February 2, 2007

MEMORANDUM TO: J. E. Dyer, Director
Office of Nuclear Reactor Regulation

THRU: Thomas O. Martin, Director ***/RA/***
Division of Safety Systems
Office of Nuclear Reactor Regulation

Michael L. Scott, Branch Chief ***/RA/***
Safety Issues Resolution Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: John Lehning, Reactor Systems Engineer
Safety Issues Resolution Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: FOREIGN TRAVEL TRIP REPORT—(NON-PROPRIETARY VERSION) NRC STAFF VISIT TO WINTERTHUR, SWITZERLAND, TO OBSERVE SUMP STRAINER TESTING PERFORMED BY CONTROL COMPONENTS, INCORPORATED

Three Nuclear Regulatory Commission (NRC) staff members traveled to Winterthur, Switzerland, on September 17–22, 2006, to observe containment sump strainer testing performed by Control Components, Incorporated (CCI), and to discuss technical issues associated with sump strainer testing and qualification. On October 23, 2006, a non-public foreign trip report was completed to document the staff's observations during the trip. To allow these observations to be shared with public stakeholders, including licensees of pressurized-water reactors (PWRs) who plan to install CCI-designed strainers, the staff has now generated a public version of this trip report. The public version of this report, which is enclosed, has been reviewed by CCI and other affected parties for proprietary information, and all proprietary information has been redacted. Small editorial changes have been made to the original report in areas where information was redacted, and several additional minor clarifications and corrections have also been implemented.

CCI is one of five vendors supplying sump strainers to U.S. pressurized-water reactors (PWRs) in conjunction with PWR licensees' efforts to respond to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation at Pressurized-Water Reactors," by resolving the sump performance issues associated with Generic Safety Issue 191. During the trip to CCI's Winterthur facilities, the staff observed a variety of tests that demonstrated the

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range of CCI's testing capabilities. Testing observed included the following: (1) a large-scale demonstration head loss test using typical PWR debris loadings and flow rates, (2) a vertical-loop head loss test performed for a Japanese boiling-water reactor, (3) a coating chip transport test for Oconee Nuclear Station conducted in the multi-functional test loop, and (4) several bench-top demonstrations of chemical effects analysis techniques. On the basis of these observations, the staff concluded that CCI's test procedures and setup were generally conducive to generating conservative results. However, as discussed further in the enclosed trip report, a number of potential concerns related to the test procedures and their interface with other areas of PWR licensees' sump strainer performance analyses were identified and discussed with CCI during the visit.

In addition to observing the tests described above, the staff conducted detailed discussions with CCI representatives on technical issues associated with chemical effects, downstream effects, and previous head loss testing and analysis performed for several U.S. PWRs. The discussions on chemical effects focused on a generic CCI chemical effects test plan, slide presentations, and a laboratory tour with demonstration tests. The staff's main question regarding chemical effects is whether the precipitates generated by CCI are representative of potential post-LOCA precipitates at PWRs. With regard to downstream effects, the staff obtained a test plan through the Oconee licensee and further discussed the results of previous strainer pass-through tests with CCI. The staff considered CCI's downstream effects approach to be generally reasonable, but could not make definitive conclusions without understanding how licensees would apply the test results to their plant-specific analyses. Finally, discussions of previous head loss testing and analysis provided the staff insight into CCI's overall strainer qualification program. The staff had a favorable impression of the general technical approaches used by CCI to design and test sump strainers.

In summary, the trip was a valuable and timely opportunity both to (1) interact with and provide feedback to CCI concerning the procedures for head loss testing and other strainer qualification tests and (2) gain insight from previous testing conducted by CCI that is relevant to the NRC's efforts to resolve Generic Safety Issue 191. Detailed observations from the staff's trip are provided in the enclosed NRC Foreign Trip Report. In addition to the three NRC staff travelers, Advisory Committee on Reactor Safeguards (ACRS) Chairman Dr. Graham Wallis and ACRS staff member Ralph Caruso also participated in the trip. They may document their observations in a separate trip report.

Enclosure: NRC Foreign Trip Report

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NRC FOREIGN TRIP REPORT

Subject

NRC Staff Visit to Winterthur, Switzerland, to Observe Sump Strainer Testing Performed by Control Components, Incorporated

Dates of Travel and Countries/Organizations Visited

Dates:
September 17–22, 2006

Organizations:
Control Components, Incorporated (CCI)
Duke Energy Corporation (Oconee Nuclear Station)
Exelon Generation Company (Byron and Braidwood Generating Stations)
Toshiba Corporation
NIUTEC AG

Location:
Winterthur, Switzerland

Authors, Titles, and Agency Affiliations

John Lehning, Reactor Systems Engineer, NRC/NRR/DSS/SSIB
Paul A. Klein, Senior Materials Engineer, NRC/NRR/DCI/CSGB
Steven M. Unikewicz, Senior Mechanical Engineer, NRC/NRR/DCI/CPTB

(Along with these three NRC staff members, Advisory Committee on Reactor Safeguards (ACRS) Chairman Dr. Graham Wallis and ACRS staff member Ralph Caruso also participated in the trip to CCI's Winterthur facility. Their observations may be documented in a separate ACRS trip report.)

Sensitivity

Non-Sensitive

Background/Purpose

In response to Generic Letter 2004-02 (GL 2004-02), "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," pressurized-water reactor (PWR) licensees are in the process of evaluating the performance of their containment recirculation sumps and making any plant modifications necessary to achieve regulatory compliance according to approved mechanistic sump performance criteria. Control Components, Incorporated (CCI), is one of five vendors supplying replacement sump strainers to U.S. PWR licensees in support of their GL 2004-02 resolution activities.

ENCLOSURE

As part of the regulatory process of verifying that PWR licensees are appropriately addressing GL 2004-02, the NRC staff has been conducting observations of head loss testing at each of the five replacement strainer vendors. These head loss testing observations have provided many benefits, including (1) opportunities for the staff to understand and provide feedback on replacement strainer designs and qualification testing approaches prior to installation, (2) assurance that an acceptable level of quality exists across the spectrum of strainer vendors contracting with U.S. PWR licensees, (3) a source of input to staff audit reports on PWR licensees' GL 2004-02 activities, and (4) a resource for the staff's review of PWR licensees' supplemental responses to GL 2004-02.

In the U.S. market, CCI has contracts to supply replacement sump strainers to 18 PWR units. The specific plants are listed in the table below:

Plant Name	Licensee	Units
Oconee Nuclear Station	Duke Energy	3
Byron Generating Station	Exelon Generation	2
Braidwood Generating Station	Exelon Generation	2
Salem Generating Station	PSEG Nuclear	2
D.C. Cook Nuclear Plant	American Electric Power	2
Arkansas Nuclear One	Entergy Nuclear	2
Calvert Cliffs Nuclear Power Plant	Constellation Nuclear	2
Palo Verde Nuclear Generating Station	Arizona Public Service	3

CCI is a worldwide corporation that specializes in designing customized severe-service control valves. Beyond valves, CCI has historically been involved in the design of various nuclear service components, including steel containments, reactor pressure vessels, high-density spent fuel racks, containment venting systems, and emergency core cooling system (ECCS) debris strainers. In addition to the U.S. plants stated above, since 1992, CCI has performed numerous strainer replacement projects throughout Europe as well as in Japan and Taiwan. In support of these projects, CCI has accumulated significant head loss testing experience from over two thousand vertical-loop tests and several hundred large-scale tests.

Abstract: Summary of Pertinent Points/Issues

The NRC staff spent three days at CCI's test facilities making observations concerning the vendor's strainer testing and qualification program. The following objectives were achieved: (1) reviewing test plan documentation and observing a demonstration large-scale head loss test, (2) reviewing test plan documentation and observing a vertical-loop head loss test for a Japanese boiling-water reactor, (3) observing a coating chip transport test performed for Oconee Nuclear Station, (4) reviewing a sample chemical effects test plan and discussing CCI's chemical effects approach and previous test results, (5) reviewing a strainer pass-through test plan for Oconee and discussing CCI's downstream effects approach and previous test results, and (6) providing feedback to CCI on the staff's observations during the trip.

Overall, the staff had a positive impression of CCI's strainer testing and qualification program. In particular, the CCI representatives the staff interacted with during the trip generally demonstrated a high level of technical competence with respect to suction strainer design issues. However, the staff identified a number of potential concerns related to CCI's strainer qualification program and its interface with other areas of PWR licensees' sump strainer performance analyses; these potential concerns were shared with CCI during the trip and are documented in the detailed discussion presented in Attachment III. A synopsis of the major test observations and interactions is provided below.

The staff had originally intended to observe a large-scale head loss test for Arkansas Nuclear One, Unit 1 (ANO-1), during the trip. However, due to extended delays in initiating the ANO-1 head loss test series, CCI instead performed a demonstration head loss test that used debris quantities and strainer flow rates that were considered typical of U.S. PWRs. Thus, while not representative of a specific plant, the demonstration test provided the staff a valuable and timely opportunity to observe CCI's large-scale test methodology and provide feedback on the overall approach. While the staff noted a number of conservative aspects of CCI's demonstration test, several potential concerns were also identified, of which the most significant were associated with (1) the procedure for preparing and adding debris to the test tank in a representative manner and (2) the procedure for ensuring that thin bed head loss tests are bounding.

Observing the coating chip transport test for Oconee Nuclear Station had also not been part of the staff's original trip plan. However, because the Oconee downstream testing that the staff had originally intended to see was completed ahead of schedule, the staff observed a subsequent coating chip transport test instead. The test observed by the staff analyzed the capability for small coating chips to transport in suspension at fluid velocities considered to bound the maximum velocities in the Oconee post-accident containment pool. Although a detailed analysis was not completed during the staff's visit, it was apparent that a large fraction of the chips settled prior to reaching the end of the flume.

Regarding chemical effects, the staff reviewed a general test plan, toured the laboratory used for performing chemical precipitate analyses, observed several demonstration chemical precipitate analysis tests, and viewed results from previous chemical effects tests conducted for Byron and Braidwood Generating Stations. In chemical effects discussions with representatives from CCI and the Byron/Braidwood licensee (Exelon), the staff identified several potential concerns, chiefly among them that, based upon the information provided during the trip, the staff could not determine whether the precipitate generated by CCI had been

adequately demonstrated to be representative of expected post-LOCA precipitates. The staff noted that a more detailed review of actual chemical effects test results could be useful in confirming or resolving potential concerns identified during the trip.

With respect to downstream effects, the staff reviewed a copy of the Oconee downstream sampling test plan provided by the licensee (Duke Energy), discussed the results of previous downstream testing, and made observations during the large-scale head loss test that were applicable to downstream effects. Although CCI's test procedures generally appeared reasonable, a definitive conclusion could not be made because it was not clear how licensees would apply the test results to their downstream effects evaluations.

Discussion

See Attachment III.

Pending Actions/Planned Next Steps for NRC

The staff will continue to evaluate the information obtained during the trip and will engage CCI in teleconferences if any additional clarification or staff feedback is necessary. The staff also plans to forward this trip report to all licensees installing CCI replacement strainers to ensure that they are informed of the staff's observations. In addition, the information documented in this trip report will constitute a source of input for the staff's review of supplemental responses to GL 2004-02 and in its audit reviews for one or more selected plants that are planning to install CCI-designed replacement strainers.

Points for Commission Consideration/Items of Interest

None.

Attachments

Attachment I:	Agenda of the NRC Staff's Visit to the CCI Test Facilities
Attachment II:	List of People Contacted
Attachment III:	Detailed Discussion

"On the Margins"

CCI invited the staff to tour the fabrication facility where the replacement strainers are being manufactured. During the staff's visit, replacement strainer parts for several U.S. PWRs and a French PWR were being fabricated and various strainer modules were being assembled. The tour provided the staff an opportunity to observe the machinery and manufacturing procedures used in constructing replacement strainers.

Attachment I. Agenda of the NRC Staff's Visit to the CCI Test Facilities

Plan for Visit of NRC/ACRS at CCI in Sept. 2006, Rev. 1

Dr.U.Blumer, 15.9.2006

Date	Time	Place	Subject	Responsible CCI persons
18.09.2006	08:15	Airport Zurich (own transport to Hotel Wartmann)	arrival of following people : John Lehning (NRC, general head loss testing) Paul Klein (NRC, chemical effects) Steven Unikewicz (NRC, downstream effects) Dr. Graham Wallis (ACRS, chairman) Ralph Caruso (ACRS, staff)	
	whole day	Hotel Wartmann	NRC/ACRS study of CCI testing plans	without CCI people
19.09.2006	09:00 - 09:20	CCI, room 4.01	Presentation companies IMI/CCI	G. Friedmann, CEO CCI Switzerland
	09:20 - 09:30	CCI, room 4.01	CCI Quality Organisation and Manual	P.Glaus, Quality Manager CCI CH
	09:30 - 10:00	CCI, room 4.01	Presentation Nuclear Services +Products	T.Zieger, Manager Nuclear Services
	10:00 - 11:30	CCI, room 4.01	Presentation/Discussion strainers/testing	TZ, ub, MS
	12:00 - 13:30	Rest. Sagi	Lunch	TZ, ub, MS
	13:30 - 15:30	CT Laboratory	MFTL Transport testing (Oconee)	WE, MS
	15:30 - 17:30	NIUTEC	Presentation/Discussion chem. Testing	NIUTEC (Graf), ub
	19:00 - 22:00	open	Dinner	open
20.09.2006	09:00 - 10:00	NIUTEC	Presentation/Discussion chem. Testing	NIUTEC (Graf), ub
	10:00 - 11:30	CT Laboratory	MFTL Transport testing (Oconee)	WE, MS
	12:00 - 14:00	Rest. Goldenberg	Lunch	TZ, ub, MS
	14:00 - 16:00	CT Laboratory	Small Scale testing for Japanese BWR	RG
	19:00 - 22:00	Rest. Rhine Fall	Dinner	TZ, ub, Friedmann
21.09.2006	09:00 - 12:00	University Winterthur	Large Scale Testing (LST)(non-plant specific)	ub, MS
	12:00 - 14:00	Rest. Rossli	Lunch	TZ, ub, MS
	14:00 - 17:00	CCI, room 4.01	LST results, Wrap up, final discussion	TZ, ub, MS
all the time		CCI, room 4.01	This room will be available for NRC/ACRS for CAUCUS purpose	

ENCLOSURE

Attachment II. List of People Contacted

Name	Title / Organization	Nature of Communication
Dr. Urs Blumer	Senior Consultant Nuclear Services Division Control Components, Incorporated	All technical aspects of CCI's strainer design process and arranging travel plans
Tobias Zieger	Deputy Director Nuclear Services Division Control Components, Incorporated	All technical aspects of CCI's strainer design process and arranging travel plans
Martin Spörri	Manager/Site Services Engineering Nuclear Services Division Control Components, Incorporated	CCI's test procedures and test results
Peter Glaus	Quality Management Control Components, Incorporated	CCI's quality control program
Deane Beck	Business Unit Manager, Americas Control Components, Incorporated	Arranging travel plans
Jason Patterson	Duke Energy (Oconee)	Oconee coating chip transport testing
Frank Eppler	Duke Energy (Oconee)	Oconee coating chip transport testing
Dan Brush	Exelon Generation (Byron/Braidwood)	Byron/Braidwood chemical effects testing
Various personnel	NIUTEC AG (CCI's contractor for chemical effects testing)	Chemical effects testing for CCI strainers
Various personnel	Toshiba Corporation	Vertical-loop head loss testing for Japanese boiling-water reactors

Attachment III. Detailed Discussion

On September 17–22, 2006, three members of the NRC staff and two representatives from the Advisory Committee on Reactor Safeguards (ACRS) visited Winterthur, Switzerland, to observe sump strainer testing conducted by Control Components, Incorporated (CCI). During the trip, the staff had the opportunity to observe a wide range of testing, including large-scale head loss testing, vertical-loop head loss testing, coating chip transport testing, and various chemical analysis demonstration tests. CCI personnel were instrumental in identifying trip dates that allowed the staff to observe this wide variety of testing. In addition to observing tests, the staff discussed a number of technical issues with CCI personnel in the areas of head loss testing, chemical effects testing, and downstream effects testing. The staff also had the opportunity to tour the fabrication facility where replacement strainers are currently being manufactured for pressurized-water reactors (PWRs) both in the U.S. and abroad.

Large-Scale Head Loss Test Observations

The large-scale head loss test observed by the staff was not associated with any particular nuclear power plant, but was conducted by CCI to demonstrate its general large-scale head loss test procedures to the NRC staff. Originally, the staff had made arrangements with the licensee for Arkansas Nuclear One, Unit 1 (ANO-1), to observe large-scale testing for its replacement strainer. However, due to extended delays in initiating the ANO-1 test program and the inability of the licensee to confirm a rescheduled test date, CCI proposed to present a demonstration test using debris quantities and flow rates considered typical of U.S. PWRs.

The large-scale test loop at CCI can accommodate head loss testing of a full-scale strainer module. A schematic diagram of a CCI pocket strainer test module is provided in Figure 1, below. As may be inferred from the figure, the test module consisted of 120 pockets, with 60 pockets facing outward on each side of a common suction header. In the test observed by the staff, the test strainer was scaled to the demonstration plant strainer by a ratio of roughly 1:25.

A schematic diagram of the test module in the large-scale test tank is provided as Figure 2. The large-scale test tank at CCI measures approximately 14 ft long, 9 ft wide, and 7 ft deep. As depicted in Figure 2, CCI used baffle plates and the pump discharge line to discourage the settling of debris away from the test module. The staff observed that the design of the discharge line created significant turbulence in the baffled region adjacent to the test module; however, the intervening baffle plate prevented this turbulence from significantly disturbing the establishment of laminar flow along the approach to the strainer pockets.

Prior to the staff’s arrival at the test facility, the large-scale tank had been filled with room-temperature water. The debris preparation process had also been completed before the staff arrived. The test debris included Thermal-Wrap and Temp-Mat fibrous debris, calcium silicate, epoxy paint chips, and stone flour (to simulate coating particulate debris). The test observed by the staff was a full debris load test, and the quantity of fibrous debris tested was sufficient to create a uniform bed having a theoretical thickness of approximately 1/2 inch.

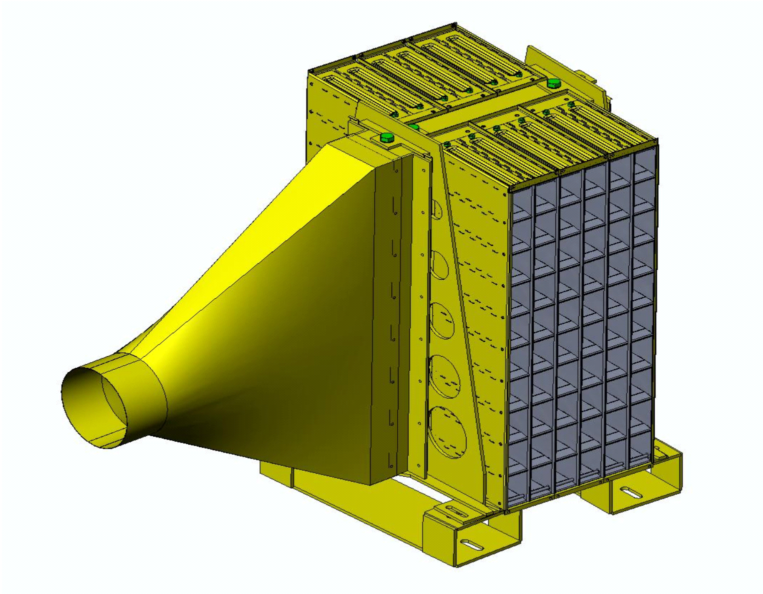

Figure 1: Schematic Diagram of a CCI Pocket Strainer Test Module

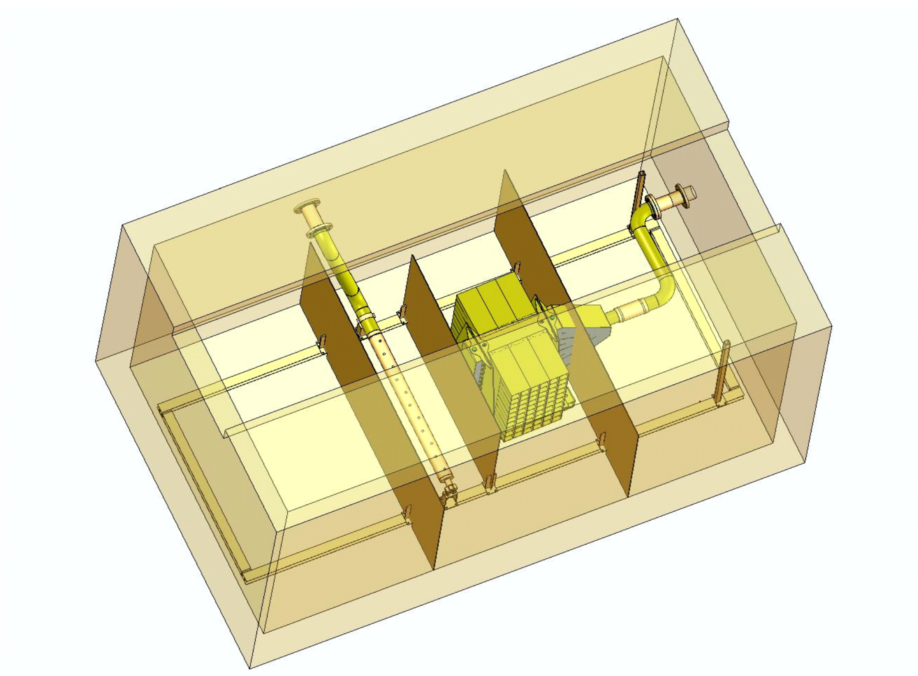

Figure 2: Schematic Diagram of the CCI Large-Scale Test Tank

The debris preparation procedure specified that fibrous debris would be removed from its jacketing and cut into pieces. Then the pieces of fibrous debris would be split into batches, soaked in water, and fragmented using a high-pressure water jet. The test procedure specified that the prepared fibrous fragments should appear smaller than 3/8 inch. The test procedure further specified that latent fibrous surrogate debris would be prepared in the same manner as fibrous debris from insulation.

The test procedure specified that unqualified coatings would be broken into chips of approximately 1/12 to 1/8 inch, based on this size range being on the order of the diameter of the screen hole openings. The qualified coatings debris from within the pipe break zone of influence (ZOI) was modeled using fine stone flour particulate. While a description of the preparation process for calcium silicate was not provided to the staff, it appeared to have been prepared as fines.

Prior to being added to the test tank, the particulate debris and coating chips were mixed with the fibrous debris in ten trash cans. The staff noted that the concentration of water in the trash cans was very low and that significant potential for debris agglomeration existed during the period between the preparation of the debris and its addition to the test tank. The degree of agglomeration appeared to increase near the bottom of the bucket.

The trash cans full of prepared debris were brought to the test tank area using a pallet jack and were held suspended above the tank surface with an overhead crane. A test technician standing on a plank above the test tank then used a pitcher to gradually transfer the test debris from the trash cans to the test tank. The test technician added approximately half the debris on each side of the test module so that a roughly symmetric accumulation of debris could form on each side of the test module.

As debris from the first trash can was added to the test tank (particularly as the water concentration decreased near the bottom of the can), the NRC staff and ACRS representatives noted that some of the debris added to the tank was in the form of agglomerated sludge rather than the fine pieces specified in the test procedure. Although the transport behavior of the debris in the test tank could not be directly ascertained due to the presence of suspended particulate, some of the agglomerated debris disappeared beneath the water surface in firm clumps that appeared likely to settle onto the floor of the test tank. Subsequently, an ACRS representative shared this observation with CCI personnel. After considering the observation, the CCI test technician directed that the agglomerated debris near the bottom of the remaining trash cans be diluted with additional water to mitigate the potential for agglomeration-induced settling. As test technicians added the remaining debris, the staff observed that the revised procedure reduced the potential for nonprototypical settling; however, due to the opacity of the test fluid, it was not clear whether the issue had been fully addressed.

Although the addition of water to reduce debris agglomeration was not performed during the test observed by the staff prior to the ACRS representative's comment, the vendor subsequently stated that adding water to the trash cans during the addition of debris to the pool is a common procedure. The vendor further added that experience has shown that debris clumps can be fragmented easily by hand or by pouring them into water.

After adding half of the test debris, the vendor paused the addition sequence to let the measured head loss reach the specified steady-state criterion of less than a 3% change in 10 minutes. However, since the test was for demonstration purposes only, the test was resumed prior to satisfying this criterion to ensure that the NRC staff and ACRS representatives could observe the completion of the test prior to departing. At this time, measured head loss had not appreciably increased above the clean strainer value.

Three additional batches of debris were then added to the test tank, which resulted in an increasing trend in the measured head loss that slowly steadied out at several tenths of a foot of water. Subsequently, technicians added the final two batches of debris, which resulted in a rapid rise in head loss by more than an order of magnitude. This rapid head loss increase suggested that the final two batches of debris had finally established a continuous debris bed over the test module surfaces. When the test measurements at design flow were halted, the measured head loss was steadily increasing; however, the NRC staff and the CCI test technician agreed to neglect the steady-state criterion once more to ensure that the staff and ACRS representatives could observe the effects of changing the strainer flow rate and stopping/restarting the test pump.

Once design flow rate head loss measurements were concluded, the test flow rate was increased to values representing 120% and 140% of the rated design flow. The head loss responded to each increase in flow by first steeply increasing and then slowly leveling off. In addition, small peaks in measured turbidity were noted following each flow increase, indicating that some of the debris accumulated on the strainer had been pushed through and resuspended in the flow being circulated through the test tank.

Although the measured head loss had not fully stabilized at 140% flow, the NRC staff and CCI test technician agreed that, due to time constraints, a demonstration of stopping and restarting the test pump could be conducted. The test pump was stopped and then restarted twice at 140% flow. Each time the pump was stopped, gas that had been trapped inside the strainer bubbled violently to the surface of the test tank. Presumably, the cause of this phenomenon was that suspended gas had previously come out of solution after undergoing a pressure drop across the debris bed and had collected inside the test module. The staff noted that the first release of trapped gas (10–15 seconds in duration) was substantially longer and more powerful than the second (several seconds long). Apparently, this difference was because the strainer had been steadily accumulating gas for a significantly longer period prior to the initial cycling of the test pump as compared to the subsequent cycling.

Despite the intensity of the releases of trapped gas, after the test pump was restarted, a substantial head loss was measured each time, indicating that the overall continuity of the debris bed structure had not been lost. This behavior was expected based upon earlier discussions with CCI personnel, who had stated that high-head-loss debris beds were generally capable of maintaining their structure despite the release of trapped gas, whereas, low-head-loss debris beds under such circumstances could lose their continuity. However, it was clear from small peaks in the measured turbidity that the disturbances from the trapped gas release and the resumption of recirculation flow caused some of the debris in the bed to be resuspended in the water being circulated through the test tank.

Although the staff could not stay to observe the draining of the test tank, CCI provided photographs of the inside of the test tank and the test strainer module after draindown. From these photographs, the staff observed that (1) the distribution of debris was nonuniformly biased toward the bottom of the test module, (2) a significant quantity of debris was resting upon the tank floor at the base of the strainer after the completion of the test, and (3) the turbulent-flow region behind the baffle plate appeared to have been relatively free of debris settling during the test, although some debris from the laminar-flow region where the test module was located appeared to have seeped backward after the test concluded.

From observations made during the test, the staff was not able to estimate to what extent the debris that settled in front of the strainer resulted from phenomena prototypical of PWR replacement strainers (e.g., low laminar flow velocities at the face of the test module), to what extent it resulted from the nonprototypical agglomeration of debris added to the tank, and to what extent it resulted from the slumping of the debris bed after the completion of the test and the draining of the test tank.

While the staff observed indications that nonprototypical debris agglomeration may have influenced the test, a significant quantity of fine fibrous debris was also observed to be present in the test tank which could presumably also have contributed to the pile of settled debris. The vendor stated that the settled debris was largely due to debris bed slumping; while this explanation is plausible, substantiating evidence was not available to the staff to confirm the vendor’s statement. The staff concluded that under conditions where the opacity of the test fluid prevents the observation of debris transporting in the test tank, it is critical to ensure that debris enters the tank in a prototypical condition if debris settling is credited.

Head Loss Discussions

From discussions during the trip, the staff observed several notable features of CCI’s head loss testing program and strainer design practices. As described below, these features include (1) the testing methodology for analyzing vortexing and air entrainment, (2) the modeling of the strainer-area geometry used for head loss testing according to the actual plant sump geometry, and (3) the use of computational fluid dynamics as a tool in the strainer design process.

The vortexing and air entrainment test procedures used by CCI appear well developed. Apparently, CCI representatives once observed whistling noises from air being sucked across a debris covered strainer through which small holes had been cleared when the test pump had been stopped and restarted. Based on subsequent testing, CCI developed an analytical model to predict the occurrence of vortexing using dimensionless parameters. As a result of these efforts, CCI noted that unperforated top plates are being installed on strainer designs if the predictive model and/or testing indicates vulnerability to vortexing or air entrainment.

CCI discussed several head loss tests that had been conducted prior to the trip. One significant point in these discussions was CCI’s attempt to ensure that the geometry surrounding a test strainer module is representative of the actual plant geometry. CCI discussed two tests in particular during the trip. The first test was for a plant with a strainer located in a sump pit. CCI designed the test such that debris accumulated around the test module in a representative fashion. The second test was for a sump area geometry with the potential for partially restricting the flow of water to the strainer as the result of debris accumulation in tight clearances blocking or “damming” certain flowpaths to the strainer. CCI stated that alternate tests had been conducted to ensure that potential flow restrictions and patterns of debris accumulation had been adequately considered in the strainer qualification process.

Discussions with CCI further identified that computational fluid dynamics (CFD) is used as a tool in various aspects of the strainer design process. CCI representatives noted that clean strainer flow characteristics and head losses have been predicted using CFD. In another case, CFD was used to model the behavior of a strainer located in a pit that was partially filled with debris. Using generally accepted debris properties, CCI computed the average porosity of the debris in the pit and subsequently simulated the flow of water through the strainer under this condition. The staff noted that, while CFD was employed as a strainer design tool, CCI ultimately performed testing to validate the adequacy of the strainer design.

In summary, while the staff did not review CCI's head loss testing and analysis methodology in detail, the staff considered many of the general technical approaches and practices to be appropriate and well developed. The staff was also generally impressed with the technical competency of CCI personnel in implementing these approaches and practices in the example cases discussed during the trip.

Vertical-Loop Head Loss Test Observations

The staff was invited to observe a vertical-loop head loss test for a Japanese boiling-water reactor. Two representatives from Toshiba were present to observe the test. Since the test was not associated with a U.S. licensee, the staff did not provide detailed feedback to CCI and will provide only a brief description of the test. More detailed information concerning the vertical-loop test apparatus (as well as other aspects of CCI's test facilities) can be found in a presentation to the NRC staff dated May 24, 2006 (ADAMS Accession Number: ML062080728).

The debris used for this test included mineral wool (i.e., rock wool), coating chips, and several types of fine particulate, including calcium silicate, stone flour, and iron oxide. The staff noted that, while the mineral wool was not boiled prior to the test, pellet-sized pieces of calcium silicate debris were boiled to facilitate the sinking of the prepared debris pieces.

Debris was added in three batches. During the debris addition process, the staff noted that a small amount of debris-laden water was drained to allow sufficient room in the loop for subsequent batches of debris to be added. Between batches, CCI technicians allowed sufficient time for the measured head loss to stabilize, at which time the loop test fluid was observed to become relatively clear.

Coating Chip Transport Testing for Oconee Nuclear Station

Originally, the staff had intended to observe downstream strainer pass-through testing for Oconee Nuclear Station; however, the downstream testing series was concluded ahead of schedule, prior to the staff's trip. In lieu of the downstream test, the licensee permitted the staff to observe a coating chip transport test in the CCI multi-functional test loop. The Oconee licensee was aware that the staff recently completed a test program on coating chip transport, but determined that the NRC study had not considered sufficiently small chips to bound Oconee's plant-specific conditions. The test observed by the staff was intended to examine the transportability of coating chips in suspension with water. Testing completed prior to the staff's arrival had examined tumbling transport of coating chips along the floor of the multi-functional test loop flume.

A schematic diagram of the multi-functional test loop is provided below as Figure 3; however, for the coating chip transport testing observed by the staff, the flume portion of the loop was extended to a length of roughly 20 ft. For the coating chip transport testing, a filter was inserted at the end of the flume nearest the pump, to capture any coating chips remaining in suspension upon traversing the length of the flume. In addition, thin plastic sheeting with small, spaced ridges was placed on the floor of the flume to prevent settled coating chips from transporting long distances along the flume floor and obscuring the test results.

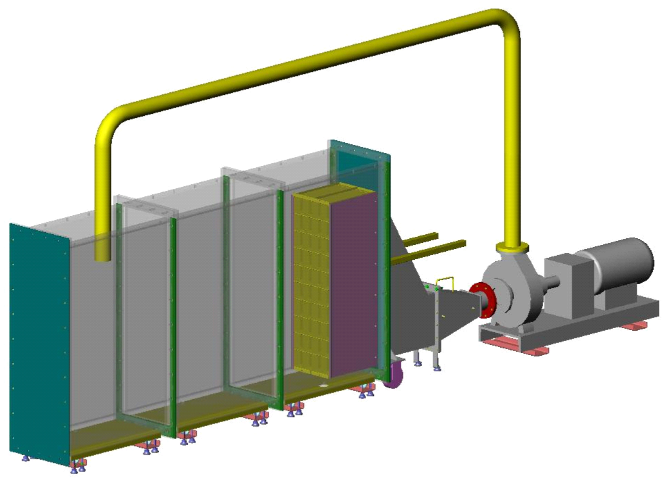

Figure 3: Schematic Diagram of the Multi-Functional Test Loop

The coating tested was an epoxy that was identified as Carboline 890. The licensee's test program examined the transportability of five size ranges of coatings debris: (1) chips between 1 mm and 4mm, (2) chips between 280 μm and 1 mm, (3) chips between 75 μm and 280 μm, (4) chips less than 75 μm, and (5) stone flour particulate approximately 10 μm in diameter. The coating chips were generated by breaking up paint that had been applied to a flexible surface and subsequently processing the coating chips through sieves to achieve the desired size ranges. A 100-g sample of coating chips was used for the testing observed by the staff.

Flow was initiated in the multi-functional test loop prior to the addition of the coating chips. Licensee personnel stated that the flow rate used for the test (which established a flume-averaged velocity of roughly 0.3–0.4 ft/s) was intended to represent the maximum velocity in the Oconee containment pool predicted by a computational fluid dynamics simulation of the worst-case accident condition.

The coating sample was added to the test flume using a small plastic cup. The test technician introduced the chips slightly beneath the surface of the flume, stirring the surrounding water to avoid agglomeration. The actual test was brief since most of the coating chips appeared to settle to the flume floor prior to traveling halfway down the flume, and, in any case, the flume transit time for chips remaining in suspension was estimated to be on the order of one minute.

Following the test, the multi-functional test loop was drained and allowed to dry overnight. The next day, the staff observed as CCI test technicians removed the plastic sheets installed over the floor and swept the coating chips that had settled between each ridged segment of the plastic sheeting into a container. The staff understood that the chips collected in each segment would subsequently be dried and weighed to provide information that could be used to formulate a distribution of transport lengths for coating chips suspended in water. The licensee representatives noted that this transport testing could form part of the basis for additional head loss testing under more realistic conditions that is being considered as a possibility to address chemical effects and/or other issues for Oconee.

A detailed discussion of the supporting technical analysis necessary to apply the coating chip transport testing to the Oconee plant-specific sump performance analysis was not conducted during the trip. However, the staff noted several potential considerations for applying such test results to a plant-specific analysis:

- comparison of the velocity profiles in the test flume with the velocity profiles predicted by computational fluid dynamics for the containment pool

- comparison of the turbulent kinetic energy in the relatively quiescent test flume to the turbulent kinetic energy predicted by computational fluid dynamics for the containment pool

- consideration of whether and/or to what extent coating chips transport while floating on the surface of the containment pool, and

- consideration of uncertainties in analyses of washdown transport that could affect predictions of where coating chips will enter the containment pool.

Chemical Effects

Prior to the visit, the NRC staff received a copy of a CCI test procedure entitled, “Containment Sump Strainer Replacement, [Multi-Functional Test Loop] Chemical Filter Performance Test.” During the visit the NRC staff discussed chemical effects testing with representatives from CCI, NIUTEC AG, Exelon Generation (Byron/Braidwood), and Duke Energy (Oconee). NIUTEC has been the central chemistry lab for Sulzer since 1950, and is providing technical support to CCI in the chemical effects area. Prior to the staff’s visit, CCI had performed a chemical effects test for Byron and Braidwood in the multi-functional test loop. The staff discussed the results from this test and CCI’s general approach to chemical effects testing, and also toured the portion of the NIUTEC laboratory dedicated to chemical effects bench-top testing. There were no chemical effects tests performed in any of the CCI test loops during the staff visit. During the laboratory tour, a NIUTEC chemist provided a small-scale demonstration on the generation of aluminum-based chemical precipitates.

For the Byron/Braidwood testing, Sargent and Lundy provided input on the amount of precipitate expected by calculating the plant-specific amount of chemical product using the chemical model spreadsheet contained in WCAP-16530-NP, "Evaluation of Post-Acccident Chemical Effects in Containment Sump Fluids to Support GSI-191." The NRC staff noted that WCAP-16530-NP is currently being reviewed by the staff and that a request for additional information (RAI) has been issued by the NRC. Although WCAP-16530-NP is used to predict the amount of plant-specific chemical product, the technique used to generate aluminum-based chemical precipitates for the CCI tests does not follow the WCAP guidelines. In particular, sodium aluminate is used instead of aluminum nitrate to generate aluminum-based chemical precipitates. Sodium aluminate was selected since it would not introduce an extra chemical species (nitrate) into the chemical system.

Prior to the chemical effects tests for Byron and Braidwood in the CCI multi-functional test loop, the NIUTEC staff performed a number of laboratory tests to evaluate the chemical precipitates generated using sodium aluminate. These tests included precipitate settling, precipitate filterability, and particle sizing. Results from the settling and filterability tests were compared to the applicable criteria provided in WCAP-16530-NP and determined to be consistent with the WCAP values. The NIUTEC chemist stated the precipitate size was approximately 10 μm. For comparison, Argonne National Laboratory (ANL) measured aluminum hydroxide precipitate median particle sizes of 19 μm (without ultrasonic deflocculation) and 2 μm (with ultrasonic deflocculation). A NIUTEC report provides the details from the laboratory tests of chemical precipitates. This report was not available to the NRC staff at the time of the visit and the staff plans to request a copy of this report from the licensee (Exelon).

During discussions about chemical precipitate generation, characterization, and testing, the NRC staff provided feedback in several areas related to chemical effects testing. The staff indicated that ANL has investigated the behavior of precipitate generated with aluminum nitrate and with sodium aluminate. Based on its evaluation, ANL decided to use aluminum nitrate as the source for aluminum-based precipitates in its vertical head loss loop tests. The staff will provide information on the ANL evaluation to CCI and the licensee, as it may be useful to their chemical effects evaluations. The NRC staff also noted that ANL testing evaluated the influence of pH, temperature, precipitate concentration, and time.

Chemical effects testing in the multi-functional test loop is accomplished by scaling the amount of chemical precipitate to the multi-functional test loop screen area. Boron is scaled based on the volume of the test loop (approximately 1700 liters) to achieve a boric acid concentration that is representative of the projected post-LOCA containment pool chemistry. Following the addition and dissolution of boric acid, plant-specific debris is added to the test loop. After the debris is added and head loss across the strainer section has stabilized, chemicals are added to the loop in the following increments: 40%, 70%, 100%, 120%, and 140%. Chemicals are introduced in the multi-functional test loop upstream of the strainer segment and precipitation occurs within the test loop. The pH in the test loop is monitored and compared to the results obtained in the laboratory tests. If the pH is outside the expected range following the addition of all chemicals, it is adjusted with either sodium hydroxide, boric acid, or nitric acid. For the two chemical effects tests conducted in the multi-functional test loop for Byron and Braidwood, the normalized pressure drop increased from 1.9 ft with debris to 2.7 ft with debris plus 100% of the chemical products. The staff notes that the Byron/Braidwood plant-specific debris loading has little fiber, and the test produced an equivalent fiber bed thickness less than 1/16-inch. While the Byron/Braidwood test showed an increase in pressure drop due to chemical effects, it is less than has been observed during testing at other facilities. At this time, it is not clear to the staff if these differences are solely due to the small quantity of fiber in the plant-specific debris bed or are also related to the behavior of the CCI chemical precipitate relative to the chemical precipitate used at other test facilities.

The NRC staff made the following observations concerning the CCI approach to chemical effects testing:

- The NRC staff understands CCI's technical basis for selecting sodium aluminate to induce aluminum hydroxide precipitates. Without the benefit of the bench-scale lab report, the NRC staff was not able to determine that the behavior of the aluminum hydroxide precipitate has been sufficiently characterized regarding the effects of temperature, pH, rate of addition, time, etc. For example, solution pH can affect the formation of aluminum hydroxide precipitates (e.g., crystalline or amorphous) and dramatically affect their solubility. Temperature affects the solubility, and the temperature at which the chemicals are added may affect the amount of precipitate. In addition, understanding the effect of time on the precipitate (e.g., changes to the precipitate as a result of hydration or precipitate aging) relative to the test duration is important.

- Chemical effects testing in the CCI multi-functional test loop using up to 140% of the chemical precipitate projected by WCAP-16530-NP was performed to measure pressure drop from chemical effects in a conservative manner. The staff agreed that addition of 140% of the projected amount is conservative, provided that the chemical precipitates are representative of those that would be formed in a postulated post-LOCA plant environment.

- Chemical effects test termination criteria were discussed with CCI. These criteria are particularly important when precipitates are generated within the test loop during the test instead of before testing. The staff discussed some of the results from head loss testing in NaOH environments at Argonne National Laboratory. In these tests, significant pressure drops were observed in NaOH environments approximately 4 to 8 days after aluminum nitrate solution had been added to the test loop. The staff expects the test termination criteria will take into consideration the potential time dependency of head loss resulting from chemical precipitates.

In summary, the staff had the opportunity to discuss the CCI chemical effects testing approach, review results from the initial multi-functional test loop chemical effects test, tour the NIUTEC laboratory, and see a bench-scale demonstration of precipitate generation. In general, the staff thinks the use of borated water and the sequence of introduction for debris and chemicals for the multi-functional test loop tests were reasonable for the plant specific environment. Due to a number of questions concerning the behavior of the CCI chemical effects test precipitates, however, the staff did not reach a conclusion on the adequacy of CCI's overall chemical effects test program. The staff will continue to interact with CCI, licensees installing CCI strainers, and contractors providing chemical effects related technical support to CCI to obtain additional information about test results and future test plans, and to discuss the resolution of outstanding technical issues.

Potential Outstanding Issues

Overall, the NRC staff concluded that CCI's strainer qualification and testing approach appeared reasonable. However, based on the NRC staff's test observations and discussions with CCI representatives, several technical issues were specifically identified as having the potential for further resolution. It should be noted that these items were identified based on a limited staff review of the information provided by CCI during the trip on the specific topics discussed in this report; therefore, the potential outstanding issues stated below do not fully represent the NRC staff's concerns on all parts of CCI's testing program or its interface with PWR licensees' strainer performance calculations. Also, in the course of the staff's future sample audits and other review efforts on GSI-191, additional issues may be identified, particularly because (1) the staff's interaction with individual licensees was limited during the trip because some of the observed testing was not directly associated with a particular U.S. PWR licensee and (2) CCI has used test procedures with significant differences while performing tests for U.S. PWR licensees. Furthermore, CCI may have adequately addressed some of the staff's potential 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 licensees using CCI strainer qualification testing include the following:

- Ensuring that crediting of debris settling during tests is based upon prototypical conditions. Although CCI made substantial efforts to ensure that debris did not settle away from the test module, the staff considered agglomeration-induced settling of highly concentrated debris as having significant potential to affect the test results in a nonconservative manner. After this issue was raised to CCI representatives, a procedural change to mix additional water into the debris being added to the tank appeared to reduce the magnitude of this effect.

- Ensuring that the thin bed test procedure considers the worst case thin bed head loss condition. In the generic test procedure provided to the staff, the thin bed test was to be conducted using a quantity of fiber sufficient to create a layer having a 1/8-inch theoretical thickness. The staff considered this procedure as having significant potential to generate nonconservative results because a 1/8-inch bed is thought to be the threshold at which the thin-bed effect occurs, not necessarily the bed thickness that maximizes head loss, particularly for a strainer design of complex geometry. Experience has shown that the worst case quantity of fibrous debris for thin bed testing cannot be predetermined, but may be ascertained by variations in the test procedure.

- Ensuring that latent fibrous debris is prepared in a representative manner. In the test procedure provided to the staff, the latent fibrous debris preparation procedure was identical to the procedure for preparing fibrous shreds representing insulation-generated debris. The vendor stated during the trip that the fibrous debris preparation procedure is very conservative and results in the generation of large amounts of fine debris. The staff partially agreed with this comment, but noted that concerns remained with the debris addition procedure (see first bullet above). The staff also pointed out that essentially all latent fibrous debris may be in the form of individual fibers and that, particularly for low-fiber plants, the fineness of the prepared latent fibrous test debris could have a significant impact on the test results.

- During the large-scale and vertical-loop head loss tests observed by the staff, relatively small quantities of debris-laden water were drained to ensure adequate space was available for additional debris being added to the test loops. While the overall effect of this procedure was likely not significant, the staff considers it a best practice to account for the volume of prepared test debris beforehand to avoid draining debris-laden water during testing.

- Ensuring that head loss termination criteria are sufficiently conservative. The termination criterion in the large-scale head test procedure provided to the staff was that head loss should not change by more than 3% in 10 minutes. However, in discussions, the staff learned that the test technician will continue to run tests that exhibit a generally increasing head loss trend even if the termination criterion is satisfied. The staff suggested that CCI could formalize this existing practice by adding additional clarification to the test procedure. Furthermore, the staff noted that slow increases in head loss over a long period of time could lead to noticeable increases in total head loss over the days or weeks that the sump may be required to operate. The staff noted that guidance in the head loss test report might be useful to licensees in ensuring that this effect is not neglected.

- Ensuring the similarity of surrogate test debris to actual plant debris. For example, the staff noted that CCI's strainer testing program has used both stone flour and zinc powder to simulate coating particulate debris. During the trip, the basis for choosing one or the other surrogate material was not clear. The staff expects that licensees will have a defensible technical basis to justify the surrogate materials they choose for testing.

- Ensuring that deviations from the staff's safety evaluation (SE) on the Nuclear Energy Institute Guidance Report are appropriately justified. While a detailed review was not conducted, the staff noted that the test debris used for the demonstration large-scale test included a smaller fraction of latent fiber than recommended in the SE. The staff also noted that the testing assumed that some coatings fail as chips, despite the SE position that failure as particulate be assumed when sufficient fibrous debris is available to create a 1/8-inch bed. The staff expects licensees to have an adequate technical basis demonstrating that such deviations from the SE are appropriate.

- Ensuring that chemical precipitates used in testing are adequately representative of expected post-LOCA precipitates. Many factors can influence the characteristics of a precipitate, such as temperature, pH, rate of chemical addition, and time. In turn, the physical characteristics of precipitates affect the head loss they are capable of inducing.

- Ensuring that chemical effects head loss test termination criteria are sufficiently conservative. Test termination criteria are particularly important when precipitates are formed in the test loop instead of prior to the test. Previous testing at Argonne National Laboratory has indicated that in certain chemical environments, significant pressure drops can occur days after chemicals solutions are added to a test loop. Prior to terminating tests, the staff expects licensees to have a basis for assuring that the peak head loss has been captured.

Conclusion

The potential outstanding issues noted above notwithstanding, the staff had a positive overall impression of CCI's strainer qualification program. The staff further appreciated the openness and cooperation of CCI during the trip. In particular, the staff recognized that CCI had made substantial efforts to ensure that the staff had an opportunity to observe a wide range of testing and had conducted a large-scale demonstration head loss test specifically for that purpose. CCI's efforts in this regard helped make the staff's trip very worthwhile. The staff informed CCI that a report would be generated to document observations made during the trip and further noted that the current GL 2004-02 audit plan proposes to select at least one plant from each strainer vendor for a detailed audit.