. The staff noted that the temperature of the test fluid was approximately 88°F.

Following the addition of the non-chemical debris, the measured steady-state head loss did not increase above the clean strainer value. After the test was run for a sufficient time to meet criteria in the test procedure, the vendor commenced addition of the surrogate chemical debris. The surrogate chemical debris was a mixture of sodium aluminum silicate and aluminum oxyhydroxide prepared using the protocol in WCAP-16530-NP, "Evaluation of Post Accident Chemical Effects in Containment Sump Fluids to Support GSI-191." After the chemical surrogate debris was added, the head loss remained close to the clean strainer value until the test termination criteria were met and the test was ended. At the end of the test, the staff noted that the measured pH of the test fluid had decreased slightly from its value prior to the addition of the surrogate chemical debris (i.e., from 7.6 to 7.2).

Following the test, the opaque test fluid was slowly drained from the tank, and the test strainer could eventually be viewed. As expected based upon the negligible measured head loss, a significant fraction of the strainer surface area did not appear to have been covered by a continuous debris bed. After the tank was drained further, the staff observed that only minimal quantities of debris had eventually settled on the floor of the test tank and, due to the powerful turbulence generated by the mechanical stirrers, further considered it likely that this debris had settled after the test had been terminated.

The next morning, the staff returned to the test facility to observe the disassembly of the test strainer. The strainer was lifted out of the tank, and one of the plates was removed from the assembly to allow the interstitial “gap” region between the two plates to be clearly viewed. The observation that a continuous debris bed had not formed over a significant fraction of the strainer was confirmed; in fact, slightly more than half the strainer area appeared to be in an essentially clean condition, with only isolated paint chips or other debris fragments sporadically appearing on the strainer surface. Although additional strainer area near the bottom of the plates also appeared to be clean, it was clear that debris had slumped off of this area after the test was completed. In fact, the majority of the test debris appeared to have been concentrated in this interstitial area by the non-uniform flow through the test strainer, which appeared to have a beneficial effect in preventing an even layer of fibrous debris from covering the strainer and filtering out both the surrogate chemical precipitates and non-chemical particulate debris.

The licensee stated that an earlier front sector test had resulted in a similar head loss and clean area fraction to those of the rear sector test observed by the staff. However, as expected due to the arrangement of the suction plenum beneath the flat plates (which aligned the suction force with gravity), the rear sector test appeared to result in a slightly higher fraction of clean strainer area. The staff noted that the accumulation of debris on the strainer plate surfaces appeared to increase toward the center of the plates. The staff could not determine whether this center-peaked debris accumulation pattern resulted from the presence of a stronger suction force near the center of the plates or whether the strong turbulence in the surrounding pool tended to disrupt the formation of an even debris bed along the edges of the strainer.

The staff noted that licensee personnel actively participated in the test preparations and carefully observed the conduct of the test. One example of the licensee’s high attention to detail was a licensee representative’s identification of a very small leak in a seal on the test tank and subsequent request that the test vendor reseal this location prior to the next test.

Discussions with Licensee

The licensee discussed the extensive efforts being performed at DCPP in response to GSI-191, which include both test programs and plant modifications.

Among the testing programs briefly discussed during the staff’s visit, the licensee noted that work had been done with respect to two-phase debris generation, debris erosion testing, debris transport testing, and head loss testing of the existing sump strainer design that the licensee proactively installed in 1998 in an attempt to address concerns associated with GSI-191 at a very early stage. The staff was impressed with the broad scope of the licensee’s testing program and considered the results of these tests to be of significant interest. Among the most notable findings from these tests are that chemical precipitates were filtered on fibrous beds having a theoretical thickness of less than 1/8 of an inch and that securely reinforcing insulation jacketing may allow a reduction in the zone of influence (ZOI) for certain insulation debris sources.

In addition to replacing the existing sump strainers, the licensee plans to complete a significant number of plant modifications in response to GSI-191. These planned modifications include the removal of significant quantities of potential debris sources from containment (e.g., mineral wool insulation on the steam generators and other potentially problematic insulation and fire stops), the protection of some potential debris sources with secure coverings (e.g., pressurizer cables, which the licensee discovered contain fibers that could be fragmented following the impact of a high-energy two-phase jet), and the reinforcement of banding for existing insulation jacketing to reduce the ZOI for certain materials. The licensee further discussed changes to the emergency procedures to ensure additional water inventory would be present in the containment for a small-break LOCA and noted that the plant has the potential to provide backflow to the strainers using the containment spray system. The licensee stated that a test would be conducted to determine the extent to which this backflow would be capable of clearing away the strainer debris bed.

The staff appreciated the openness and cooperation of the licensee in discussing these test programs, test results, and plant modifications with the staff. A significant part of the testing performed by the licensee covered areas that have not been thoroughly explored by past research and have potential applications to the industry at large. As a result, the staff considered this work a potentially valuable addition to the existing knowledge base regarding GSI-191.

Potential Outstanding Issues

Overall, the NRC staff concluded that the observed head loss test conducted by the DCPP licensee appeared reasonable. However, based on the NRC staff's test observations and discussions with licensee representatives, several technical issues were identified as having the potential for further resolution. It should be noted that these items were identified based on limited staff observations during the trip; therefore, the potential outstanding issues stated below may not fully represent the NRC staff's concerns on all parts of the licensee's testing program and associated analysis. Furthermore, the licensee may have adequately addressed some of the staff's concerns but may not have had an opportunity to clarify these points fully during the staff's visit.

In light of the above qualifications, potential outstanding issues for the licensee to address with regard to strainer testing include the following:

- The chemical surrogate used in the rear sector test observed by the staff had been prepared in large holding tanks and stored for approximately one month prior to the test. In accordance with the procedure outlined in WCAP-16530-NP, the vendor conducted a one-hour settling test with the intent of verifying that the chemical surrogate adequately represented the chemical precipitate analyzed in the WCAP. The staff noted that the amount of chemical surrogate that settled during the one-hour settling test had increased relative to that observed in the same test for freshly prepared surrogate (although the settling test results were still well within the WCAP acceptance criteria). Given the possibility of time-dependent changes to the chemical surrogate properties, the staff questioned whether long-term aging of the WCAP chemical surrogate had been evaluated and if there was industry guidance relative to the shelf life of chemical surrogates. The licensee indicated that they would investigate this issue.

- The turbulence in the test tank needs to be high enough to avoid non-prototypical debris settling without inhibiting debris bed formation. Earlier staff observations of GE testing at the CDI facility noted that non-prototypical debris settling may have occurred. Based in part on this previous staff observation, the test vendor used powerful stirrers to prevent debris settling for the DCPP tests. While these stirrers accomplished their intended function of preventing the settling of virtually all of the test debris, the staff noted the potential concern that high levels of turbulence in a test tank could inhibit the establishment of a uniform covering of debris on a test strainer, particularly near the edges of the strainer that are most affected by the flow in the surrounding pool. Although the potential effect of turbulence-induced bed disruption did not appear sufficient to impact the overall outcome of the particular test observed by the staff, the staff noted that controlling the magnitude, position, and/or directionality of the turbulence or positioning baffle plates near the gaps in the test strainer are some of the means potentially available to address this concern in the general case.

- During the trip, the staff understood that the preliminary location identified for collecting downstream samples for strainer pass-through testing would be on the outlet side of the test pump. Both the licensee and staff recognized that passing debris through a pump could affect its size distribution. Detailed discussions on how the licensee plans to use the results of any collected debris samples were not conducted, but, as applicable, the staff expects the licensee to account for any pump-induced changes to the size distribution of the collected strainer pass-through debris samples.

<u>Follow-Up Phone Call</u>

On January 19, 2007, the staff had a follow-up phone call with the licensee to discuss additional test results following the staff's visit during December 14–15, 2006. The most significant topic discussed in the call was how aging of surrogate chemical precipitates could affect the behavior of the surrogates with respect to debris bed accumulation and head loss.

As background, following the test observed by the staff, the licensee conducted a head loss test in which the chemical surrogate debris was added to the test tank prior to the non-chemical debris. The head loss measured for this test was significantly higher than the negligible head loss resulting from the test observed by the staff. This observed behavior initially led to the suspicion that the debris addition sequence had resulted in the significant change in measured head loss. However, when the normal debris sequence (non-chemical debris added prior to chemical debris) was resumed for the next four front sector repeatability tests, the measured head losses were even higher than the value from the test in which chemicals were added first (although all of the measured head losses remained within a range considered acceptable by the licensee).

From these additional test results, as well as other indications such as trends in the settling rate data for the chemical surrogate debris and low-power microscopic examination, the licensee concluded that aging of the surrogate chemical precipitate (as opposed to the debris addition sequence) had been the cause of the significant increase in measured head loss for the later tests. In particular, the settling rate data for the aluminum oxyhydroxide appeared to have changed substantially since the time that it had been generated (approximately one month prior to the staff's December visit). Based upon this hypothesis, the licensee created a fresh batch of surrogate chemical precipitates and used the new surrogate chemical debris for a rear module head loss test (as opposed to a sector test, which uses a strainer assembly having 2 "half" plates, the module test uses an assembly having 15 plates). The settling rate data for the fresh aluminum oxyhydroxide surrogate debris was comparable to the value measured prior to the rear sector test observed by the staff, and the rear module test similarly resulted in a very low head loss.

Therefore, based upon these test results and post-test examinations of the test strainers, the licensee suggested that aged chemical precipitates had apparently been able to block a significant fraction of the 3/32-inch perforations on the strainer surfaces, even in the absence of a continuous layer of fibrous debris or other debris acting as a filtering medium. However, it is important to note that the ambient temperatures experienced by the surrogate storage tanks during the storage period of slightly over one month was not representative of post-LOCA containment pool temperatures.

At the conclusion of the call, the licensee agreed to have an additional phone call with the staff regarding the results of testing that had not yet been concluded.

<u>Conclusions</u>

While several potential outstanding issues remain, the staff was generally impressed with the licensee's head loss testing program as well as its overall testing program for GSI-191. The licensee personnel present during the observed head loss test appeared attentive to detail and generally knowledgeable of sump performance issues. The staff was further impressed by the broad scope of the licensee's planned modifications to resolve GSI-191. Finally, the staff appreciated the licensee's invitation to observe testing, as well as the licensee's willingness to discuss additional test results with the staff.

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