Appendix A

Comparison of IRWST Sump Strainer Design to NRC RG 1.82 Requirements

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1	**General** This section includes regulatory positions on design criteria, performance standards, and analysis methods that relate to all water-cooled reactor types (Section C.1.1) and to specific light-water reactor types (PWRs in Section C.2 and BWRs in Section C.3). As stated in the introduction to this guide, the purpose of the guidance is to identify information and methods that the NRC staff considers acceptable for use in evaluating analytical techniques and implementing regulations related to water sources for long-term cooling of both existing and future reactor systems.	**No response necessary – Introductory Material.**
1.1	**Regulatory Positions Common to All Water-Cooled Reactors** Research, analysis, and lessons learned have shown that similar approaches are appropriate for water-cooled reactors in a number of areas when the long-term recirculation capability evaluation is performed. These areas include net positive suction head (NPSH) evaluation, selection of limiting pipe breaks, debris generation, debris transport, coating debris, latent debris, sump structure, downstream effects, chemical effects, structural analyses, and head loss testing.	**No response necessary – Introductory Material.**
1.1.1	**Emergency Core Cooling System Sumps, Suppression Pools, Suction Strainers, and Debris Interceptors** The emergency core cooling system (ECCS) sumps or suppression pools, which are the source of water for functions such as ECCS and containment heat removal following a loss of coolant accident (LOCA), should contain an appropriate combination of the features and capabilities listed below to ensure the availability of the water sources for long-term cooling.	**No response necessary – Introductory Material.** The design features and capabilities that minimize the potential for loss of water sources for long-term cooling are presented below.

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1.1.1.1	A minimum of two independent ECCS suction strainers should be provided, each with sufficient capacity to accommodate the full plant debris loading while providing sufficient flow to one train of the ECCS and containment heat removal pumps. To the extent practical, the redundant suction strainers should be physically separated from each other by structural barriers to preclude damage resulting from a LOCA, such as whipping pipes or high-velocity jet impingement.	**Conformance.** Four separate, independent, and redundant trains of the safety injection system (SIS) and containment spray system (CSS) with two safety injection (SI) pumps and one containment spray (CS) pump in each division are provided. Within each division, the two SI trains (and each CS train) are separated by a quadrant wall to isolate the trains from each other to the maximum extent practical. Each of the four SI pumps has its own suction connection to the in-containment refueling water storage tank(IRWST), and each of two CS pumps shares one of these four connections. Four sumps are provided in the IRWST. Each IRWST sump contains paired CSS/SCS and SI suction pipes (two sumps: SI and CS pump suction pipes, two sumps: SI and SC pump suction pipes). Each pair of CSS/shutdown cooling system (SCS) and SI suction pipes ends in a suction sump, with each suction sump installed adjacent to an associated strainer (four total). Four strainers and sumps are located inside the IRWST isolated compartment, which protect high-energy piping systems in containment. The IRWST is inside the vertical concrete of the reactor containment buildings. The IRWST is toroidal and arranged continuously around the lower containment. The bottom of the IRWST is formed by the upper concrete of the internal structure. The top is formed by the concrete slab. This provides for an enclosed structure. The strainers are installed away from the spargers to minimize the effect of hydrodynamic loads induced by the discharge of water, air, and single- and two-phase steam due to the opening of the pressurizer pilot-operated safety relief valves (POSRVs) into the IRWST.

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1.1.1.2	The containment floor in the vicinity of floor-mounted ECCS strainers should slope gradually downward away from the strainers to retard floor debris transport and reduce the fraction of debris that might reach the suction strainer. Similar floor sloping should be used in the vicinity of a sump pit if the ECCS strainers are installed in a pit configuration. Debris interceptors or curbs can also be used to retard debris transport.	**Not applicable** The APR1400 design does not require that the floor in the vicinity of the IRWST sumps be sloped away from the sump for the following reasons: The trench is provided upstream of the trash racks facing each opening in the shield wall to prevent high-density debris from being swept along the floor into the holdup volume tank (HVT). The vertical trash racks, located at the entrance to the HVT on El. 100′-0″, will intercept any debris entering the HVT. The IRWST, due to the location of the isolated compartment, is not subject to heavy debris loading. The IRWST sump strainers have a significant surface area and the effect of debris will be minimal. All these features, coupled with the very low flow velocities in the IRWST, will significantly reduce the amount of debris that might reach the strainer.
1.1.1.3	The inlet of pumps required for long-term cooling should be protected by a suction strainer placed upstream of the pumps to prevent the ingestion of debris that may damage components or block restrictions in the systems served by the pumps.	**Conformance.** Each IRWST sump contains paired CSS/SCS and SI suction pipes (two sumps: SI and CS pump suction pipes, two sumps: SI and SC pump suction pipes). Each pair of CSS/SCS and SI suction pipes ends in a suction sump, with each suction sump installed adjacent to an associated strainer (four total). The strainers in the IRWST filter the finer debris (typically down to 2.34 mm [3/32 in]) that is passed through the HVT trash rack plus any debris left in the IRWST from maintenance operations. This provides more area to stop debris while allowing more than adequate flow for the safety system.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.1.1.4	All drains from the upper regions of the containment should terminate in such a manner that direct streams of water will not directly impinge on, or discharge in close proximity to, the ECCS strainers. Streams of drainage from upper containment may contain entrained debris and could also result in air ingestion and other issues if they directly impinge on the strainers. The drains, drain piping internal clearances, and other pathways that connect containment compartments with potential break locations to the sump or suppression pool should be designed to ensure that they would not become blocked by the debris; this will ensure that water needed for an adequate NPSH margin could not be held up or diverted from the pool.	**Conformance.** The IRWST sumps are located inside the IRWST compartment where drains do not directly impinge on them. The drain piping empties into the containment drain sump. There are no drains or narrow pathways directly to the IRWST. Floor drain piping that collects in the containment sump, such as the compartment floor and operating floor, is assumed to become blocked. CS water is drained to lower containment levels by stairway openings, equipment hatch, or compartment access openings. These openings are not considered to be narrow pathways vulnerable to blockage. Since the floor drains are assumed to be blocked, an amount of CS water is assumed to collect and remain on various containment levels. The heights of the water remaining on the containment floors are assumed to be 0.05 m (2 in) on the floors above El. 114′-0″, 0.31 m (12 in) on the refueling cavity, 0.11 m (4.375 in) in the annulus area, and 0.31 m (12.332 in) in the secondary shield wall on the El. 100′-0″ floor. This amount of remaining water is factored into the return water holdup volume in the calculation of IRWST water levels.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.1.1.5	Trash racks, suction strainers, and debris interceptors should be capable of withstanding the loads imposed by expanding jets, missiles, the accumulation of debris, and pressure differentials caused by post-LOCA blockage under design-basis or realistic flow conditions, whichever causes the greater loads. When evaluating the impacts from potential expanding jets and missiles, licensees should justify credit for any protection offered by surrounding structures or credit for remoteness of trash racks and strainers from potential high-energy sources.	**Conformance.** A vertical trash rack is located at each entrance to the HVT. Two trash racks are located in the side wall of the HVT within the secondary shield wall. Two trash racks are located facing the opening in the secondary shell wall from the annulus. The trash racks are designed to seismic Category I and provide distance for protection from jet impingement and missiles. The strainers and sumps are located inside the IRWST compartment. The IRWST is protected by concrete walls and structures, so the strainer will not be exposed to missiles. Strainers are designed to seismic Category I. The structural analysis of the strainer includes static loads imposed by maximum flow with the debris in place and hydrodynamic loads from a seismic event.
1.1.1.6	ECCS strainers, trash racks, and debris interceptors should be designed to withstand the inertial and hydrodynamic effects caused by the vibratory motion of a safe-shutdown earthquake following a LOCA without loss of structural integrity.	**Conformance.** The strainer design basis includes seismic and hydrodynamic loads caused by design basis safe shutdown earthquake (SSE).
1.1.1.7	Licensees should select materials for debris interceptors, trash racks, and suction strainers that do not degrade during periods of inactivity or operation and that have a low sensitivity to stress-assisted corrosion or general corrosion that may be induced by chemically reactive spray or by the containment or suppression pool liquid during a LOCA.	**Conformance.** The strainers are made of stainless steel materials that resist degradation during inactive periods and resist degradation in the chemically reactive post-LOCA environment.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.1.1.8	Licensees should choose a suction strainer design (i.e., size and shape) that will prevent unacceptable loss of NPSH margin from debris accumulation during the period that the ECCS and CSS are required to operate in order to maintain long-term cooling or to maximize the time before the loss of NPSH caused by debris blockage when used with an active mitigation system (see Section C.1.1.4).	**Conformance.** The IRWST sump strainers are designed so that NPSH is not lost even with maximum debris loading due to their large surface area, which provides ample filtration area. An active strainer blockage mitigation system is not applicable to the APR1400.
1.1.1.9	Licensees should assess the possibility of debris clogging narrow flow passages downstream of the ECCS strainer to ensure adequate long-term recirculation cooling, containment cooling, and containment pressure control capabilities. The size of the openings in the strainer should be determined by considering the flow restrictions of systems served by the containment pool. Licensees should consider the potential for long, thin slivers passing axially through the suction strainer and then reorienting and clogging at any flow restriction downstream.	**Conformance.** The debris strainers are made of stainless steel and could use perforated plate with a 2.38 mm (3/32 in) diameter hole. The APR1400 design has been evaluated for strainer downstream effects. All downstream components are capable of fulfilling their design basis functions for the required duration post-LOCA.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.1.1.10	Licensees should consider the buildup of debris and chemical reaction products at downstream locations, including containment spray nozzle openings, HPSI throttle valves, coolant channel openings in the core fuel assemblies, fuel assembly inlet debris screens, ECCS pump seals, bearings, and impeller running clearances. The design of the ECCS pumps is a large factor in determining the sensitivity of the pump operability to ingestion of debris. Three aspects of pump operability— hydraulic performance, mechanical shaft seal assembly performance, and pump mechanical performance (vibration)—must be considered when evaluating the ECCS pumps for operation with debris-laden water. Westinghouse Commercial Atomic Power (WCAP)-16406-P-A, “Evaluation of Downstream Sump Debris Effects in Support of GSI-191” 5 (Reference 21), and its SE (Reference 22) provide evaluation methods and criteria that the NRC considers acceptable. If wear or internal blockage evaluations indicate that a component may not be able to accomplish its design function throughout its mission time and that it is not practical to install a suction strainer with openings small enough to filter out debris that cause excessive damage to ECCS pump seals or bearings, the NRC expects licensees to modify the ECCS pumps or procure new ECCS pumps that can operate long term under the postulated conditions. WCAP-16793-NP, Revision 2, “Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid,” issued October 2011 (Reference 23), discusses a method for use in evaluating the downstream impact of debris on the fuel assemblies,	**Conformance.** The WCAP-16406-P methodology and its associated acceptance criteria were used to evaluate APR1400 downstream ECCS and CSS components. The effects of debris ingested through the containment sump strainer during the recirculation mode of the ECCS and CSS include erosive wear, abrasion, and potential blockage of flow paths. The smallest clearance found for heat exchangers, orifices, and spray nozzles in the recirculation flow path is 9.271 mm (0.365 in) for orifices on the SI pump discharge flow path; therefore, no blockage of the ECCS flow path is expected with an IRWST sump strainer with a hole size of 2.38 mm (0.09 2/32 in). The instrumentation tubing is also evaluated for potential blockage of the sensing lines. The transverse velocity past this tubing is sufficient to prevent debris settlement into these lines, so no blockage will occur. The heat exchangers, orifices, and spray nozzles were evaluated for the effects of erosive wear over the mission time of 30 days. The erosive wear on these components is determined to be insufficient to affect system performance. For pumps, the effect of debris ingestion through the IRWST sump strainer on three aspects of operability, including hydraulic performance, mechanical shaft seal assembly performance, and mechanical performance (vibration) of the pump, were evaluated. The hydraulic and mechanical performance of the pump was determined to be unaffected by the recirculating debris.

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1.1.1.10 (cont.)	as discussed further in Section C.1.3.8.b of this guide. (At the time this guide was revised, the NRC staff had not yet completed its review of WCAP-16793-NP). WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids To Support GSI- 191," issued March 2008 (Reference 24), provides a general approach to conducting chemical effects evaluations, as discussed in Section C.1.3.10 of this guide.	A LOCADM calculation is performed to assess the in-vessel downstream effect on the APR1400, applying the evaluation methods and acceptance bases provided in WCAP-16793-NP, Revision 2. An analysis was performed to determine the type and quantity of chemical precipitates that may form in the post-LOCA recirculation fluid for the APR1400 design. The analysis evaluated these post-LOCA chemical effects using the methodology developed in WCAP-16530-NP-A.
1.1.1.11	ECCS strainers and suction inlets for pumps required for long-term ECCS, CSS, or suppression pool cooling functions should be designed to prevent degradation of pump performance through air ingestion, flashing, and other adverse hydraulic effects (e.g., circulatory flow patterns, high-intake head losses, gas void intrusion).	**Conformance.** During a LOCA, the minimum depth of water in the IRWST is1.52 m (5 ft). At that minimum depth, the top of each strainer is submerged 0.61 m (2 ft) below the surface of the IRWST water. The minimum water level is sufficient to preclude adverse hydraulic effects (e.g., vortex formation and high suction head loss). A low approach velocity at the strainer surface also mitigates the risk of a vortex.
1.1.1.12	Advanced strainer designs have demonstrated capabilities that are not provided by simple flat plate or basket type strainers or screens. The performance characteristics and effectiveness of such designs should be supported by appropriate test data for any particular intended application.	**Conformance.** Advanced strainer designs have demonstrated capabilities that are not provided by simple flat plate or basket type strainers or screens. The performance characteristics and effectiveness of such designs should be supported by appropriate test data for any particular intended application. Under the APR1400 design attributes, the IRWST sump strainers are verified by testing for head loss or chemical effects.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.1.1.13	Prototypical head loss testing should be done to verify suction strainer designs. Section C.1.3.12 provides guidance on prototypical head loss testing.	**Not applicable.** Prototypical head loss testing is done to verify suction strainer designs. Section C.1.3.12 provides guidance on prototypical head loss testing.
1.1.2	**Minimizing Debris** The debris and chemical reaction products (see Sections C.1.3.3 and C.1.3.10) that could accumulate on the suction strainer should be minimized.	The design features and capabilities employed to minimize debris are presented below.
1.1.2.1	Licensees should maintain debris source terms to less than the amount assumed in the strainer performance analysis. For example, cleanliness programs should ensure that the assumed latent debris and suppression pool sludge loading is not exceeded, and controls should be maintained to ensure that problematic debris (e.g., insulations, signage, coatings, foreign materials, and chemically reactive materials) are not introduced into containment to an extent that would exceed the analytically assumed values. In addition, permanent plant changes inside containment should be programmatically controlled so as to not change the analytical assumptions and numerical inputs of the licensee analyses.	**To be addressed by the combined license (COL) applicant.** Performance of the strainers is enhanced by cleanliness programs that limit debris in the containment. A COL applicant that references the APR1400 design certification is to describe the containment cleanliness program that limits debris in containment.

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1.1.2.2	When latent debris is a significant source of debris (i.e., latent debris contributes more than a minimal amount to strainer head loss) that can affect strainer performance or create downstream effects, periodic containment surveys or sampling should be performed to verify that the amount of latent debris is within the assumed limits. Such periodic monitoring may not be necessary if the latent debris evaluation incorporates sufficient conservatism to account for the substantial uncertainties associated with latent debris sampling (See section 1.3.6 for more information regarding latent debris).	**To be addressed by the COL applicant.** As noted in Item 1.1.2.1, this is to be developed by the COL applicant. The program will be established for control a permanent and temporary modifications to ensure that potential quantities of post-accident debris are maintained within the bounds of the analyses and design bases that support ECC and CS recirculation functions and ensure the long term core cooling requirements of 10 CRF 50.46. The program will also be established for control the foreign material exclusion to limit the introduction of foreign material and debris sources into containment.
1.1.2.3	Licensees should adequately assess any new or unanalyzed potential debris sources (e.g., fiber and coatings) resulting from future equipment modifications inside containment against assumptions of debris quantities and types inside containment, as specified in the post-accident sump/pool analysis. Additionally, licensees should assess tags and labels, which can fail and be transported to the strainer, and determine a sacrificial strainer area to account for the strainer area that could become fully blocked by these transportable tags, labels, and other miscellaneous debris.	**To be addressed by the COL applicant.** The APR1400 does not define specific type of materials for miscellaneous debris, such as tapes, tags or stickers, because these are controlled by foreign material control program established by plant owner. To deal with this uncertainty, a 9.29 m^2 (100 ft^2) penalty of sacrificial strainer surface area per sump is applied as a margin for future detail design and installation of the APR1400.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.1.2.4	Licensees should consider using insulation types (e.g., reflective metallic insulation) that transport less readily and cause less severe head losses once deposited onto the strainer in place of insulation types (e.g., fibrous and microporous) that can become debris which can more readily transport to the strainer and cause higher head losses. If insulation is replaced or otherwise removed during maintenance, abatement procedures should be established to avoid generating latent debris in the containment.	**Not applicable.** (This item applies to potential insulation replacement after the plant is licensed and is operating) The APR1400 design uses reflective metal insulation (RMI) for piping and components inside containment. Use of fibrous or particulate insulation could adversely affect sump strainer performance and is limited to the greatest extent practicable. Programmatic controls will be in place to verify containment cleanliness and provide reasonable assurance that no problematic material is present in the containment.
1.1.2.5	To minimize potential debris caused by the chemical reaction of the pool water with metals in the containment, licensees should reduce as much as practical the exposure of bare metal surfaces (e.g., aluminum and uncoated carbon steel) to containment cooling water through spray impingement or immersion either by removal or by chemical-resistant protection (e.g., qualified coatings or jacketing).	**Conformance.** Trisodium phosphate (TSP) is used as a buffering agent, and the use of the aluminum is minimized to preclude adverse chemical effects. As part of the evaluation of IRWST strainer performance for the APR1400, a chemical effects evaluation was conducted to identify specific compounds and quantities of materials that may precipitate within IRWST sump following a LOCA. An analysis was performed to determine the type and quantity of chemical precipitates that may form in the post-LOCA recirculation fluid for the APR1400 design. The analysis evaluated these post-LOCA chemical effects using the methodology developed in WCAP-16530-NP-A.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.1.3	**Instrumentation and Operator Actions** If a licensee relies on operator actions to mitigate the consequences of the accumulation of debris on the ECCS suction strainer, it should ensure that safety-related instrumentation that provides operators with an indication and audible warning of impending loss of NPSH for ECCS pumps is available in the control room. If a licensee relies on operator actions to prevent the accumulation of debris on ECCS suction strainers or to mitigate the consequences of the accumulation of debris on the ECCS strainers, it should evaluate whether the operator has adequate indications, training, time, procedural guidance, and system capabilities to perform the necessary actions.	**Not applicable.** The APR1400 does not rely on operator action as the primary mitigation strategy. CS pump and SI pump operating information is available in the main control room (MCR) to assist in an NPSH evaluation, which includes flow, suction, and discharge pressure.
1.1.4	**Active Systems** An active device or system may be provided to prevent excessive accumulation of debris on the ECCS strainers or to mitigate the consequences of debris accumulation on the strainers. An active system should be able to prevent the accumulation and entry into the system of debris that may block restrictions found in the systems served by the ECCS pumps. The operation of the active component or system should not adversely affect the operation of other ECCS components or systems. In some operational modes, an active system may allow more debris to pass through the strainer. If this is the case, then the downstream effects analysis should be performed accordingly. Performance characteristics of an active system should be supported by appropriate test data that address head loss performance. Active systems should meet the requirements for redundancy for active components.	**Not applicable.** An active strainer blockage mitigation system is not applicable to the APR1400.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.1.5	**Inspection** To ensure the operability and structural integrity of the ECCS strainers and associated structures, access openings may be necessary to permit inspection of the ECCS strainers and associated structures, sump pits, and pump suction piping inlets. On a regular basis, licensees should inspect (including visual examination) strainers, trash racks, vortex suppressors, and pump suction piping inlets for evidence of structural degradation, potential for debris bypass, and presence of corrosion or debris blockage. The licensee should conduct similar inspections for drainage flowpaths (e.g., refueling cavity drains, floor drains), debris interceptors, trash racks, and other design features upstream of the ECCS strainers that are credited in the strainer performance analysis. Inspection of the ECCS strainer, associated structures, and upstream components is best conducted late in a refueling outage to ensure the absence of debris generated by construction or maintenance in the vicinity of the ECCS strainers and upstream design features.	**Conformance.** Personnel hatches are provided on top of the IRWST for access to the IRWST and strainers include openings to allow inspection, so that structural integrity can be confirmed. Access into the sump allows inspection of piping ends and evidence of structural distress or abnormal corrosion of strainers can be detected. The sump and strainer are inspected as part of the containment closeout process to minimize the potential for operation with an unacceptable configuration. In-service inspection of strainers is addressed in the Technical Specification surveillance 3.5.2.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.2	**Evaluation of Alternative Water Sources** Licensees should establish emergency operating procedures to use alternative water sources, either safety-related or non-safety-related, that will be activated if unacceptable head loss renders the ECCS strainers inoperable. For some plant designs, the use of alternative water sources may involve replenishing the inventory of the water storage tank that served as the source of inventory for core cooling during the injection phase of the LOCA. In this case, if the flow rate of the makeup supply to the alternative water source is not larger than the core boiloff rate, procedures should direct replenishment of the water storage tank with alternative water sources following the switchover to recirculation. This flowpath should have a sufficient flow rate to ensure that an adequate water supply will be available in the water storage tank if excessive debris blockage subsequently renders the ECCS strainers inoperable. Licensees should periodically inspect and maintain the valves needed to align the ECCS, CSS, and suppression pool cooling pumps from the recirculation water source to an alternative water source. The impact of adding water volume to containment should be evaluated, if this step is to be used.	**Not applicable.** The APR1400 design does not require an alternate source of water. As described in Item 1.1.3, operator actions are not relied upon to mitigate the consequences of debris accumulation. The strainer is adequately sized to provide reasonable assurance that the available NPSH is sufficient.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3	**Evaluation of Long-Term Recirculation Capability** a. To demonstrate that a combination of design features and operator actions are adequate to ensure long-term cooling and that the criteria of 10 CFR 50.46(b)(5) will be met following a LOCA, licensees should evaluate the long-term recirculation capability. The techniques, assumptions, and guidance described below should be used in a plant-specific evaluation to ensure that any implementation of a combination of the features and capabilities listed in Section C.1.1 are adequate to ensure the availability of a reliable water source for long-term recirculation following a LOCA. These assumptions and guidance can also be used to develop conditions for the suction strainer testing.	**Conformance.**

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1.3 (cont.)	b. Licensees should evaluate (1) ECCS strainer hydraulic performance (e.g., geometric effects, air ingestion, flashing, gas void accumulation), (2) debris effects (e.g., break selection, debris generation, debris transport, latent debris, chemical precipitation, upstream, downstream, interceptor blockage, strainer head loss, and structural integrity), and (3) the combined impact on NPSH available at the pump inlet to confirm and ensure that long-term recirculation cooling can be accomplished following a LOCA. Such an evaluation should demonstrate adequate strainer and pumping performance (e.g., adequate pump NPSH margins, adequate strainer structural strength, and no excessive air ingestion). Licensees should also assess the susceptibility to debris blockage of the containment drainage flowpaths to the recirculation sump or suppression pool. A holdup of water to the pool could affect the NPSH available, flashing and/or air ingestion evaluations. In addition, licensees should assess the structural adequacy of any interceptors or trash racks used to prevent debris blockage of these flowpaths to protect against a reduction in available NPSH if substantial amounts of water are held up or diverted away from the sump or suppression pool. A susceptibility assessment should also be made of the flowpaths and components downstream of the strainers to failure from debris blockage, particulate ingestion, and abrasive effects to protect against long-term degradation.	As part of the GSI resolution for the APR1400 design, IRWST sump performance was evaluated in accordance with NRC RG 1.82 requirements. Vortexing, air injection, flashing, and deaeration were assessed to address adverse hydraulic effects. The break selection, debris generation, and debris transport were analyzed to identify the potential debris that may reach the strainers in the IRWST assuming a number of conservative considerations. The characteristics of potential debris are set, identified, and referred appropriately, and used in the NPSH evaluation of SI, CS, and SC pumps, as well as in the design values for purchase specification of IRWST sump strainers. The upstream effect used to identify the flowpaths that could result in blocking the return water, which could challenge the IRWST minimum water level evaluation, was evaluated and the downstream effects of debris flow through the strainers were also evaluated. As a result of the evaluation, it was verified that the APR1400 design does not challenge long-term recirculation capability in the event of a postulated LOCA.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.1.1	The design of the emergency core cooling and containment heat removal systems should ensure that sufficient available NPSH is provided to the system pumps, assuming the maximum expected temperature of the pumped fluid and no increase in containment pressure from that present before the postulated LOCA. a. It is conservative to assume that the containment pressure equals the vapor pressure of the pool water. This ensures that credit is not taken for containment pressurization during the transient. b. For PWR subatmospheric containments, this guidance should apply after termination of the injection phase. For these subatmospheric containments, before termination of the injection phase, NPSH analyses should include conservative predictions of the containment atmospheric pressure and sump water temperature as a function of time.	**Conformance with exception.** The APR1400 design does not fully conform to Section 1.3.1.1. Credit was taken for containment accident pressure in determining available NPSH of SI pumps and SC/CS pumps of the APR1400. The containment pressure is assumed to be equal to the initial containment pressure prior to the start of the accident. This fulfills the requirements of RG 1.1 and RG 1.82 that the NPSH available is evaluated without crediting any increase in pressure resulting from accident conditions at low temperatures less than 212^{o}F. This approach verifies that sufficient containment pressure is available under accident conditions. For temperatures higher than the initial saturation pressure, containment pressure was assumed to be equal to the sump fluid vapor pressure. The NPSH margin calculation was conducted to verify that NPSH available margin exists.
1.3.1.2	For certain operating reactors in which it is not practicable to alter the design, conformance with Section C 1.3.1.1 may not be possible. In these cases, the determination of available NPSH should not include containment pressure above that which is necessary to preclude pump cavitation. The calculation of available containment pressure and sump/pool water temperature as a function of time should underestimate the expected containment pressures and overestimate the sump/pool water temperatures when determining available NPSH for this situation.	**Not applicable.** As described in Item 1.3.1.1, credit was taken for containment accident pressure in determining available NPSH.

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1.3.1.3	If credit is taken for operation of an ECCS or containment heat removal pump in cavitation, licensees should conduct prototypical pump tests along with a posttest examination of the pump to demonstrate that pump performance will not be degraded and that the pump continues to meet all of the performance criteria assumed in the safety analyses. The time period in the safety analyses during which the pump may be assumed to operate while cavitating should not be longer than the time period for which the performance tests demonstrate that the pump meets the performance criteria.	**Not applicable.** As described in Item 1.3.1.1, the SI pumps and SC/CS pumps are designed with sufficient NPSH margin to preclude pump cavitation.
1.3.1.4	Because high water temperatures reduce available NPSH and can affect the potential for flashing and impacts fluid properties, such as density and viscosity, the determination of the water temperature should include the decay and residual heat produced following accident initiation. This calculation should include the uncertainty in the determination of the decay heat (uncertainty in decay heat is typically included at the 2-sigma level). The licensee should calculate the residual heat with margin.	**Conformance.** The containment post-LOCA pressure and IRWST temperature profiles were used in NPSH calculation. The calculation for IRWST water temperature includes decay heat with margin and all residual heat sources.
1.3.1.5	The correction factor for pumping high-temperature fluid discussed in ANSI/HI 1.3-2009 (Reference 5) to determine the margin between the available and required NPSH for the ECCS and the containment heat removal systems should not be used.	**Conformance.** The assessment of available NPSH for the SI pumps and CS pumps of the APR1400 conservatively does not use the hot fluid correction factor specified in ANSI/HI 1.3-2009 to allow for reduction in NPSH required.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.1.6	The calculation of available NPSH should take into account the minimum calculated height of water above the pump suction and strainer surfaces. The calculated height of water should not consider quantities of water that do not contribute to the sump or suppression pool (e.g., atmospheric steam, pooled water on floors and in refueling canals, spray droplets and other falling water, holdup in containment coolers, water held up by upstream obstructions, and the volume of empty system piping). Licensees should not credit non-leaktight structures, such as ducting for heating, ventilation, and air conditioning, for the displacement of water for the purposes of determining the minimum water level. The calculated height of water available should not include the amount of water in enclosed areas that cannot readily be returned to the sump or suppression pool. Minimum water level calculations should consider worst-case break locations (e.g., breaks at high elevations) that could lead to a minimum quantity of reactor coolant reaching the sump or suppression pool. Licensees should consider volume shrinkage of the reactor coolant inventory as it cools in terms of crediting the contribution of spilled coolant to the sump or suppression pool and in terms of the volume reduction of the coolant remaining in the primary system that will allow the ECCS to inject additional inventory into the primary system before filling it. Licensees should explicitly consider the limiting small-break LOCA water level because elevated break locations may be possible and certain sources of inventory (e.g., PWR accumulators) may not inject.	**Conformance.** The minimum water level in the IRWST during post-LOCA is 26.2 m (86.0 ft) (1.52 m [5 ft] above the IRWST bottom floor at elevation 81′-0″). The minimum post-LOCA water level in the IRWST was used in evaluation of available NPSH for SI pumps and SC/CS pump. The evaluation of minimum water level includes identifying the holdup volumes, such as water volume lost to the containment atmosphere and on containment wall surfaces, piping fill volume, flooded volume of all compartments in the containment at an elevation lower than the main spillways, spray volume, and other water volumes that could affect the flood height.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.1.7	Licensees should calculate the pipe and fitting resistance and the nominal strainer resistance without blockage by debris in a recognized, defensible method or determine it from applicable experimental data. The clean strainer head loss (i.e., the friction head loss caused by the passage of flow through the strainer and any associated connecting pipes and plenums) calculations should consider the distribution of flow through the strainer that produces the highest head loss. For some curvilinear-type strainer designs, this occurs with a filtering debris bed near the strainer outlet and a clean strainer where the unobstructed flowpath is longer. If the strainer were partially covered with a filtering debris bed, much of the strainer flow could occur through the unblocked strainer surfaces, which could be more limiting for some designs.	**Conformance.** The calculation of hydraulic resistance of piping, fittings, and valves was performed using a conservative value from Crane Technical Paper 410. The clean strainer head loss was performed using widely recognized and approved industry standards.
1.3.1.8	Licensees should use Sections C 1.3.10 and C 1.3.11 to determine strainer head loss caused by blockage from LOCA-generated debris and its chemical reaction products or from foreign material in the containment that is transported to the suction intake screens.	**Conformance.** The strainer head loss use a conservative of 0.61 m-water (2 ft-water) over the temperature of interest. The actual debris head loss is evaluated by qualified test results conducted specific to the APR1400 plant conditions. Based on the results of strainer testing, the maximum head loss for the 46.5 m^2 (500 ft^2) effective strainer area with the maximum debris load is 0.25 m–water (0.81 ft-water) at the design flow rate and includes a clean screen component of 0.16 m-water (0.51 ft-water). The strainer testing head loss of approximately 41 % of the design strainer head loss of 0.61 m-water (2.0 ft-water) ensures adequate NPSH margin for the ECCS pumps.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.1.9	Licensees should calculate available NPSH as a function of time until it is clear that the available NPSH will not decrease further.	**Conformance.** The NPSH margin calculation as a function of time was performed to provide reasonable assurance that NPSH available margin exists.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.2	**Pipe Break Characterization** a. A sufficient number of high-energy pipe break locations resulting in ECCS recirculation should be considered to reasonably bound variations in debris generation by the size, quantity, and type of debris. The objective of the break selection process is to identify the break location and size that results in debris generation that produces the maximum head loss across the sump screen. Licensees should consider all aspects of the accident scenario for each postulated break location, including debris generation, debris transport, latent debris, coating debris, chemical effects, upstream and downstream effects of debris accumulation, and sump screen head loss. b. The objective of strainer head loss testing is to simulate the debris from the break location that transports the maximum amount of debris to the sump strainer or the combination of debris types that produces the maximum head loss. At a minimum, licensees should consider the postulated break locations and pipe break characteristics described in the following sections. c. Section 3.3.3 to 3.3.5 of NEI 04-07 (Reference 26) and the associated SE (Reference 27) and Section 3.2.1.1 of Reference 15 provide additional guidance in break selection	**Conformance.** The methodology described in NEI 04-07 and the NRC Safety Evalution Report (SER) for NEI 04-07 was used to assess pipe break characterization. The following general break locations are considered: • Break Type No. 1: Break in the reactor coolant system (RCS) with the largest potential for debris • Break Type No. 2: Largest break with two or more different types of debris • Break Type No. 3: Break in the most direct path to the sump • Break Type No. 4 : Large break with the largest potential particulate debris to insulation ratio by weight • Break Type No. 5 : Break that generates “thin bed”-high particulate with low fiber The debris generated by the most limiting cases in Break No. 1 bounds Break Nos. 2 and 4 because the only type of insulation used for the piping and equipment in containment is RMI. There are no breaks of a high-energy line within the IRWST, and Break No. 3 is not evaluated. Therefore, Break Nos. 1 and 5 are applicable. The junction of the RCS hot leg pipe (106.7 cm [42 in]) and the steam generator was selected as the postulated limiting break

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.2 (cont.)		location. Destruction of insulation and coatings conservatively used a zone of influence (ZOI) from a 106.7 cm (42 in) hot leg break. As noted in Item 1.3.2.2, the D-ring with the largest debris generation source is used. Further evaluation is addressed in the sump design technical report.
1.3.2.1	Licensees should consider breaks where debris is most easily transported to the suction strainer (e.g., breaks in areas with the most direct path to the sump strainer or suppression pool).	**Conformance.** See response to Item 1.3.2..
1.3.2.2	Licensees should consider a spectrum of breaks, including the breaks with the largest quantity and greatest variety of debris within the expected zone of influence (ZOI).	**Conformance.** See response to Item 1.3.2
1.3.2.3	Licensees should consider medium and large breaks that have the greatest potential ratio of particulate to fibrous insulation debris by weight and breaks that generate an amount of fibrous debris that, after its transport to the strainer, could form a thin layer that could subsequently filter sufficient particulate debris to create a relatively high head loss (called the “thin-bed effect”). A “thin bed” is a relatively thin layer of debris on a screen or strainer that causes a large flow resistance and, consequently, a large pressure drop for flowing liquid.	**Conformance.** The performance of the IRWST sump strainers is based upon strainer validation testing. Four types of debris were used in the test. Aged Nukon fiberglass prepared as fines to simulate latent fiber, silicon carbide to simulate epoxy paint, sand mixture to simulate latent particulate, and aluminum oxy-hydroxide to simulate chemical debris The IRWST sump strainer testing has shown a thin bed developed on the strainer.
1.3.2.4	Licensees should disregard break exclusion zones in their evaluations (i.e., pipe breaks must be postulated in break exclusion zones).	**Conformance.** The break exclusion zone was not considered in the APR1400 design in accordance with the general guidance of NEI 04-07.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.2.5	Licensees should exclude NRC Branch Technical Position (BTP) 3-4, “Postulated Rupture Locations in Fluid System Piping inside and outside Containment” (Reference 25), as a basis for selecting break locations because limiting conditions for ECCS strainer performance are not related to the pipe vulnerability issues addressed in BTP 3-4.	**Conformance.** The APR1400 design did not use BTP 3-4 as a basis for determining potential break location.
1.3.2.6	Licensees should consider locations that result in a unique debris source term (i.e., not multiple, identical locations). Particular consideration should be given to breaks that result in the destruction of materials known to cause high head loss, such as microporous insulation (e.g., calcium silicate, Min-K, and Microtherm).	**Not applicable.** The APR1400 design does not use microporous insulation in the containment.
1.3.2.7	If the LOCA blowdown does not generate a significant amount of fibrous debris, the contribution of latent debris sources may become the limiting factor in ECCS strainer and downstream evaluations.	**Not applicable.** No fibrous debris is generated by LOCA blowdown in the APR1400 design because RMI, which contains no fibrous material, is used on components that may be subjected to jet impingement loads from a LOCA jet. **Conformance.** The APR 1400 design is used 90.7 kg (200 pounds) of latent debris in the evaluation of debris generation and 92.5 % of the latent debris is considered particulate, and 7.5 % is considered fibrous. These values are used for the evaluation of sump strainer performance.
1.3.2.8	If long-term cooling requires recirculation flow through the ECCS strainer for non-LOCA HELBs (e.g., main steam break, feedwater line break), then licensees should use the same selection criteria for break locations as those specified for a LOCA.	**Conformance.** Main steam line break was used as the non-LOCA event in the APR1400 evaluation of debris generation.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.3	**Debris Generation/Zone of Influence** The initial pressure wave and erosion associated with the jet impingement can generate debris from the blowdown of a ruptured pipe. Insulation, coatings, fire barriers, shielding blankets, and other materials that are located within a material-dependent range of distances from the pipe rupture location can become debris as the result of the LOCA blowdown. The volume of space affected by this impact, or ZOI, is modeled to define and characterize the debris generated.	**Informational Material.**
1.3.3.1	**Zone of Influence Model** a. The size and shape of the ZOI should be consistent with experiments performed for specific debris sources (e.g., insulation, coatings, fire barrier materials). The ZOI should extend until the pressure wave impulse and jet pressures decrease below the experimentally determined damage pressures appropriate for the debris source.	**Conformance.** The method described in NEI 04-07 and the NRC SER for NEI 04-07 is used for determining the ZOI in assessing debris generation for the APR1400.
1.3.3.1 (cont.)	b. Licensees should use the volume of material contained within the ZOI to estimate the amount of debris generated by a postulated break. The size distribution of debris created in the ZOI should be determined from applicable experiments. It is noted that if robust barriers intersect the postulated jet zone, the extended volume may be truncated within the limitations of NEI 04-07, "PWR Sump Performance Evaluation Methodology," Section 3.4.2.3, and its associated SE (References 26 and 27).	**Conformance.** The debris size distribution for RMI debris used in the APR1400 debris generation evaluation is broken into two categories, 75% small fines and 25% large pieces, based on NEI 04-07 and the NRC SER for NEI 04-07. Small fines are defined as debris capable of passing through openings in gratings, trash racks, and radiological fences that are smaller than a nominal 101.6 mm (4 in). Thus, within small fines, there are fines and small pieces.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
	c. Licensees should use the pressure wave impulse and jet impingement generated during the postulated pipe break as the basis for estimating the amount of debris generated and the size or size distribution of the debris generated within the ZOI.	**Conformance.** The APR1400 design uses the guidance provided in NEI 04-07 and the NRC SER for NEI 04-07 to determine the size or size distribution of debris generated within the ZOI.
1.3.3.1 (cont.)	d. Licensees should perform debris generation testing to determine the ZOI in a manner that is prototypical of the plant condition. Test scaling is complicated because material destruction may result from both pressure waves and jet impingement. Scaling considerations for debris generation testing include the test fluid used (e.g., air or saturated water), the initial thermodynamic conditions of the test fluid, the rupture disk opening time, the blowdown period, the size and orientation of the test nozzle relative to the target, and the specific configuration of the target material to the various plant materials to which it is being applied (e.g., insulation jacketing seam, jacketing thickness, and banding and latching strength The staff has not developed specific guidance for the performance of ZOI testing. Methods and results are reviewed on a case-by-case basis. One example is the Air Jet Impact Tests documented in Section 3.2.1 of the NRC RG (Reference 15).	**Not Applicable.** The method described in the NEI 04-07 and NRC's SER for NEI 04-07 is utilized for determining the ZOI in assess debris generation of APR1400.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.3.1 (cont.)	e. If the evaluation uses simplified ZOI models, such as the spherical ZOI models that are discussed in Section 3.2.1 of NEDO-32686-A (Reference 15) and Section 3.4.2 of NEI 04-07 (References 26 and 27), licensees should apply sufficient conservatism to account for simplifications and uncertainties in the model. For example, a spherical ZOI model assumes that the blowdown from a LOCA is evenly distributed in all directions radiating from the break location. Although, with sufficiently conservative inputs, a spherical model may be appropriate for estimating the loadings of debris within a ZOI, such a model does not account for non-uniform blowdown that could create damage in a particular direction at much greater distances from the break. Therefore, such a spherical model would likely be non-conservative when specifying an exclusion zone for particularly problematic materials (e.g., calcium silicate insulation for a PWR with a trisodium phosphate buffer, fibrous debris for a plant with a limited strainer area that intends to demonstrate that a fibrous debris bed cannot be formed).	**Not applicable.** As noted in Item 1.3.3.1, the APR1400 design use the spherical ZOI model described in the NEI 04-07 and NRC's SER for NEI 04-07. The APR1400 design has no problematic debris generated by LOCA blowdown.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.3.2	Certain types of material used in small quantities inside the containment can, with adequate justification, be demonstrated to make a marginal contribution to the debris loading for the ECCS sump. If debris generation and debris transport data have not been determined experimentally for such material, the material may be grouped with another material with similar physical and chemical characteristics existing in large quantities. For example, a small quantity of fibrous filtering material may be grouped with a substantially large quantity of fibrous insulation debris, and the debris generation and transport data for the filter material need not be determined experimentally. However, such analyses are valid only if the small quantity of material treated in this manner does not have a significant effect when combined with other materials (e.g., combining a small quantity of calcium silicate with fibrous debris may not be valid).	**Conformance.** The APR1400 uses the methodology outlined in the NEI 04-07 guidance report and its associated NRC SER to determine the debris loading that will result in the maximum head loss across the sump strainer. The APR1400 evaluation conservatively assumed that all latent debris will be transported to the sump strainer and RMI debris will not be transported to sump strainer. All particulate and coating debris is assumed to be fine debris and 100% transported to the sump strainer. The chemical debris that is generated during long-term recirculation is considered in the strainer head loss evaluation.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.3.3	All insulation (e.g., fibrous, calcium silicate, and reflective metallic); painted surfaces; fire barrier materials; and fibrous, cloth, plastic, or particulate materials within the ZOI should be considered as potential debris sources. Licensees should use applicable test data as the basis for predicting the size of the postulated debris. For breaks postulated in the vicinity of the containment penetrations, licensees should also consider the potential for debris generation from the packing materials used in the penetrations. In addition, licensees should consider breaks that could destroy the insulation installed on the pressure vessel. The potential for particulate debris to be generated by the action of pipe rupture jets stripping off paint or coatings and erosion of concrete at the point of impact should also be considered.	**Conformance.** All potential debris material within the ZOI that could adversely affect the operation of the ECCS and CSS following a LOCA is considered in the APR1400 debris generation evaluation.
1.3.3.4	In addition to debris generated by jet forces from the pipe rupture, the analyses should consider (1) debris existing before the pipe rupture that is transported to the suppression pool, (2) debris created by the reactor pressure vessel environment (i.e., thermal and chemical), (3) debris created by the atmospheric environment (i.e., thermal and chemical), and (4) debris created by the environment of the submerged containment or suppression pool, as appropriate. Examples of debris created by the environment include disbonded coatings in the form of chips and particulates or the formation of chemical products caused by chemical reactions in the containment pool or the suppression pool or the reactor vessel (see Sections C.1.3.5 and C.1.3.10).	**Conformance.** Debris created by the resulting reactor pressure vessel environment (thermal and chemical) is considered in the APR1400 debris generation evaluation. This type of debris includes disbondment of coating and formation of chemical debris (precipitants) caused by adverse chemical effects.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.3.5	The analyses should consider debris erosion that results from continued degradation of insulation and other debris when subjected to turbulence caused by cascading water flows from upper regions of the containment or that result from the flows in the sump or suppression pool or chemical decomposition. The determination of eroded quantities for various types of debris should be based on testing that is prototypical of plant conditions. In the absence of applicable testing, demonstrably conservative assumptions should be used. (For example, the SE for NEI 04- 07 Appendix III (Reference 27) recommends using a bounding value of 90% erosion for fibrous debris).	**Not applicable.** The APR1400 evaluation assumed that the post-LOCA 30-day erosion of fiber insulation debris in containment is no longer required to be considered because all the fiber debris is assumed to be fines. The effect of erosion during post-LOCA 30-day operation is not required to be considered for RMI debris characterization.
1.3.4	**Debris Transport** The debris transport evaluation determines the fraction of containment debris that is transported to the ECCS strainer.	**Informational Material.**

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.4.1	The calculation of debris quantities transported to the ECCS strainers should consider all modes of debris transport, including blowdown transport, spray transport, washdown transport, and transport within the containment pool. Consideration of containment pool debris transport should address (1) debris transport during the pool fill phase, as applicable, and during the recirculation phase, (2) the velocity and turbulence in the sump, suppression pool, or storage tank (i.e., turbulence caused by the flow of water to the ECCS strainers, water splashing down from the break, containment spray drainage, and the discharge of pressure-relief flowpaths such as from downcomers, vents, and safety/relief valve spargers), and (3) the density, characteristic size, and other properties of the debris. Section 3.2.3 of the SE for NEDO-32686-A, (Reference 15), and Section 3.6 of the SE for NEI-04-07 (Reference 27) discuss staff accepted methods to evaluate debris transport. NUREG/CR-6369 (Reference 28) is also a useful reference document for debris transport evaluations. Section 3.6.4 of NEI 04-07 (Reference 26) contains a sample calculation for debris transport that the staff finds acceptable.	**Conformance.** The evaluation of debris quantities transported from debris sources to the sump strainer is conservatively bounded by the assumption that all latent debris will be transported to the sump strainer and RMI debris will not be transported to sump strainer. All particulate and coating debris is assumed to be small fine debris and 100% transported to the sump strainer. The chemical debris that is generated during long-term recirculation is considered in the strainer head loss evaluation.
1.3.4.2	Transport analyses within the containment pool should include debris that may transport through the following modes: (1) floating along a water surface, including debris that may float temporarily because of air entrapment, (2) traveling with the containment flow (i.e., debris suspended within the flow) because of neutral buoyancy or turbulence (e.g., individual fibers and fine particulates), and (3) settling to the floor and tumbling along the floor to reach the strainer.	**Conformance.** See response to Item 1.3.4.1.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.4.3	The debris transport analyses should consider each type of insulation (e.g., fibrous, calcium silicate, and reflective metallic), other debris such as chemical precipitates, coatings, latent debris, and debris size (e.g., fine, readily suspendable, small, large, and intact). The analyses should also consider the potential for further decomposition of the debris as it is transported to the ECCS strainers.	**Conformance.** See response to Items 1.3.4.1 and 1.3.3.5.
1.3.4.4	An acceptable analytical approach to predict debris transport resulting from fluid flows caused by long-term recirculation or pool fill is to use appropriately verified computational fluid dynamics (CFD) simulations in combination with experimental debris transport data. The CDF simulations can be used to predict fluid flows, while debris transport thresholds can be determined experimentally. Section 4.2.4 of NEI 04-07 (Reference 26) and Section 4.2.4 and Appendix III in the associated SE (Reference 27) provide guidance and an example of this approach. Alternative methods for debris transport analyses are also acceptable, provided that they are supported by adequate validation of analytical techniques using experimental data to ensure that the debris transport estimates are conservative with respect to the quantities and types of debris transported to the strainer.	**Not applicable** Conservative assumptions regarding debris transport as provided in response to Item 1.3.4.1 are used in the APR1400; hence, use of CFD is unnecessary.
1.3.4.5	The analysis may credit curbs for removing heavier debris that has been shown analytically or experimentally to travel by sliding along the containment floor and that cannot be lifted off the floor within the calculated water velocity range. Curbs around the ECCS strainers may reduce or prevent some types of debris from transporting to floor- or pit-mounted strainers during the pool fill phase (see NUREG/CR-6772 (Reference 13) for limitations).	**Not applicable.** Curbs are not considered in the APR1400 to maximize debris transport to the sump strainer.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.4.6	If transported to the containment pool, all debris that would remain suspended because of turbulence (e.g., fine fibrous and particulates) should be considered to reach the ECCS strainers. However, if settlement of fine fibrous and particulate debris is credited during recirculation or pool fill, licensees should provide adequate theoretical and experimental basis to demonstrate that such settling is prototypical of plant conditions. This settlement analysis should include the potential for natural convection through the water column providing a motive force to keep the material in suspension.	**Not applicable.** Conservative assumptions regarding debris transport as provided in response to Item 1.3.4.1 are used for the APR1400.
1.3.4.7	In lieu of performing detailed blowdown and washdown debris transport analyses, licensees can conservatively assume that all debris entering or originating in the sump or suppression pool is transported to the ECCS strainers when estimating strainer debris bed head loss.	**Conformance.** See response to Item 1.3.4.
1.3.4.8	The effects of floating or buoyant debris on the integrity of the ECCS strainers and on the strainer head loss should be considered during the initial filling of the sump (if applicable) and during recirculation. For strainers that are not fully submerged or are only shallowly submerged, floating debris could contribute to the debris bed head loss. Entrapped air may cause some types of debris to temporarily float; the debris may then be transported to the vicinity of the ECCS strainers by surface currents and then sink on top of the strainers. A design feature (e.g., use of trash racks and solid cover plate) that keeps floating debris from reaching the sump or suppression pool strainer could reduce head loss caused by floating or buoyant debris.	**Not applicable.** As noted in Item 1.1.1.11, the top of each strainer is submerged below the surface of the IRWST water. The strainers are always fully submerged for post-LOCA, which minimizes the effects of floating or buoyant debris on the integrity of the sump strainer and on subsequent head loss.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.4.9	**Use of Debris Interceptors** Credit for the performance of debris interceptors upstream of the ECCS strainers should be based on results of tests that are demonstrated to be either conservative or representative with respect to the plant condition. If the interceptors are credited with capturing fine debris to reduce the ECCS strainer debris load, licensees should perform time-dependent analyses and tests that consider the conditions that would lead to minimum debris capture fractions. This analysis also should include the potential of trapped debris further eroding into fines that could then pass through the interceptors. Iterative analyses of the flow in the sump or suppression pool (e.g., multiple computational fluid dynamics simulations that have been acceptably verified) may be necessary if the blockage of the interceptors has a significant impact on the containment pool flow pattern.	**Not applicable.** No debris interceptors are installed or credited in the APR1400.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.5	**Coating Debris** Coating debris is generated from the postulated failure (destruction) of both DBA-qualified and unqualified coatings within the ZOI and from the postulated failure of unqualified coatings outside the ZOI. NRC reports entitled, “NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Coatings Evaluation,” issued March 2008 (Reference 29), and “Revised Guidance Regarding Coatings Zone of Influence For Review of Final Licensee Responses To Generic Letter 2004-02, ‘Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents At Pressurized-Water Reactors,’” dated April 6, 2010 (Reference 30), provide a general approach to conducting plant-specific coatings evaluation.	**Informational Material.**
1.3.5.1	Licensees should use a ZOI for coatings that is determined by applicable testing and plant specific analysis. The fluid used for the test, i.e., steam, air, two-phase water, should be representative of the plant exposure conditions.	**Non Conformance.** A ZOI of 4D in the evaluation of the quantity of coating debris was used based on the NRC letter in 2010 (Reference [3-4]).
1.3.5.2	All (100 percent) unqualified coatings should be assumed to fail. However, licensees may also be able to demonstrate the performance of their unqualified coatings through plant-specific and coating-specific testing.	**Not applicable.** Unqualified coatings are not used in reactor containment in the APR1400. Hence, a coating-specific test is unnecessary.
1.3.5.3	Licensees should determine the debris characteristics (e.g., size, shape, density) of failed coatings separately for each coating within containment.	**Conformance.** Per Section 3.4.3.2 of NEI 04-07, all qualified coatings within the coating ZOI are assumed to fail and all qualified coatings located outside the coatings ZOI are considered not to fail. The size of coating debris is considered to be small fines.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.5.4	Licensees may determine coating chip debris transportability in flowing water by using the results in NUREG/CR-6916 (Reference 14) to the extent they apply to a licensee's plant-specific coating types.	**Not applicable.** As noted in Item 1.3.4.1, all particulate and coating debris is assumed to be small fine debris and 100% transported to the sump strainer.
1.3.6	**Latent Debris** a. Latent debris present in containment during operation may contribute significantly to head loss across the ECCS strainers. Licensees must determine the types, size, quantities, and locations of latent debris. NEI 04-07, and its associated SE (Reference 26 and 27), provide general considerations for latent debris in terms of its potential impact on strainer blockage and some plant-specific variables. In collecting latent debris samples for analysis, licensees should use a sampling technique with demonstrated collection efficiency for fine particulate and fibrous debris. NEI 02-01, "Condition Assessment Guidelines: Debris Sources inside PWR Containments," dated September 30, 2002 (Reference 31), provides an accepted approach for determining latent debris quantities.	**Conformance.** As noted in Item 1.3.2.7, 90.7 kg (200 lb) of latent debris was used in the APR1400 debris generation evaluation. The 92.5 percent of the latent debris is considered particulate and 7.5 percent is considered fibrous.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.6 (cont.)	b. Applicants or licensees should not assume that their (existing) foreign material exclusion programs have entirely eliminated miscellaneous debris. Results from plant-specific walkdowns should be used to determine a realistic amount of latent debris in containment and to monitor cleanliness programs for consistency with committed estimates. Evaluation of the results of latent debris walkdowns should include sufficient conservatism to account for substantial uncertainties inherent in the debris sampling and collection process. In lieu of plant-specific walkdowns, 10 CFR Part 52 applicants may perform conservative analyses that are based on latent debris measurements made for operating plants.	**Conformance.** See responses to Items 1.1.2.1 and 1.1.2.2.
1.3.7	**Upstream Effects** a. Section 7.2 of the staff's SE on NEI 04-07 (Reference 27) provides guidance on evaluating the flowpaths upstream of the PWR containment sump for the holdup of inventory, which could limit flow to, and possibly starve, the suction strainer. A similar approach may be used for BWRs.	**Conformance.** The APR 1400 design is evaluated for upstream effects to assess the flowpaths upstream of the IRWST sump for holdup of inventory that could reduce flow to and possibly starve the sump.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.7 (cont.)	b. Licensees should use the results of their debris assessments to estimate the potential for water inventory holdup. Based on these assessments and the mapping of probable flowpaths, licensees should determine whether trash racks or debris interceptors are necessary to protect flowpaths in upper containment to prevent the holdup of water upstream of the sump, storage tank, or suppression pool. Licensees should also evaluate the effect that the placement of curbs and debris interceptors may have on the holdup of water en route to the sump, storage tank, or suppression pool.	**Conformance.** See responses to Items 1.1.1.2, 1.3.4.5, and 1.3.4.9..
1.3.8	**Downstream Effects** a. Debris may be carried downstream of the ECCS strainer, thus causing downstream blockage or wear and abrasion. The three areas of concern identified are (1) blockage of system flowpaths at narrow flow passages (e.g., containment spray nozzles, some pump internal flow passages, and tight-clearance valves), (2) wear and abrasion of surfaces (e.g., pump running surfaces) and heat exchanger tubes and orifices, and (3) blockage of flowpaths through fuel assemblies.	**Conformance.** The APR1400 downstream effects evaluation of debris ingestion on the auxiliary equipment, including the pumps, heat exchangers, orifices, spray nozzles, and instrumentation tubing, follow the methodology in WCAP-16406-P-A.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.8 (cont.)	b. The quantity and size characteristics of this strainer bypass debris will be unique to each strainer vendor and plant-specific debris mixtures and should be determined during strainer head loss tests, as discussed in Section 1.3.12.g. WCAP-16406-P-A (Reference 21) provides a method that the NRC considers acceptable for PWR licensees to use in evaluating the downstream impact of sump debris on the performance of their ECCSs, CSSs, and components following a LOCA. The NRC has received WCAP-16793-NP (Reference 23) for review.7 This report provides a method and reference for PWR licensees whose plants are bounded by its input assumptions to use in evaluating the downstream impact of sump debris on the performance of fuel following a LOCA, subject to the conditions and limitations specified in the NRC SE to be prepared for WCAP-16793-NP, Revision 2. Neither of these reports applies to BWRs at this time.	**Informational Material.**
1.3.9	**Strainer Structural Analysis** This Regulatory Position also applies to trash racks and debris Interceptors, if used.	

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.9.1	General items identified for consideration in the structural analyses should include (1) the verification of maximum differential pressure caused by the combined clean strainer and worst case debris scenario at rated flow rates or maximum realistic flow rates, whichever is greater, (2) geometry concerns (i.e., mesh and frame versus perforated plate), (3) ECCS strainer material selection for the post-accident environment (i.e., corrosion-resistant materials that can withstand the post-LOCA environment), and (4) the addition of hydrodynamic loads.	**Conformance.** The strainers are installed away from the spargers to minimize the effect of hydrodynamic loads induced by the discharge of water, air, and single- and two-phase steam due to the opening of the pressurizer POSRVs into the IRWST. Strainers are designed to seismic Category I and quality Class Q. The structural analysis of the strainer is performed to verify the structural adequacy of the sump strainer, including seismic, differential pressure, and hydrodynamic loads. The strainers are made of stainless steel materials that resist degradation during inactive periods and resist degradation in the chemically reactive post-LOCA environment.
1.3.9.2	Licensees should compute structural loads on a strainer using the maximum pressure drop across the strainer. Licensees should also evaluate the limiting conditions corresponding to the break location and debris source term that induce the maximum total head loss at the ECCS strainer.	**Conformance.** See response to Item 1.3.9.1.
1.3.9.3	For some licensees, the minimum structural design criterion for the ECCS strainer can depend on the plant's NPSH margin. Plant-specific licensing bases may dictate the structural capacity of the ECCS strainer for supporting water flow through a debris bed under recirculation velocities, depending on strainer geometry (i.e., fully submerged versus partially submerged or vented designs).	**Conformance.** See response to Item1.3.9.1.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.9.4	Load combinations (e.g., safe-shutdown earthquake, deadweight, crush pressure, thermal, and live loads) used for structural analysis should be performed in accordance with the specific plant licensing basis requirements and the applicable design code of record. Licensees should also reference Regulatory Guide 1.92, “Combining Modal Responses and Spatial Components in Seismic Response Analysis” (Reference 32), when analyzing the seismic loading conditions during the structural analyses of the strainers.	**Conformance.** The sump strainers are safety-related components and are designed to meet APR1400 seismic Category I requirements based on NRC RG 1.92.
1.3.9.5	Licensees should include the effects of the fluid temperature and containment ambient temperature (e.g., restrained thermal growth, temperature dependent material properties) in determining the structural integrity of the strainer.	**Conformance.** See response to Item 1.3.9.1.
1.3.9.6	Licensees should perform an evaluation to determine the possibility for dynamic loading on the strainers caused by HELBs and other structures, systems, and components that could produce missiles, pipe whipping, or jet impingement loads. Chugging and condensation oscillation loads can be a significant contributor in some BWR designs. This evaluation should be done in accordance with GDC 4 and should be based on the plant’s design basis for postulated dynamic effects within the region of the strainers. Based on the SE for NEI 04-07 (Reference 27), in general, if a postulated pipe break is located more than 10 pipe diameters away from the strainer, the dynamic effects of such a break may be neglected with respect to the structural integrity effects on the strainer.	**Conformance.** See response to Item 1.3.9.1.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.10	**Chemical Reaction Effects**	
	a. Chemical reaction products in the post-LOCA environment of containments can contribute to blockage of the ECCS strainers and increase the associated head loss. The final SE by the Office of Nuclear Reactor Regulation on WCAP-16530-NP-A (Reference 24), and the NRC report entitled, "NRC Staff Review Guidance Regarding Generic Letter 2004-02, Closure in the area of, Plant-Specific Chemical Effect Evaluations" (Reference 33), provide a general approach to conduct plant-specific chemical effects evaluation.	**Conformance.** A chemical effects analysis was performed for the APR1400. The quantity of chemicals dissolved in the post-LOCA sump pool is determined using WCAP-16530-NP and associated letters and SE. The dissolved chemical quantities along with the boron and phosphate concentrations due to the borated sump water and TSP, respectively, were considered in the evaluation of chemical effects.
	b. During a LOCA, materials in the ZOI of the break can become debris that may transport to the containment pool where spray solution, spilled reactor coolant, and water from other safety injection sources accumulate. Subsequently, the combination of spray chemicals, insulation, corroding metals, and submerged and unsubmerged materials can create a potential condition for the formation of chemical substances that may impede the flow of water through the ECCS suction strainers or downstream components in the ECCS, CSS, or reactor coolant system.	**Conformance.** As part of the APR1400 IRWST strainer performance evaluation, a chemical effects evaluation was conducted to identify specific compounds and quantities of materials that may precipitate within the reactor containment sump pool following a LOCA. An analysis was performed to determine the types and quantities of chemical precipitates that may form in the post-LOCA recirculation fluid for the APR1400 design.
	c. New reactors with configurations different than those of operating PWRs (e.g., different containment materials, lack of buffering agents) may require additional evaluation.	**Conformance.** See responses to Items 1.1.2.5, 1.3.10.a, and 1.3.10.b.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.11	**Debris Accumulation, Head Loss, and Vortexing** a. In a letter to NEI dated March 28, 2008 (References 4 and 8), the NRC provided guidance for evaluating the potential for debris accumulation and its impact on strainer head loss during a LOCA that could impede or prevent the ECCS or CSS from performing its intended safety functions. b. Testing and analyses performed to address GL 2004-02 indicate that the maximum head losses for the ECCS strainers in some plants can occur when a layer of fiber just thick enough to fully cover the strainer accumulates on the strainer along with a bounding quantity of fine particulate matter. This case may result in a thin, dense debris bed with low porosity that could maximize head loss. The thickness of the fiber layer necessary to filter fine particulate cannot be specified in general, but it is dependent on a number of factors, including the strainer design, the strainer geometry and orientation, the approach velocity, the type and size of the fibrous debris, the type of particulate debris, and the presence of chemical effects. Appendix A, Section 6, of Reference 8 provides testing methods acceptable to the NRC staff to evaluate thin bed effects.	**Informational Material.**

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.11 (cont.)	c. Other testing and analyses have shown that the maximum debris loading case can also be a limiting head loss condition for strainers. Therefore, licensees should test for both the thin-bed and maximum loading cases. If the maximum debris loading case can result in a circumscribed debris accumulation, licensees should ensure that the strainer design and head loss test scaling accounts for this effective reduction in the strainer surface area.	
1.3.11.1	Debris accumulation on the ECCS strainers for the head loss evaluation should be based on the amount of debris generated and the formation of different combinations of fibers and particulate mixtures (e.g., a fiber bed with a minimum thickness necessary to effectively filter particulate debris, as well as maximum debris loading) using the guidelines described in Section C.1.3.3 and on the debris transported to the strainers in accordance with Section C.1.3.4. The evaluation should be based on plant-specific debris loads determined in accordance with these regulatory positions.	**Conformance.** The performance of the sump strainers is based on conservative assumptions relative to the quantity of debris, ECC and CS flow, and temperature conditions.
1.3.11.2	The degree of ECCS strainer submergence (full or partial) at the time of switchover to recirculation should be considered in calculating the available (wetted) screen area. For plants in which certain pumps take suction from the ECCS strainers before the switchover of other pumps, the available NPSH for these pumps should consider the submergence of the strainers at the time these pumps initiate suction through the strainers. Unless otherwise shown experimentally, licensees should assume that debris is uniformly distributed over the available strainer surface.	**Not applicable.** Following an accident, water spilled from an RCS break and the uniformly distributed CS water drain back to the HVT. The water drains into the HVT and is ultimately returned to the IRWST through the IRWST spillways, by gravity, once the HVT water level reaches the IRWST spillways. The APR1400 eliminates the need to switch over from the injection mode to the recirculation mode.

Appendix A – Comparison of IRWST Sump Strainer Design to NRC RG 1.82 Requirements

NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.11.3	Strainer submergence should be adequate to preclude vortexing, sump fluid flashing, and deaeration induced by excessive differential pressure drop. Vortexing can cause the ingestion of unacceptable quantities of air into the ECCS and CSS pumps, potentially resulting in unacceptable pump performance. Water, when flashing to steam, can result in recirculating coolant that transforms a portion of the fluid into the vapor phase if the strainer pressure drop is sufficiently large. For partially submerged strainers, licensees should evaluate the potential for vortex formation internal to the strainer. Deaeration can similarly result in ingested air and unacceptable pump performance, whereas both deaeration and sump fluid flashing can result in an unacceptable increase in strainer head loss caused by the increased resistance associated with two-phase flow.	**Conformance.** The top of each strainer is submerged below the surface of the IRWST water. The minimum water level is sufficient to preclude adverse hydraulic effects (e.g., vortex formation, sump fluid flashing, and deaeration).
1.3.11.4	Licensees should validate the adequacy of ECCS strainer designs through testing applicable to plant-specific conditions. Analytical or empirical head loss correlations should not be used to validate plant-specific debris bed head losses. However, correlations may be useful in conducting scoping evaluations for conditions and debris loads with the range of applicable test data.	**Conformance.** See response to Item 1.3.2.3.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.12	**Prototypical Head Loss Testing** a. The methodology to predict the key inputs to the head loss testing has been conservatively developed and documented in NEI 04-07, referred to as the guidance report and its associated SE (References 26 and 27). Additionally, the NRC staff review guidance (Reference 8) provides a general approach to conducting plant-specific prototype head loss testing. This guidance report document discusses the staff positions on various aspects of head loss testing including scaling of the plant strainer design to the test strainer module, similitude considerations for debris transport and debris accumulation on the strainer, surrogate debris similitude requirements, and posttest data processing extrapolation.	**Conformance.** The performance of the IRWST sump strainers is based on conservative assumptions relative to the quantity of debris, ECCS flow, and temperature conditions. The strainer design provides sufficient strainer area for acceptable strainer head loss under debris laden conditions. The strainer head loss is validated by testing. The APR1400 design is such that the IRWST sumps remain continuously submerged.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.12 (cont.)	b. The objective of prototypical head loss testing is to determine the potential peak or bounding head loss that could occur across a suction strainer debris bed during a postulated LOCA scenario. If the test facility is scaled properly and the testing procedures are conservative, the measured head loss is also expected to be conservative. To ensure adequate strainer function, licensees should design the test facility properly and conduct testing following conservative testing procedures. The conditions within the test tank should be prototypical or conservative with respect to the plant, including the postulated debris loading, the recirculation system hydraulics, and key aspects of various accident scenarios. The primary scaling parameters include the screen area, the dimension of the strainer elements (e.g., disks), and the submergence level, the number of strainer elements, the debris amounts, and the local fluid flow conditions, as applicable. These parameters affect the flow velocities approaching the test strainer and the velocities through accumulated debris.	**Conformance.** The prototypical head loss test is designed in accordance with the head loss testing guidance provided in NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing dated March 2008. This staff guidance provides acceptable methods to perform prototype strainer head loss testing. Further details regarding strainer head loss tests are discussed in Appendix C.
	c. The test specifications should be designed to determine a reasonably bounding head loss from all of the possible types of debris beds that could accumulate on the strainer considering the plant specific debris quantities that would transport.	**Conformance.** See response to Item 1.3.2.3.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.12 (cont.)	d. Post-test evaluations are required to validate the head loss results, apply the results to the proposed strainer, and ensure that the debris penetrating the strainer cannot cause adverse effects to downstream equipment. Licensees that want to scale the results of head loss tests conducted using colder water to the plant water temperatures should ensure that boreholes, bed degradation, open strainer area, or other phenomena that could affect the head loss response of the debris bed do not have a non-conservative effect when the temperature is scaled. The NRC does not recommend scaling of head loss results to alternate approach velocities or debris loadings because the theoretical debris bed head loss behavior is not well understood and the results of experiments examining these parameters have varied.	**Conformance.** See response to Item 1.3.12.b.
	e. Licensees may need to extrapolate the results of head loss testing for a time period matching the mission time of the ECCS. The method of extrapolation used should be one that conservatively fits the data (e.g., linear, log, quadratic) over the time period of interest.	**Conformance.** See response to Item 1.3.12.b.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.12 (cont.)	f. Because of the complexity of modeling and scaling multiple, complex physical phenomena in a single test, licensees should conduct head loss tests in a manner that ensures complete transport of debris (as determined by transport analysis) to the test strainer. Agitation of the test fluid with stirrers may be necessary to achieve conservative debris transport. If desired, licensees may conduct separately testing to credit reductions in debris transport (i.e., settling) to the strainer under conditions that are conservatively or prototypically scaled to the plant condition. However, strainer head loss testing that credits debris settlement within the test tank should carefully evaluate the flow characteristics (e.g., velocity and turbulence) in the test to ensure that the simulated flows are prototypical or conservative with respect to the plant condition. Licensees should consider scaling of debris per unit area of floor in the flume versus debris per unit floor area of the plant with respect to effects on debris transport caused by potential piling up of debris in areas of flow restrictions. The quantity of debris per unit width of the flume relative to the flow passages in the plant is also an important scaling parameter. Licensees should also give special consideration to the adequacy of other aspects of the test protocol, such as debris preparation, addition sequencing, debris concentration in the flume, and test flume geometry, to conclude that similar or larger amounts of debris settling would occur in the plant containment. Consideration should also be given to how debris settlement during a head loss test impacts other aspects	**Conformance.** See response to Item 1.3.12.b.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.12 (cont.)	of the analysis. For example, allowing debris to settle in the test tank can lead to a failure to account for erosion of this settled debris in the analysis. Because of the practical inability to simultaneously scale multiple, complex phenomena associated with debris transport and head loss in a rigorous way, licensees should apply conservatism to tests that model both transport and head loss. Section 4.0 of Appendix A of Reference 8 provides more details on this topic.	**Conformance.** See response to Item 1.3.12.b.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.12 (cont.)	g. Licensees may sample the flows downstream of the test strainer to determine the amount of debris passing through the strainer. The sampling should be performed on a frequency that ensures adequate characterization of the total bypass content. This debris could potentially damage or clog components, such as pumps, throttling valves, or components within the reactor core. Licensees may use the downstream debris characteristics to determine the likelihood that downstream blockage or wear and abrasion could threaten long-term core cooling or impact heat transfer of the fuel cladding. The conditions for the limiting downstream sampling tests will typically differ from the conditions for the limiting debris bed head loss tests because a filtering debris bed will tend to reduce the quantity of debris that passes through the strainer. A large strainer surface area, higher ECCS flow rates, low rate of debris introduction into the water, or thinner debris beds can result in higher quantities of bypass debris. Licensees may need to conduct separate strainer pass-through tests for fibrous and particulate debris to avoid crediting filtration caused by one debris type that might affect the other debris type. Collecting bypass debris in a filter with very small pore size, downstream of the strainer has also been successfully used to characterize the bypass content8.	**Conformance.** See response to Item 1.3.12.b.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.12 (cont.)	h. The analyses and testing should consider worst-case single failures. For example, licensees with plant designs that include low-pressure safety injection (LPSI) pumps that shut down during the switchover from the refueling water storage tank to the sump should consider one LPSI train failure to stop. This assumption leads to a conservatively calculated maximum flow rate to and through the screen.	**Conformance.** See response to Item 1.3.12.b.
	i. The time dependence of debris arrival at the strainer is difficult to model in a practical number of head loss tests. A conservative assumption is that all of the LOCA debris is present on the strainer at the beginning of recirculation. This debris should include the debris generated from the LOCA blowdown, failed unqualified coatings, eroded fine debris, chemical precipitates, and all other debris predicted to transport to the strainer.	**Conformance.** See response to Item 1.3.12.b.
	j. Head loss testing for complex combinations of debris that typically result from limiting plant debris loads has, in some cases, shown significant variation for the same debris loading. As a result, licensees should ensure that head loss test results have been demonstrated to be sufficiently repeatable, in light of known margins, uncertainties in debris quantities, the collective body of knowledge from tests on similar strainers, and other relevant information.	**Conformance.** See response to Item 1.3.12.b.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
1.3.12 (cont.)	k. Proper debris introduction procedures should take into account the fact that variations in the sequence and rate of debris introduction can potentially affect the head loss measurement. The approach that is considered most conservative is to introduce the debris slowly into the test tank with the pump running and prototypical hydraulic conditions established. The most transportable debris should be added first and the least transportable last. Licensees may also use other approaches, if justified. Testing that takes credit for near-field settlement should either realistically or conservatively simulate the strainer upstream flow and turbulent conditions. Licensees should conduct proper analytical evaluation of the similitude between the test tank and the actual plant condition. The NRC staff considers computational fluid dynamic codes to be useful tools to assist the evaluation. Surrogate debris materials used in head loss testing should be either the actual plant materials or suitable substitutions. Licensees should justify substitutions by comparing the important characteristics of the plant debris sources and the surrogate to ensure that the debris preparation creates prototypical or conservative debris characteristics.	**Conformance.** See response to Item 1.3.12.b.
2	**Regulatory Positions Specific to Pressurized Water Reactors** Any evaluation of the susceptibility of a PWR to debris blockage should address the considerations and events shown in Figure 3 (see page 33).	**Informational Material.**

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
2.1	**Emergency Core Cooling System Sumps, Strainers, and Debris Interceptors** Distribution of water sources and containment spray between the sumps should be considered in the calculation of boron concentration in the sumps for evaluating post-LOCA subcriticality and shutdown margins. Typically, these calculations are performed assuming minimum boron concentration and maximum dilution sources. Similar considerations should also be given in the calculation of time for hot-leg switchover, which is calculated assuming maximum boron concentration and a minimum of dilution sources. Additionally, the evaluation of debris transport to the sump screen should consider the time to switch over to sump recirculation and the operation of containment spray.	**Conformance.** Four separate, independent, and redundant trains of the SIS and CSS with two SI pumps and one CS pump in each division are provided. Within each division, the two SI trains (and each CS train) are separated by a quadrant wall to isolate the trains from each other to the maximum extent practical. Each of the four SI pumps has its own suction connection to the IRWST and each of two CS pumps shares one of these four connections. The four sumps are provided in the IRWST. Each IRWST sump contains paired CSS/SCS and SI suction pipes (two sumps: SI and CS pump suction pipes, two sumps: SI and SC pump suction pipes). Each pair of CSS/SCS and SI suction pipes ends in a suction sump, with each suction sump installed adjacent to an associated strainer (four total). The IRWST contains approximately 2,457 m^3 (649,000 gal) of 4,000 ~ 4,400 ppm boric acid at pH 3.8 ~ 10.5. To minimize the corrosion of stainless steel in containment during a LOCA, long-term post-LOCA pH control (between 7.0 and 10.0 within the first 4 hours, between 7.0 and 8.5 up to 30 days after 4 hours) of the IRWST water is provided by granular trisodium phosphate (TSP), which is stored in the HVT. The stainless steel TSP storage baskets have a solid top and bottom with mesh sides to provide reasonable assurance of dissolution when submerged in water. The risk of dilution is considered negligible because the amount of diluent required to achieve a significant reduction in boron concentration is unrealistic (i.e., without being undetected).

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
2.1.1	The ECCS strainers should be located on the lowest general area floor elevation in the containment, exclusive of the reactor vessel cavity and the normal drainage sump, to maximize the pool depth relative to the strainers. Design considerations for recirculation strainers should ensure that they protect the pump inlets for which they supply water. A curb could be provided upstream of the strainers to prevent high-density debris from being swept along the floor into the sump strainer. To be effective, the height of the curb should be appropriate for the pool flow velocities and plant debris types because debris can be carried over a curb if the velocities are sufficiently high. Estimation of pool flow velocities should include both the pool fill (as applicable) and recirculation phases of the event. Licensees should also consider that turbulence in the pool may keep some debris in suspension that would otherwise settle. Experiments documented in NUREG/CR-6772 (Reference 13) and NUREG/CR-6916 (Reference 14) demonstrated that some types of settled debris could transport across the containment pool floor to the suction strainer by sliding or tumbling at typical containment pool velocities.	**Conformance.** The methodology described in NEI 04-07 and the associated NRC SER was used to perform the analysis of susceptibility of the ECCS and CSS recirculation functions to the adverse effects of post-accident debris blockage and operation with debris-laden fluids.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
2.1.1 (cont.)	The ECCS strainer structures should include access openings and other design features, as required, to facilitate inspection of the strainer structures, any vortex suppressors, and the pump suction piping inlets. Where consistent with overall design and functionality, the top of the ECCS strainer structures should be a solid cover plate that is designed to be fully submerged after a LOCA and completion of the ECCS injection from the water storage tank. The cover plate is intended to provide additional protection to debris interceptor structures from LOCA-generated loads and from water drainage from upper containment. However, the design should also provide a means for venting any air trapped underneath the cover.	
2.2	**Chemical Reaction Effects**	
	a. The Westinghouse report, WCAP-16530-NP-A, and the limitations discussed in the associated SE (Reference 24) provide an acceptable approach for PWRs to evaluate chemical effects that may occur in a post-accident containment sump pool.	**Conformance.** See response to Item 1.3.2.
	b. Plant-specific information should be used to determine chemical precipitate inventory in containment. However, plant specific chemical effect evaluations should use a conservative analytical approach. Additionally, "NRC Staff Review Guidance Regarding Generic Letter 04-02 Closure in the Area of Plant-Specific Chemical Effect Evaluations" (Reference 33) provides a general approach for PWR licensees to conduct plant-specific chemical effect evaluations.	**Conformance.** See response to Item 1.3.10.

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NRC RG Item No.	Regulatory Position	APR1400 Design Features and Capabilities
2.2. (Cont.)	c. WCAP-16793-NP “Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid,” (Reference 23) is still under review by the NRC staff. When approved by the staff, it, along with the SE, will provide guidance for evaluation of chemical debris within the reactor.	**Conformance.** The testing and analysis were performed for in-vessel downstream effects using the methodology developed in WCAP-16793-NP to demonstrate reasonable assurance that sufficient LTCC is achieved for PWRs to satisfy the requirements of 10 CFR 50.46 for debris and chemical products that might be transported to the reactor vessel and core by the coolant recirculating from the containment sump.

Appendix B

IRWST Sump Strainer Performance Testing

List of Appendix B

Appendix B-1

Head Loss Test Plan of the APR1400 IRWST Sump Strainer

Appendix B-2

Bypass Test Plan of the APR1400 IRWST Sump Strainer

Appendix B-3

Head Loss Test Report of the APR1400 IRWST Sump Strainer

Appendix B-4

Bypass Test Report of the APR1400 IRWST Sump Strainer

Head Loss Test Plan of the APR1400 IRWST Sump Strainer

Non-Proprietary

October 2013

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Acronyms and Definitions

CSS	Containment Spray System
ECCS	Emergency Core Cooling System
GSI	Generic Safety Issue
HELB	High Energy Line Break
IRWST	In-containment Refueling Water Storage Tank
LDFG	Low Density Fiberglass
LOCA	Loss of Coolant Accident
M&TE	Measuring and Test Equipment
NEI	Nuclear Energy Institute
NPP	Nuclear Power Plant
NPSH	Net Positive Suction Head
NRC	Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
RHR	Residual Heat Removal
RMI	Reflective Metallic Insulation
SER	Safety Evaluation Report
SIS	Safety Injection System
TPI	Transco Products Incorporated

1. BACKGROUND

The APR1400 has four (4) ECCS/CS trains with an independent 600 ft^2 strainer for each train for a total of 2,400 ft^2 [1]. The design requires a minimum of three trains in operation (1,800 ft^2) assuming one train with a single failure and one train with a maintenance outage. The strainers prevent debris from being ingested into the Safety Injection system (SIS) and Containment Spray system (CSS) in the event of a loss-of-coolant-accident (LOCA) and are located within the In-containment Refueling Water Storage Tank (IRWST).

The design and evaluation methods for the strainer performance are in accordance with the latest revision of Regulatory Guide 1.82 [2]. If a LOCA inside the reactor building were to occur, it could generate debris that, if transported to and deposited on the recirculation sump screens, could challenge the safety function of the recirculation sumps. Specifically, debris that could accumulate on the sump screens would increase head loss across the resulting debris bed and sump screen. This head loss might be sufficiently large such that it may exceed the net positive suction (NPSH) margin of the SIS and CSS pumps that draw from the sump.

The purpose of this test is to develop head loss data to validate IRWST sump strainer performance using a conservative assumption that all debris is 100% transported to a single sump strainer. Should this test program find the head losses to be unacceptable, the mass of latent fiber may be reduced or the strainer surface area can be increased.

2. TEST APPROACH

This head loss test plan is designed in accordance with the head loss testing guidance provided in NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing dated March 2008 [3]. This staff guidance provides acceptable methods to perform prototype strainer head loss testing.

2.1 Test Objective

The objective of the tests is to develop experimental head loss data associated with the debris accumulated on the sump strainer from the most limiting high-energy line break in containment.

Flow sweeps will be conducted to obtain additional head loss data as a function of flow rate (i.e., approach velocity) to adjust the head loss over the range of fluid temperatures required for sump operation. While the flow sweeps are often the norm and used to determine the relative proportionality of laminar and turbulent flow, the objective of this test is to achieve little or no head loss as a result of open screen area and therefore may ultimately be scaled by density due to primarily turbulent flow.

The tests will collect and record differential pressure across the strainer, fluid temperature, and pump flow rate for the debris mixtures identified in the test matrix. The proposed tests in this test plan are designed to demonstrate that the head loss associated with the strainer configuration is acceptable for the design debris loading. Acceptance in this definition is within available ECC/CS pump NPSH margin. This evaluation will take place outside this test report. A data report will be developed presenting the results of the testing associated with this test plan.

2.2 Test Description

A test matrix is designed to validate the performance of the sump strainer for varying debris loads from a spectrum of break locations identified in the debris generation and transport calculation [1]. For plants with the potential to generate relatively large quantities of fibrous debris, the test matrix should provide confidence that the peak head loss has been conservatively or prototypically determined. The approach is to validate the head loss from the maximum debris bed case either in a single test or multiple tests as accepted by the NRC in their Supplemental Guidance [3].

The APR1400 utilizes reflective metallic insulation (RMI) as the primary insulation system in containment and therefore has very little fibrous debris that reaches the IRWST sump strainer. In fact, the only fiber component resulting from the spectrum of break locations is latent fibrous debris. The quantity of latent debris at this time (since the plant is not yet built) is an assumption. KHNP has selected 200 lbs of latent debris with 92.5 percent / 7.5 percent split of particulate and fibrous constituents.

A full scale prototype section of the strainer will be installed in a test tank and loop with sufficient water volume to allow circulation of debris around the prototype. The recirculation flow through the test loop and strainer is established based on the plant strainer and flow rate.

The test will begin with a clean strainer flow sweep with no debris in the tank. This flow sweep will measure the head loss created by a clean strainer at each of the flow rates in the Test Matrix. These head loss values will be compared to the analytical values developed in the clean strainer head loss calculation. At the end of this flow sweep, the flow will be adjusted to the target test flow rate.

The debris test will begin by first adding in the full mass of particulate and then adding the scaled masses of fiber that correspond to 7.5 lbs and 15 lbs of fiber on a single 600 ft^2 plant strainer (2 batches will be added), which will produce slightly greater than a 1/8 in debris bed. After the fiber loads have been introduced and debris head loss stabilized, chemical precipitate loads will be introduced into the tank. Flow sweeps are performed at the stabilized head loss before and after the chemical precipitates are added and head loss stabilization has been achieved. Once stabilization has been achieved and flow sweeps performed, the test is terminated and complete.

2.3 Test Acceptance

The testing is designed to obtain steady-state debris head loss data as a function of flow rate and temperature for the prototype strainer assembly. Given the nature of the chemical precipitates, it is not possible to predict the head loss associated with these materials with any certainty.

However, it is expected that with this small quantity of fiber debris, there will be very little head loss associated with the fiber, particulate and chemical effects.

3. TEST ARTICLE

3.1 IRWST Sump Strainer Design

The IRWST sump strainer will fit over the existing sump pits (Figure 3-1). There are four (4) IRWST sump strainers, each with a minimum of 600 ft^2 for a total of 2,400 ft^2. To be conservative, the entire debris load will be applied to a 600 ft^2 single strainer. The test prototype will represent a single strainer during testing. Therefore, the test parameters must be scaled to this value. The flow rates for the safety injection, containment spray and shutdown cooling are also shown in Figure 3-1. Under a normal LOCA, all four (4) sumps are operational with four (4) trains of safety injection (SIP) and two (2) trains of containment spray (CSP). Considering a single failure and a maintenance outage, only two (2) trains of safety injection and one (1) train of containment spray would be operational. Shutdown cooling would not be running during the LOCA.

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Figure 3-1: Plant Recirculation Sump Strainers (4 total) [10]

The APR1400 utilizes RMI as the primary insulation system and does not use fibrous or other problematic materials inside containment, the only source of fibrous insulation is latent debris. Therefore, the types and quantities of debris are limited to latent fiber and particulate, coatings and chemical effects. A portion of the sump strainer will be considered blocked with 100 ft^2 of labels and tags. Therefore the effective area of the strainer will be considered to be 500 ft^2.

The strainer is designed based on the following conditions [1]:

1) Flow Condition
   - a) Flow rate (gpm)..6,660
   - b) Fluid temperature (°F)... ....140 – 230

2) Debris Quantities
   - a) Epoxy paint (ft3)...0 – 3.1
   - b) Latent fiber (lbs)* ....15 [7.5]
   - c) Latent particulate (lbs)* ....185 [192.5]
   - d) Chemical Effects
     - i) Calcium Phosphate (kg) 0.7
     - ii) Sodium Aluminum Silicate (kg) 4.3
     - iii) Aluminum Oxy-hydroxide (kg).. 180.1

*will be finalized during strainer bypass testing

3.2 Test Prototype Strainer

A full-scale section of the strainer prototype will be tested in the tank. This assures a 1:1 scaling ratio for test parameters, e.g. flow rate, tube diameters, and perforated plate hole size which is 3/32 in [5]. The debris quantities for the prototype tests shall be in proportion to the full-scale screen size, and the flow rate through the prototype will be proportional to the full-scale strainer. The prototype strainer design is shown in Figure 3-2. The design uses cartridge assemblies to increase the surface area to any given allowable surface area. For this testing, three cartridges of four tubes each will be used. The surface area of the prototype is 75.1 ft^2 [6]. The tubes are attached to a plenum that allows a flow path from each tube to the pump suction pipe. See Figures 3-3 and 3-4. All materials of the strainer and plenum are stainless steel.

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Figure 3-2: Strainer Prototype

Figure 3-3: Strainer Prototype in Tank
(Top View)

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Figure 3-4: Strainer Prototype in Tank
(Side View)

4. TEST FACILITY

The test facility to be used will have performed strainer testing for US PWRs in the United States. There are several acceptable test facilities in the US with GSI-191 experience that have been visited/audited by the USNRC. This will assure that the protocols (debris prep, etc.) used by the facility for testing meet the USNRC expectations. The facility will contain a 2,500 gallon or greater tank capable of holding the strainer with adequate room around the test prototype and the capability to achieve the target flow rate. A schematic of an example facility is shown in Figure 4-1.

The filter cartridges must be attached and sealed against the flow plenum. A return line or sparger system should be installed to aid in the suspension of the debris within the water. Sufficient turbulence shall be employed to keep the debris from settling while not disturbing the debris bed.

The data acquisition program must be programmed to match the test parameters. English units will be displayed and recorded in the test logs and data files.

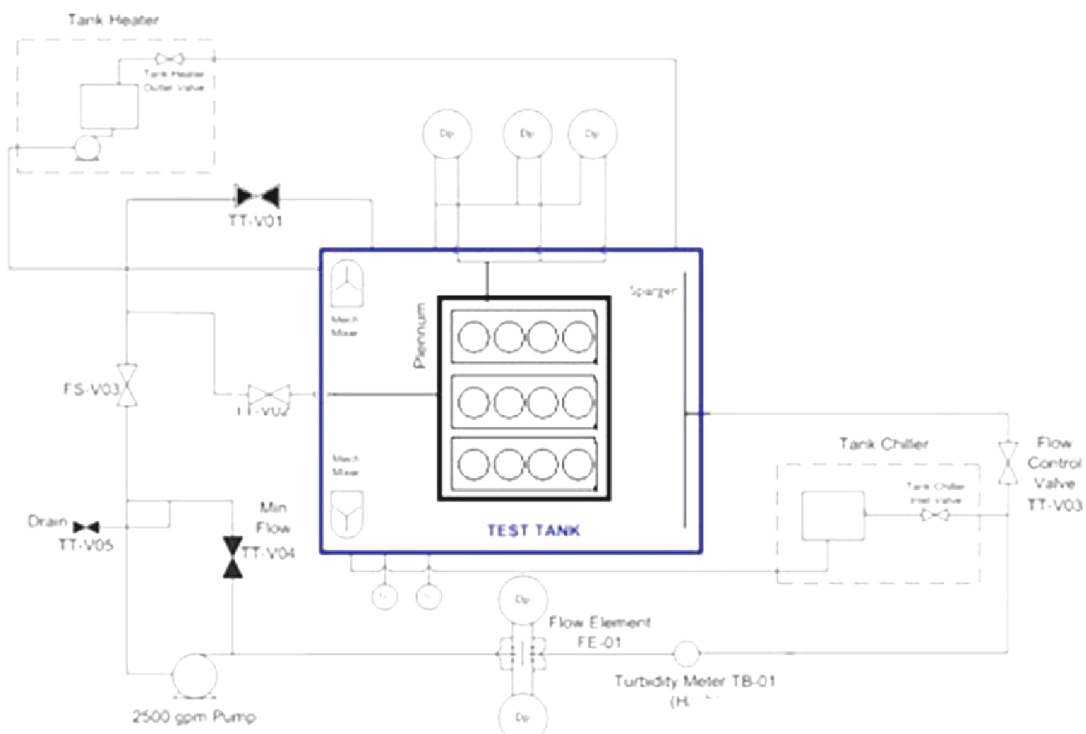

Figure 4-1: Example Tank Piping and Instrumentation Diagram

4.1 Test Equipment

The instrumentation available for use must conform to the following specifications and be within the approved calibration date.

Table 4-1: Required M&TE

Instrument	Range	Accuracy
Pressure transmitter	0 – 100 in-water 0 – 300 in-water	± 0.25% of span ± 0.25% of span
Flow meter	90 – 1200 gpm	± 2.5% of reading
Thermocouple	32 ˚F to 212 ˚F	± 1% of reading
Benchtop chemistry equipment	As needed to produce WCAP-16530-NP chemical precipitates	*Various as required by test control*

Data Acquisition system, verified prior to testing and after testing

- Real-time analog data acquisition system, allowing continuous display of test parameter values and trends. Data is sampled at least every two seconds, and averaged over the previous 10 data points. Test data is recorded for each instrument in a simple spreadsheet for later analysis.
- The data acquisition system is used to collect time, flow rate, differential pressure, and temperature data throughout the performance of the tests. This system also allows for the creation of graphs of the data as well as tables of the raw data.

5. TEST CONDITIONS

5.1 Hydraulic Conditions

5.1.1 Test Strainer Flow Rate

The maximum post-LOCA recirculation flow rate is 6,660 gpm for a single sump. The IRWST sump strainer is 500 ft^2 of effective screen area per train. Given the prototype strainers size of 75.1 ft^2, the prototype strainer target flow rate is the plant flow rate multiplied by the ratio of the strainer areas:

$$6{,}660 \text{ gpm x } \frac{75.1 ft^2}{500\, ft^2} = 1{,}000\ gpm$$

5.1.2 Water Temperature and Chemistry

The water temperature at the beginning of testing will between 80 °F and 100 °F. This temperature will increase during testing as the pump adds energy into the fluid, but the temperature should be limited to 100 °F. A tank chiller should be utilized to limit the water temperature to 100 °F. Tap (potable) water shall be used as the testing fluid to ensure the stability of the WCAP-16530-NP precipitates.

5.1.3 Water Level

The strainers must remain submerged during testing except during vortex formation studies. The required minimum submergence during head loss testing is 2’-0” (+/- ¼ inches).

5.1.4 Turbulence

Sufficient turbulence shall be added into the test tank during testing to preclude settling of debris. The turbulence must be limited, however, to avoid artificially removing debris from the strainers. The turbulence can be added via mixing motors or equivalent.

5.2 Debris Conditions

The following section describes the types and quantities of debris to be used for the testing.

5.2.1 Epoxy Coatings

Epoxy coatings are considered to be destroyed within the Zone of Influence. Based on the upstream analysis, the quantity of destroyed coatings is 3.1 ft^3. NEI-04-07 [4] estimates the particle size of failed coatings to be 10 μm on average with a density of 94 lbs/ ft^3. A suitable and common surrogate used in US testing is silicon carbide (SiC) with a mean particle size of 10 μm and material specific gravity of 3.2 which corresponds to a density of 199.5 lb/ft^3. Silicon Carbide is selected for resistance to dissolution in the potable water and interaction with other materials (and relative availability). While the requirement for the characteristic size is 10 μm spheres, the SiC surrogate contains a size distribution. This is actually quite conservative since it will create a higher packing density (small spheres fit within the spaces of the larger spheres) and creates more drag and head loss in the debris bed. The source and measured size distribution of the SiC used in testing shall be provided in the test report summary. In determining the amount of SiC to add to the test it is important that the volume of particulates is preserved. Therefore the amount of SiC to be added to the test is:

$$m_p = \frac{75.1\, ft^2}{500\, ft^2}\, x\, 3.1 ft^3\, x\, 199.5 \frac{lbs}{ft^3} = 92.9 lbs$$

5.2.2 Latent Debris

Latent debris defined as dirt and dust on surfaces inside containment and is comprised of a fibrous and particulate component. For strainer testing the quantity of latent debris is 200 lbs, with 185 lbs of particulate and 15 lbs of fiber.

1) Latent Fiber

The latent fiber will be represented by NUKON low density fiberglass which per NEI-04-07 has an as-fabricated density of 2.4 lbs/ ft^3 (see NEI-04-07 SER Appendix VII). **The source of the NUKON used in testing shall be provided in the test report summary.** The fiber added to the tank shall have a size characteristic of fines (Class 1-3) per Attachment B of NUREG/CR-6224 [7] skewed more favorably toward Classes 1 and 2. A suitable procedure for producing these fines is presented in Reference [8]. The mass of fiber to be added to the test is:

$$m_f = \frac{75.1\, ft^2}{500\, ft^2}\, x\, 15\, lbs = 2.3\, lbs$$

This will produce a conservative debris bed thickness slightly greater than 1/8 in.

2) Latent Particulate

The NRC (Appendix VII of NEI-04-07) states that a suitable surrogate formulation for latent particulate is 28 percent mass fraction between 500 μm and 2 mm, a 35 percent mass fraction between 75 μm and 500 μm and 37 percent mass fraction <75 μm. The latent dirt and dust of the plant will be represented by a blend of silica sand made specifically for head loss testing. Dirt/Dust PWRII Mix will be the surrogate debris material for the latent dirt/dust, which is a material blend of silica sand representative of PWR latent dirt/dust for head loss testing. The size distribution of the silica sand shall be prepared to be consistent with the latent dirt/dust size distribution provided in Table 5-1. The source and measured size distribution of the dirt/dust mix used in testing shall be provided in the test report summary.

Table 5-1: Dirt/Dust Mix Requirements

PWR Mix 2	Sand Type Distributions Based on Product Data Sheets			Size Classification / Consolidation			
Sand Recipe Mix (lbs)	Coarse Sand 8	Medium Sand 54	Fine Sand 38	Allocation Basis (lbs)	PWR 2 Calc	NRC Target	
< 75 microns			98.50%	37.4	37.4%	37%	Fines
> 75 microns			1.50%	0.6	35.3%	35%	Medium
< 500 microns		63.77%		34.4			
> 500 microns		36.23%		19.6	27.3%	28%	Coarse
< 500 microns	3.37%			0.3			
> 500 but < 2000 microns	96.63%			7.7			
Note: Each type of sand has particles in two size ranges				100.0	100.0%	100.0%	
The above recipe will achieve the NRC Target.			Sand Class Key	Fine	Medium	Coarse	

Similarly, the mass of latent particulate to be added to the test is:

$$m_{lp} = \frac{75.1\ ft^2}{500\ ft^2}\ x\ 185\ lbs = 27.8\ lbs$$

5.2.3 Chemical Precipitates

Based on the design conditions presented in Section 3.1, the following chemical precipitates may be available in the IRWST sump fluid.

- Calcium Phosphate 0.7 kg
- Sodium Aluminum Silicate 4.3 kg
- Aluminum Oxy-hydroxide 180.1 kg

Given the relative proportions and since aluminum oxy-hydroxide can be conservatively used to represent the other precipitates [9], only AlOOH will be used in the test program. The total chemical precipitate mass of 185.1 kg will be represented by AlOOH.

The chemical precipitate shall be prepared in accordance with the WCAP-16530-NP [9] (in terms of settling rates) and batched into the test tank in pre-defined quantities to collect the head loss data required by the test program. This precipitate suspension must have a calculated concentration of 11 g precipitate/L of water. The chemical precipitate settling shall be measured within 24 hours of the time the precipitate will be used and the 1-hour settled volume of 10 mL solution shall be 6.0 ml or greater and within 1.5 ml of the freshly prepared precipitate.

Chemical precipitates shall be used within one week of manufacturing. The volume of prepared AlOOH surrogate for the test are as follows:

$$V_{AlOOH} = \frac{75.1\ ft^2}{500\ ft^2}\ x\ 185.1\ kg\ x\ \frac{L}{.011kg}\ x\ \frac{1\ gal}{3.785L} = 667.8\ gal$$

This is a significant amount of chemical precipitates. However, it is anticipated that the test will not need this much precipitate due to the fact that either 1) the debris bed will not cover the entire strainer uniformly by design and/or 2) the head loss will reach a maximum and adding more precipitate will not cause any further increase in head loss. The test protocol will make provisions for either of these cases.

Table 5-2: Debris Load Summary

	APR1400 Strainer		Test Strainer	
Strainer Surface Area	500	ft^2	75.1	ft^2
Coatings	3.1	ft^3	92.9[1]	lbs
Latent particulate	185	lbs	27.8	lbs
Latent fiber	15	lbs	2.3	lbs
Chemical load	180.1	kg	667.8	gal

[1] mass of SiC surrogate.

6. TEST PERFORMANCE

All personnel working on the test (engineers, technicians, chemists, managers) must be trained to the applicable test procedures of the laboratory. At a minimum, this includes the Test Procedure, Lab Safety Procedure, Debris Preparation Procedures, Tank Operation Procedures including the operation of M&TE, and the laboratory Project Plan.

6.1 Test Procedures

All testing actions will be governed by an approved Test Procedure to be developed by the testing vendor. The test-specific procedure provides the instruction for performing the required test steps, and the associated signatures provide documentation for the performance and witnessing of critical steps. This test procedure shall also provide for a test log, which is used to document significant points during the performance of the test. Actions that affect the testing environment (debris additions, flow adjustments, stirring, etc.) shall be noted in the Test Log by a trained Test Engineer. Visual observations should also be noted. All documentation in the test log shall be legible.

The test vendor shall develop generic test procedures for debris preparation, fill and start-up testing including M&TE installation and verification, tank cleaning, lab safety, nonconformance/deviations, and head loss testing.

6.2 Debris Preparation

The debris batches shall be prepared according to the Test Matrix. The NUKON LDFG shall be processed using an approved laboratory procedure that prepares the insulation into fine debris (see Reference [8]). This procedure produces the required size distribution and fiber fines that are easily transportable and readily disperse in the testing medium. At a minimum, the insulation must be shredded and beaten into a thin slurry to produce the industry standard "fines" testing size distribution. Samples shall be taken and photographed to document the extent of fiber destruction. SiC and dirt/dust mix can be weighed out in dry form and do not require further preparation. Before introduction, water shall be carefully added into the buckets and mixed lightly to suspend the particulate and ease pouring. The recommended ratio is 10 lbs of particulate to 3 gallons of water.

The chemical precipitate batches must be prepared per the test matrix and an approved laboratory procedure that follows standard industry guidance on the formation of chemical debris in a separate tank. Once settling criteria are met, the precipitate does not need further preparation and can be slowly poured or pumped into the tank per the Test Matrix.

6.3 Test Operation

Vortexing

During testing, visual observations are required to ensure that no significant vortices form (See Appendix A). Vortex and/or swirl up to and including a Type 4 are considered acceptable. A significant vortex is defined as a Type 5 or a Type 6 vortex. Observations and photographs will also be recorded of any debris settling and abnormal loading of the prototype strainers. A vortex suppressor (floor grating or equivalent) may be installed for Type 5 or 6 vortices. The customer and test coordinator will be notified in the event of Type 5 or 6 vortices and the installation of a vortex suppressor.

Water Level

Water level will be recorded during testing and increase with each debris addition.

If the test tank becomes nearly full, test tank water may be removed to mix with the next debris addition, and re-introduced into the test tank. This will prevent tank overflow with subsequent debris additions. Furthermore, tank volume must be left over for the additions of the chemical precipitates, which cannot be mixed with the test tank water prior to addition.

Flow Rate

The flow rate of the system must be maintained at ±10 gpm of the prescribed value. If the flow drifts beyond this range, a note must be logged, and the flow rate must be adjusted.

Debris Add

All debris will be added directly over a high-turbulence area. These areas will have maximum relative turbulence and will allow for debris reaching the strainer from all sides. The debris must be added in a controlled manner as to not disturb the debris bed through unnecessary turbulence.

Progression

The entire particulate debris load will be added at once for the test. The debris load will be measured into buckets and mixed with water (tap or from the test tank) via an electric paint mixer until a slurry is prepared. Then, the fiber batches will be added incrementally per the test matrix. After all non-chemical debris are added, the chemical precipitate debris will be added. The chemical precipitates will first be mixed via an electric mixer or shaken and then will be added slowly into the tank, not exceeding approximately 10 gallons per minute.

The fiber and chemical debris loads may be adjusted at the discretion of the customer and test coordinator. If the stabilized head loss is marginally less than the limiting head loss at the test temperature (19 ft-water, see Section 6.6), the next (non)chemical load may be decreased in order to enable an additional chemical load without exceeding the given head loss limit. This option allows smaller chemical load increments towards the end of the test to facilitate determination of the maximum allowable chemical load. These adjustments shall clearly be noted in the test log if exercised.

Photos/Notes Photographs shall be taken at the end of each subtest if water condition allows. These photographs should show how the bed is forming onto the strainers and also document any settled debris. Notes shall be taken in the Test Log of all testing actions and observations, which shall include the test parameters (flow rate, dp across strainer, water temperature, turbidity, etc.) of that instant and the time. If actions continue beyond a small amount of time, the beginning and end of the action should be noted.

6.4 Data Acquisition

Electronic data acquisition must be controlled per the laboratory procedure as safety related. All test parameters must be recorded at least every 2 seconds and stored electronically in a tab delimited or Microsoft Excel file. This test data will be used in the Strainer Qualification report and does not require conditioning or filtering prior to that. During on-site storage, the test data shall be backed-up onto a local server or hard drive to prevent loss.

6.5 Test Matrix

The following sections describe in detail how to conduct each test. These test matrices are to be followed in order to accomplish the test plan objective. Any deviation from the given plans must be noted and rationalized in the test logs. See Section 6.6 and 7.0 for Stability and Termination Criteria.

6.5.1 Test #0 – Clean Screen Flow Sweep

With the tank filled to the appropriate water level at temperature, set the flow rate to the value and allow stability to be achieved (3 minutes). Record a data point before changing to the next flow rate. The final step consists of setting the flow at the target test flow rate.

Table 6-1: Clean Screen Flow Sweep Steps

Flow Sweep Step	Scaled Test Tank Flow (gpm)
Step 1 (Target Test Flow)	1000
Step2	740
Step 3	660
Step 4	575
Step 5	495
Step 6	660
Step 7 (Target Test Flow)	1000

6.5.2 Test #1 – Maximum Debris Design Loading

Table 6-2: Test Matrix for Test #1

Subtest	Flow Rate (gpm)	Latent Fiber Fines (lbm)	Dirt/Dust Particulate (lbm)	Coatings Particulate (lbm)	AlOOH (gal)	Nominal Bed Thickness (in)
P.1	1000	0	27.8	92.9	0	0
F.1	1000	1.15	0	0	0	1/16
F.2	1000	1.15	0	0	0	1/8
C.1	1000	0	0	0	50	1/8
C.2	1000	0	0	0	501	1/8
C.3	1000	0	0	0	501	1/8
C.4	1000	0	0	0	TBD1	1/8
V.1	834	Upon completion of the debris load testing the water level shall be reduced to 2.0 ft to check for vortexing.				
FS	Variable	Flow reduction in 100 gpm increments shall be performed to obtain pressure drop vs head loss data. These flow reductions can continue down to termination.				

Note 1: The maximum amount of chemical precipitate is 667.8 gallons. There are two potential outcomes from this test at this point.

Outcome 1: The addition of chemical precipitates do not produce any additional head loss, or cause the head loss to decrease. In which case as soon as the stabilization criteria is met or a peak is identified, the test may progress to the flow sweeps and termination without the full load of chemicals.

Outcome 2: The chemical precipitates continue to increase the head loss as each batch is added and reach the limit of the system defined as 19 ft-water. In this case, the test should be secured at a steady state at an acceptable or reduced flow and the client will be notified on how to proceed.

6.6 Test Durations and Stability

Clean Screen Flow Sweep – The clean strainer head loss is measured at the flow rates given in Table 6-1. Each point is held for a minimum of 3 minutes.

P (Particulate Addition) – The entire particulate debris load shall be added according to Table 6-2. The flow rate shall be maintained at 1000 gpm for a minimum of 2 pool turnovers (PTO), based on tank volume.

F (Fiber Addition) – The fiber debris batches shall be added according to Table 6-2. The flow rate shall be maintained at 1000 gpm for at least 10 PTO and a change in head loss less than 1% over a one-hour period.

C (Chemical Additions) – The chemical debris batches shall be added according to Table 6-2. The flow rate shall be maintained at 1000 gpm for at least 10 PTO and a change in head loss less than 1% over a one-hour period.

V (Vortexing) – The flow rate at the required water level will be held for a minimum of 1 PTO.

FS (Flow Sweep) – The strainer head loss is measured at the reduced flow rates (decrements of 100 gpm) until the flow is stopped. Each point is held for a minimum of 2 PTO.

After the final flow sweep and required laboratory test completion procedures are fulfilled, the pump may be secured off, and Test #1 is complete.

7. TEST TERMINATION

In accordance with the test objective, the acceptance criterion for this testing is to successfully collect and record the specified test data.

Maximum Head Loss Limit – To prevent structural failure to the prototype or tank system, a head loss limit of 19 ft-water (10 psi x 80%) will be imposed during testing. If the head loss approaches this value, the test coordinator and customer must convene to decide the new flow rate of the system to maintain test continuance. The test vendor shall notify Customer of the hard limit of the test facility at which the flow must be reduced. Should the flow ever achieve this hard limit and the test operator require action, the flow should be reduced to maintain the flow at an acceptably high head loss, but less than the hard limit while Customer and test vendor determine new target flow rate. Under no circumstances should the test be aborted due to reaching a head loss limit unless a lower flow cannot be maintained.

7.1 Testing Stabilization Criteria

The head loss measurements for each test will be recorded and monitored continuously throughout the test. There are several stabilization points throughout each test that require different levels of stability as given in Sections 6.6. The test engineer and test coordinator must agree upon the fulfillment each Subtest criterion before continuing to the next Subtest.

Furthermore, a note must be logged explaining why the Subtest is complete. Note that pool turnover times are based on water level and flow rate, and they must be calculated separately for each Subtest.

7.2 Atypical Head Loss Stability

In some cases, the head loss will stabilize atypically, or the head loss will be too low to calculate a 1% change. In these cases, the time period may be shortened or lengthened depending on test coordinator direction and client input. Whenever the head loss is declared as stable, a detailed note must be written on the test log that describes why the head loss was declared as stable before the next Subtest is initiated. If the above guidelines are modified, a more detailed note must be given in the test log that explains how and why the Subtest was declared as stable.

8. TEST DOCUMENTATION AND RECORDS

The Test Procedure shall provide the documentation for performing the required test steps and the associated signatures for the performance and witnessing of critical steps. The Test Procedure also provides for a test log, which is used to document significant points during the performance of the test. Test procedures shall be submitted to Customer for review and approval prior to testing.

The data acquisition system is used to collect flow rate, differential pressure, turbidity, and temperature data throughout the performance of the tests. This system also allows for the creation of graphs of the data as well as tables of the raw data. The electronic file of the raw data shall be provided to Customer on CD along with the final Test Report.

After testing is completed, a Test Report Summary document shall be prepared that contains the Test Logs, Test Data, Observations, and other pertinent information regarding the conduction of the tests. The following is table of contents for the Test Report that would be acceptable.

1. Introduction
2. Test Facility Description
3. Test Prototype
4. Debris Description
5. Test Procedure Summary
    a. Debris Preparation
    b. Test Setup
    c. Test Initiation
    d. Debris Addition
    e. Test Termination
    f. Post Test Observations
    g. Test Discrepancies and Nonconformance
6. Results of Testing
7. Quality Assurance
8. References

Appendix 1 – Test Log Sheets
Appendix 2 – Calibration Data Sheets
Appendix 3 – Material Data Sheets

9. QUALITY ASSURANCE REQUIREMENTS

This Test Plan is developed in accordance with Structural Integrity Associates Corporation's Quality Assurance Program and Procedures. The Test Procedure and subsequent qualification testing shall be conducted in accordance with an approved Quality Assurance Program that meets the requirements of 10 CFR 50 Appendix B. The results of the testing will be used in nuclear safety-related qualification documents.

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Lab procedures used during testing must be the most recent revision of each and each personnel working on the test must be fully trained and qualified to any procedures he or she is working to. Training logs to lab procedures and applicable project plans must available during testing.

10. REFERENCES

[1] APR1400-E-N-NR-13001-P, APR1400 Design Features to Address GSI-191 Technical Report, Revision A, May 2013

[2] USNRC, Regulatory Guide 1.82, Revision 4, "Water Sources for Long-term Recirculation Cooling Following a Loss-of-Coolant Accident", Washington D.C., March 2012

[3] NRC Staff Review Guidance regarding Generic Letter 2004-02, "Closure in the Area of Strainer Head Loss and Vortexing," U.S. Nuclear Regulatory Commission, Washington, DC, March 28, 2008 (ADAMS Accession No. ML080230038)

[4] Safety Evaluation for NEI Guidance Report 04-07, "PWR Sump Performance Evaluation Methodology," U.S. Nuclear Regulatory Commission, Washington, DC., December 2004 (ADAMS Accession No. ML050550156)

[5] Transco Drawing GS-50873-GA, APR1400 Strainer General Arrangement, Revision 0.

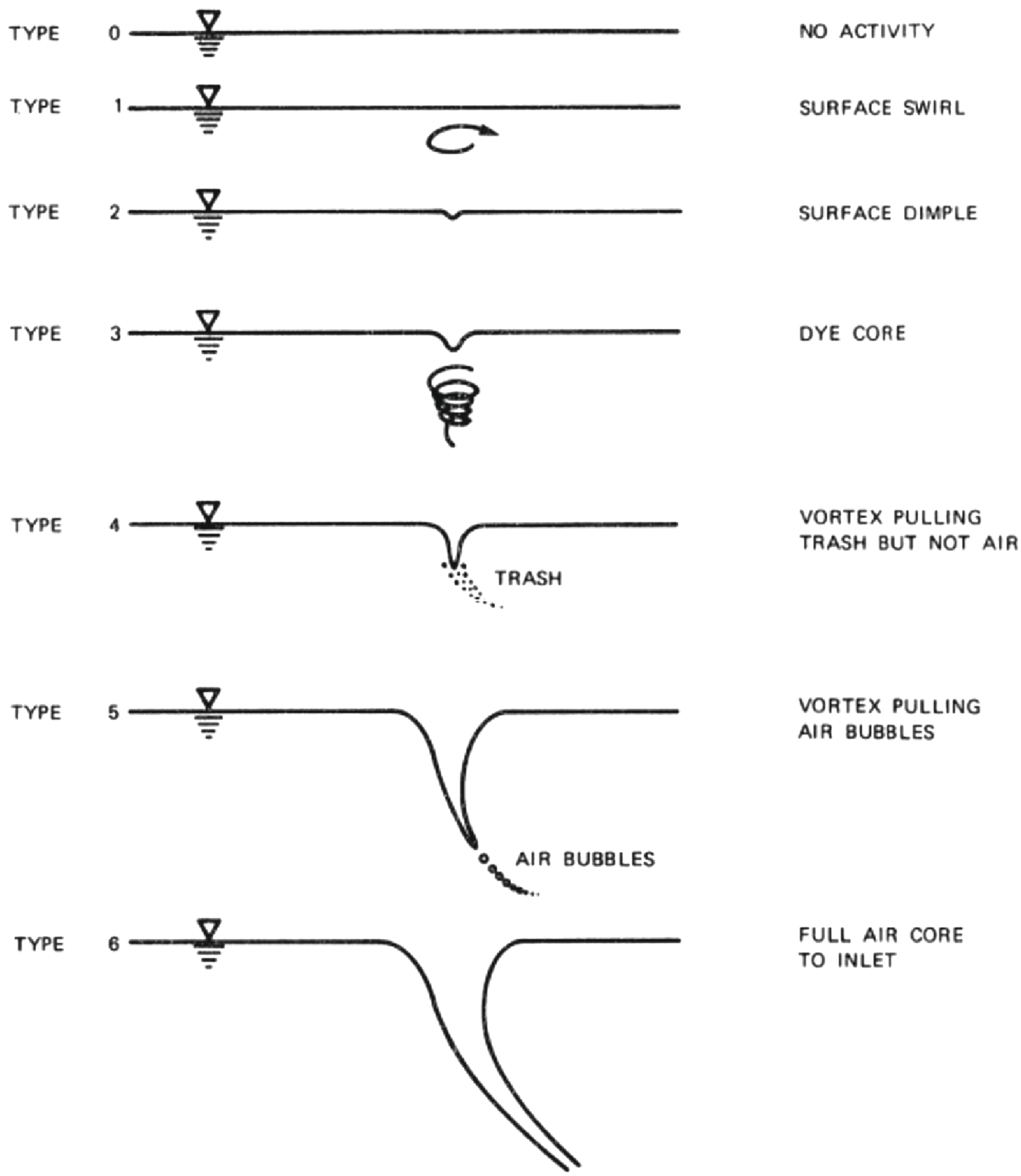
[6] Transco Strainer Prototype Drawing SP-1, Strainer Test Assembly SP-1, Subassemblies and Parts, Revision 1, Sheets 1 and 2

[7] NUREG/CR-6224, Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris, October 1995

[8] Nuclear Energy Institute, "ZOI Fibrous Debris Preparation: Processing, Storage and Handling," Revision 1, January 2012 [ADAMS Accession Nos. ML120481052 and ML120481057]

[9] "Final Safety Evaluation by the Office of Nuclear Reactor Regulation, Topical Report WCAP-16530-NP-A 'Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids To Support GSI-191,'" U.S. Nuclear Regulatory Commission, Washington, DC, and Topical Report WCAP-16530-NP-A. (ADAMS Accession Nos. ML073520891 and ML08115037)

Appendix A: Vortex Strength Scale



Ref: Rindels and Gulliver, An Experimental Study of Critical Submergence to Avoid Free- Surface Vortices at Vertical Intakes, University of Minnesota, June 1983.

Bypass Test Plan of the APR1400 IRWST Sump Strainer

Non-Proprietary

October 2013

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LIST OF ACRONYMS

CSS	Containment Spray System
CSP	Containment Spray Pump
ECCS	Emergency Core Cooling System
GSI	Generic Safety Issue
IRWST	In-containment Refueling Water Storage Tank
LDFG	Low Density Fiberglass
LOCA	Loss of Coolant Accident
M&TE	Measuring and Test Equipment
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
SCP	Shutdown Cooling Pump
SEM	Scanning Electron Microscope
SER	Safety Evaluation Report
SIP	Safety Injection Pump
SIS	Safety Injection System
TPI	Transco Products Incorporated

1. BACKGROUND

The APR1400 has four (4) ECCS/CSS trains with an independent 600 ft² strainer for each train for a total of 2400 ft². The strainer size is currently an assumption, and this test program is part of the validation process. The design requires a minimum of three trains in operation (1800 ft²) assuming one train with a single failure. The strainers prevent debris from being ingested into the Safety Injection (SIS) and Containment Spray systems (CSS) in the event of a loss-of-coolant-accident (LOCA) and are located within the In-containment Refueling Water Storage Tank (IRWST).

The design and evaluation methods for the strainer performance are in accordance with the latest revision of Regulatory Guide 1.82, Rev.4 [1]. If a Loss-of-Coolant-Accident (LOCA) inside the reactor building were to occur, it could generate debris that, if transported to and deposited on the recirculation sump screens, could result in some debris passing through the strainers which could challenge long term core cooling (LTCC). Specifically, this bypassed debris may have the potential to clog downstream components, including the fuel grids.

2. TEST APPROACH

The purpose of this test plan is to measure fiber bypass data to determine what quantity of fiber can pass through the plant ECCS strainers. The bypassed fiber will be analyzed after testing to characterize the fiber that could be transported downstream of the strainers. Results of this testing will provide fiber bypass quantities and characteristics that may be used for the recirculation sump strainer evaluation and post-LOCA LTCC analysis.

This test plan is designed to be consistent with the testing guidance provided in NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing dated March 2008 [2] and NEI 04-07 [3], [4].

3. TEST OBJECTIVE

The objective of bypass testing is to measure the quantity of fiber that passes through a prototype ECCS suction strainer under representative post-LOCA conditions. Particulate and chemical debris will not be tested since the particle sizes of these debris types are much smaller than the perforated plate hole size (3/32 in) [5]. They are assumed to pass through the plant strainer, which could confound the fiber bypass test results. The bypass test will collect and record fiber bypass data for each added fiber batch to measure the total quantity of bypass (in terms of g/ft^2) for the strainer as well as the quantity of bypass for each bed thickness tested. Due to the increase of the fiber bed filtration efficiency with bed thickness, the fiber bypass rate will decrease to zero as the fiber bed forms. The test will be run at plant-equivalent approach velocity and use the maximum quantity of fiber. Fiber captured during testing will be collected for subsequent fiber characterization and scanning electron microscope (SEM) analysis.

3.1 Test Description

A prototype section of the strainer will be connected to a test loop and installed in a test tank with sufficient volume to allow circulation of water and debris around the prototype. The flow rate through the test loop and strainer is calculated based on the plant strainer and flow rate scaled to the prototype strainer size. Fiber bypass is conservatively maximized during testing through the addition of very small fiber quantities to the test tank to allow the fiber-only debris bed to gradually accumulate on the prototype strainer. This slow bed growth will maximize fiber bypass and allow for many data points of the filter bypass vs bed thickness curve, and will clearly demonstrate the reduction of fiber bypass

quantity as the bed thickness increases.

Fiber that passes through the strainer shall be captured in a fine mesh filter and not allowed to return to the tank. Each fiber addition will have corresponding filter bags that reveal how much fiber bypassed for that particular addition. After all debris had been added and has reached the strainer, the sum of the filter bags will equal the amount of bypass associated with the prototype screen area.

3.2 Test Acceptance

The test is complete and acceptable when all fiber of the test matrix has been added onto the strainer and all fiber bypass from the strainer and has been collected and measured.

4. TEST ARTICLE

4.1 IRWST Sump Strainer Design

The IRWST sump strainer (Figure 4-2) will fit over the existing sump pits. There are four (4) IRWST sump strainers, each with a minimum of 600 ft² for a total of 2400 ft².

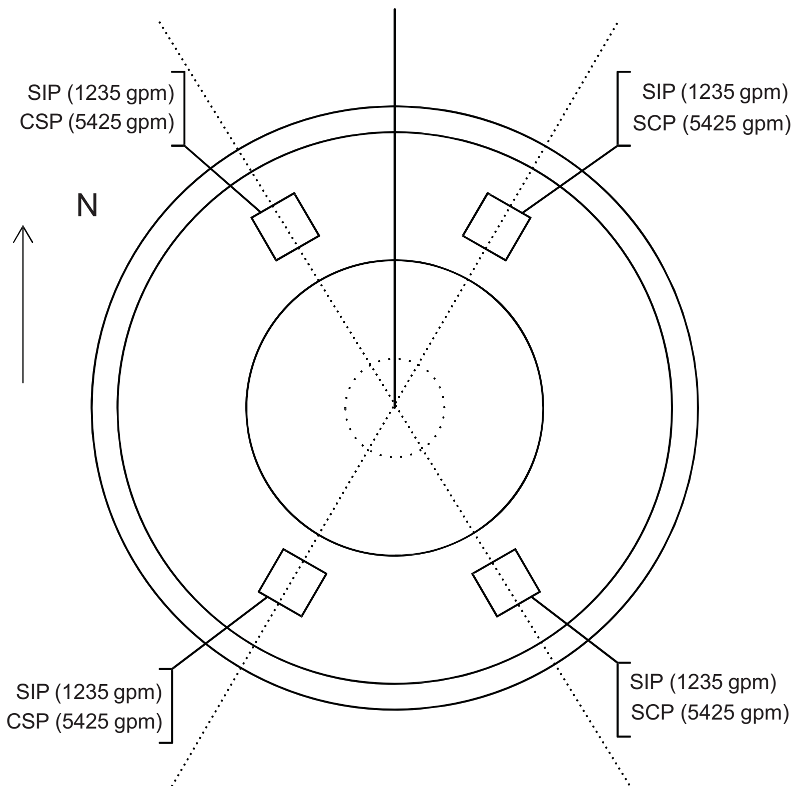

Figure 4-1: ECCS Flow Distribution

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Figure 4-2: Plant Recirculation Sump Strainer

4.2 Test Prototype Strainer

A full-scale prototype section of the strainer will be tested in the tank. This assures a 1:1 scaling ratio for test parameters, e.g. flow rate, tube diameters, and perforated plate hole size which is 3/32 in [5]. The debris quantities for the prototype tests shall be in proportion to the full-scale strainer size, and the flow rate through the prototype will be proportional to the full-scale strainer.

The prototype strainer design is shown in Figure 4-3 through Figure 4-5. The design uses cartridge assemblies to increase the surface area to any given allowable surface area. For this test program, three cartridges of four tubes each will be used. The surface area of this configuration is 75.1 ft^2 [6]. The tubes are attached to a plenum that allows a flow path from each tube to the pump suction pipe. All materials of the strainer and plenum are stainless steel.

TS

Figure 4-3: Strainer Prototype

Figure 4-4: Strainer Prototype in Tank, Top View

TS

Figure 4-5: Strainer Prototype in a Tank

4.3 Test Boundary Conditions

The prototype strainer represents any given section of the plant strainer. Adjacent strainers to the represented section do not need to be represented by walls during testing because the volume of debris is not expected to fill the interstitial volume of the strainer since the debris bed is only 1/32 in thick (See Section 6.2 and [6]) and the strainer cylinders are ~2 in apart. Since the volume of fiber is less than the volume available for debris, simulating adjacent strainers around the perimeter of the prototype is unnecessary.

5. TEST FACILITY

The facility must contain a tank capable of holding the strainer and 2 ft of submergence with adequate room around the test prototype for natural debris accumulation and a pump with the capability to achieve an 834 gpm flow rate with the head loss corresponding to a debris-laden strainer. Visibility of the tank and strainer is critical to determine when all the fiber of each addition has accumulated on the strainer. A filter housing system must be installed downstream of the strainer to capture fiber bypass.

The strainer cartridges must be attached and sealed against the flow plenum. A sparger system should be installed on the return line to aid in the suspension of the debris within the water. The sparger is installed to maximize debris suspension in the tank. In addition to the sparger, mechanical mixers may be required to keep the debris from settling.

Adequate fiber preparation equipment is necessary to destroy low-density fiberglass blankets into the fiber fines as described in NUREG/CR-6808 [7], Classes 1-3 of Figure 5-2. A suitable procedure for producing these fines is presented in Reference [8].

5.1 Test Equipment

The instrumentation available for use must conform to the following specifications and be within the approved calibration date.

Table 5-1: Required M&TE

Instrument	Range	Accuracy
Scale	0 - 15 lbs.	0.2 lbs readability
Balance	0 - 600 g	0.01 g readability
Differential pressure transmitter	As needed to assure filter bags do not fail	
Flow meter	270 - 900 gpm	± 2.5% of reading
Thermocouple	32 °F - 212 °F	± 2 °F

A real-time analog data acquisition system is required that allows continuous display of test parameter values (time, flow rate, differential pressure of filter bags, and temperature) and trends. System must be verified prior to and after testing. Data is sampled at least every two seconds. Test data is recorded for each instrument in a simple spreadsheet for later analysis.

The filter housing system used for testing must be installed downstream of the strainer and allow for on-the-fly switching of housings to allow for continuous testing and swapping of filter bags. When switching filters, one set of filters will closed as the other is opened. This must be completed with very little variation in flow rate to preclude bed deformation due to lack of flow. The filters must have a maximum 5-micron hole size to ensure capture of the 7 micron diameter LDFG fines.

5.2 Test Hydraulic Conditions

5.2.1 Strainer Flow Rate

There are four independent 600 ft² ECCS strainer trains in the APR1400, and the conservative scenario for bypass is that all pumps are operating as designed and no single failure. Shutdown cooling (SDC) is not operational at this time.

Table 5-2: Lineup A: LOCA without Single Failure

Strainer	Pumps	Flow Rate (gpm)
1	SIP+CSP	6660
2	SIP+CSP	6660
3	SIP	1235
4	SIP	1235
Total		15,790

Since strainer approach velocity increases with flow rate, and fiber bypass increases with approach velocity, it is conservative to conduct the fiber bypass test(s) at the scaled maximum strainer flow rate and associated approach velocity.

The maximum post-LOCA recirculation flow rate is 6,660 gpm [9]. The IRWST sump strainer is 600 ft^2 of strainer area per train. Given the prototype strainers size of 75.1 ft^2, the prototype strainer flow rate is the plant flow rate multiplied by the ratio of the strainer areas:

$$6{,}660 \text{ gpm x } \frac{75.1 ft^2}{600\ ft^2} = 834\ gpm$$

5.2.2 Water Temperature and Chemistry

The water temperature at the beginning of testing will between 60 °F and 80 °F. This temperature may increase during testing as the pump adds energy into the fluid, but the temperature should be limited to 100 °F. A tank chiller should be utilized to limit the water temperature to 100 °F.

Clean tap water may be used as the testing fluid. pH and turbidity are not required to be controlled or monitored.

5.2.3 Water Level

The required minimum submergence during testing is 2 ft (+/- 2 inches).

5.2.4 Turbulence

Sufficient turbulence shall be added into the test tank during testing to preclude settling of debris. The turbulence must be limited, however, to avoid artificially removing debris from the strainers. The turbulence can be added via mixing motors or pump discharge.

6. DEBRIS LOADING

The design fiber debris load of the strainer specification will be tested using surrogate material as recommended in NEI 04-07 ([3], [4]) and scaled based on strainer area. Particulate and chemical debris will not be tested.

6.1 Fiberglass

NUKON® LDFG shall be used to represent the latent fiber. The density of NUKON is 2.4 lbs/ft^3 (38 kg/m^3) and the fiber diameter is 7 microns [7]. The source of the NUKON used in testing shall be provided in the test report summary. The fiber added to the tank shall have a size characteristic of fines (Class 1-3) per NUREG/CR-6808 [7]. A suitable procedure for producing these fines is presented in Reference [8].

6.2 Calculation of Debris Quantities

The test will measure the bypass of the maximum fiber load of 15.0 lbm [9], which is an assumption made in this test program. LDFG batches will be tested at a size distribution of 100 percent fines to maximize bypass. Since all four strainers could be active, the debris load will be distributed to each of the strainers based on flow rate. Therefore, two of the strainers will get (6,660 gpm / 15,790 gpm) x 15 lbs, or 6.33 lbs of debris and two of the strainers will get (1,235 gpm / 15,790 gpm) x 15 lbs, or 1.17 lbs of debris. Since only the higher flow rate strainers will be tested, the following batches of debris will be added to the test:

Mass of latent fiber:	15 lbs
Prototype Area:	75.1 ft²
Max. distributed fiber on one strainer:	6.33 lbs
Fiber load	$6.33 \text{ lbs} \times \frac{75.1 \text{ ft}^2}{600 \text{ ft}^2} = 0.79 \text{ lbs}$
Density of NUKON	2.4 lbs/ ft3
Equivalent Bed Thickness	$0.79 \text{ lbs} \times \frac{1 \text{ ft}^3}{2.4 \text{ lbs}} \times \frac{1}{75.1 \text{ ft}^2} \times \frac{12 \text{ in}}{1 \text{ ft}} = 0.053 \text{ in}$

In order to measure the bypass performance of the test strainer over a range fiber thicknesses, four batches of 0.40 lbm (0.0265 in equivalent thickness) will be added.

7. TEST PERFORMANCE

All personnel working on the test (engineers, technicians, chemists, managers) must be trained to the test plan and applicable test procedures of the laboratory.

7.1 Test Procedures

All testing actions will be governed by an approved Test Procedure to be developed by the testing vendor. The test-specific procedure provides the instruction for performing the required test steps, and the associated signatures provide documentation for the performance and witnessing of critical steps.

This test procedure shall also provide for a test log, which is used to document significant points during the performance of the test. Actions that affect the testing environment (debris additions, flow adjustments, stirring, etc.) shall be noted in the Test Log by a trained Test Engineer. Visual observations should also be noted. All documentation in the test log shall be clearly legible.

The test vendor shall develop generic test procedures for debris preparation, fill and start-up testing including M&TE installation and verification, tank cleaning, lab safety, nonconformance/deviations, and bypass testing.

7.2 Debris Preparation

The debris batches shall be prepared according to the Test Matrix. The NUKON LDFG shall conform to an approved laboratory procedure that prepares the insulation into fine debris. Samples shall be taken and photographed to document the extent of fiber destruction.

7.3 Test Operation

<u>Vortexing</u> During testing, visual observations are required to ensure that no significant vortices form.

<u>Water Level</u> Water level will be recorded during testing and increase with each debris addition. If the test tank becomes nearly full, test tank water may be removed to mix with the next debris addition, and re-introduced into the test tank. This will prevent tank overflow with subsequent debris additions.

Flow Rate — The flow rate of the system must be maintained at ±20 gpm of the prescribed value. If the flow drifts beyond this range, a note must be logged, and the flow rate must be adjusted.

Debris Add — All debris will be added directly over a high-turbulence area away from the strainer. These areas will have maximum relative turbulence and will allow for debris reaching the strainer from all sides. The debris must be added in a controlled manner as to not disturb the debris bed through unnecessary turbulence.

Progression — After the flow rate is set, fiber batches will be added incrementally per the test matrix.

The fiber debris loads may be adjusted at the discretion of the customer and test coordinator. If the fiber is clearly covering the entire strainer, then subsequent debris loads may be combined because further fiber bypass is unexpected. These adjustments shall be clearly noted in the test log if exercised.

Stabilization — Each fiber batch must be allowed 2 pool turnovers after all fiber has reached strainer (a minimum of 7 pool turnovers between each batch).

Photos/Notes — Photographs shall be taken at the end of each step. These photographs should show how the bed is forming onto the strainers and also document any settled debris. Notes shall be taken in the Test Log of all testing actions and observations, which shall include the test parameters (flow rate, dP, water temperature, etc.) of that instant and the time. If actions continue beyond a small amount of time, the beginning and end of the action should be noted.

7.4 Test Matrix

The following test matrix is to be followed in order to accomplish the test plan objective. Any deviation from the given plans must be noted and rationalized in the test logs.

Table 7-1: Fiber Bypass Test Matrix

Step	Action	Type	Quantity	Duration
0	Install the prototype strainer into the test tank and clean, pre-weighed filters into housings			
1	Fill loop with water, allowing room for water additions			
2	Pre-filter the water in the tank			
3	Set flow rates	Strainer	834 gpm	
4	Heat water to at least 60 °F; check instrumentation and debris preparation			
5	Begin test with Control Filters			3 PTO
6	Swap out filters			
7	Add fiber fines batch	NUKON	0.40 lbm	2 PTO after complete transport (min. 7 PTO between batches)
8	Swap out filters			
9	Repeat 7 and 8 until four batches have been added.	NUKON	0.40 lbm per batch	2 PTO after complete transport (min. 7 PTO between batches)

0. Install the prototype strainer into a clean tank ensuring no gaps greater than 3/32 in exist. Install clean, dried filter bags into the inline filter housings.

1. Fill the system with water, allowing room for subsequent debris additions. Cover the tank to eliminate foreign debris contamination.

2. With the pump at a high flow rate, pre-filter the water in the tank sufficiently such that any debris or particulates in water are removed prior to testing. A recommendation of 10 PTO is a minimum. Then, install clean, pre-weighed filters to use for testing.

3. Align the control valves to allow flow through the strainer, through the pump, through the filter housings, and back into the tank. Turn on the pump and set the flow rate according to Table 7-1.

4. Turn on the heating system if necessary and raise the fluid temperature to at least 60 °F. As the water is heating, the instrumentation and data acquisition system shall be verified. The debris quantities of the Test Matrix will also be verified as available.

5. With clean, pre-weighed filters installed and the flow rate set as described above, run the system without debris for 3 PTO. This allows the Control Filters to capture any particulates that may affect all filter bags during the test.

6. The filter system must be swapped to new, clean and pre-weighed filters. The used filters should be removed and processed for drying and mass gain measuring.

7. The fibrous fines debris load of Table 7-1 shall be slowly added as a slurry. Then, allow for 2 PTO after all fiber has been visually verified on the strainer (allow a minimum of 7 PTO between batches).

8. The filter system must be swapped to new, clean and pre-weighed filters. Filter swap should be conducted so that flow is maintained and the debris bed is not disturbed. The used filters should be removed and processed for drying and fiber mass gain measuring.

9. Repeat Steps 7 and 8 three additional times to add four total batches of 0.79 lb each.

After testing is complete, the tank shall be drained and thoroughly cleaned per laboratory procedures. Bed samples may be taken for future analysis. The filter bags removed from testing will be dried to the same controlled conditions as during preparation. After the dried weight maintains consistently (for examples, less than 0.08 g change in three consecutive measurements over 2 hours in controlled conditions), the mass gain in the bags will be evaluated as the mass of fiber bypass. The total mass gained by all bags will yield the total bypass quantity for the prototype strainer surface area. Fibers may be removed from the bags after weighing for microscopic analyses. The bags must be retained after testing for potential post-testing SEM analysis.

8. TEST DOCUMENTATION AND RECORDS

The Test Procedure shall provide the documentation for performing the required test steps and the associated signatures for the performance and witnessing of critical steps. The Test Procedure also provides for a test log, which is used to document significant points during the performance of the test. Test procedures shall be submitted to KEPCO for review and approval prior to testing.

The data acquisition system is used to collect flow rate, differential pressure, and temperature data throughout the performance of the tests. This system must allow for the creation of graphs of the data as well as tables of the raw data. The electronic file of the raw data shall be provided to KEPCO on CD along with the final Test Report.

After testing is completed, a Test Report Summary document shall be prepared that contains the Test Logs, Test Data, Observations, and other pertinent information regarding the conduction of the tests. The following is table of contents for the Test Report that would be acceptable.

1. Introduction
2. Test Facility Description
3. Test Prototype
4. Debris Description
5. Test Procedure Summary
   a. Debris Preparation
   b. Test Setup
   c. Test Initiation
   d. Debris Addition
   e. Test Termination
   f. Post Test Observations
   g. Test Discrepancies and Nonconformance
6. Results of Testing
7. Quality Assurance
8. References

Appendix 1 - Test Log Sheets
Appendix 2 - Calibration Data heets
Appendix 3 - Material Data Sheets
Appendix 4 - Raw Data in Digital Format

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Any nonconformance that arises during the test program shall be brought to the attention of the SI Project Manager or his designee. In case of nonconformance affecting the test output, the test vendor shall notify SI immediately and obtain their review and approval of the disposition.

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10. REFERENCES

[1] US NRC Regulatory Guide 1.82, Rev. 4, March 2012, Water Sources For Long-Term Recirculation Cooling Following a Loss-Of-Coolant Accident

[2] NRC, Staff Review of Guidance Regarding Generic Letter 2004-02, Closure in the Area of Strainer Head Loss and Vortexing, March 2008

[3] NEI 04-07, Volume I, “Pressurized Water Reactor Sump Performance Evaluation Methodology”, Rev.0, December 6, 2004 (SER)

[4] NEI 04-07, Volume II, “Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02”, Rev.0, December 6, 2004 (SER)

[5] TPI Drawing “CARTRIDGE LAYOUT”, 36” CARTRIDGE (4-CYL) FLOOR STANDING, Rev.B

[6] SP-1, Revision 0, Reactor Sump Filters Top Hat Assembly (drawing). (Included in Attachment A)

[7] NUREG/CR-6808, Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance, February 2003

[8] Nuclear Energy Institute, “ZOI Fibrous Debris Preparation: Processing, Storage and Handling,” Revision 1, January 2012 (ADAMS Accession No. ML120481052 and ML120481057)

[9] APR1400-E-N-NR-13001-P, APR1400 Design Features to Address GSI-191 Technical Report, Revision 0, May 2013

ATTACHMENT A - TPI Prototype Strainer Drawing

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ATTACHMENT A - TPI Prototype Strainer Drawing

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ATTACHMENT A - TPI Prototype Strainer Drawing

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ATTACHMENT A - TPI Prototype Strainer Drawing

Head Loss Test Report for APR1400 IRWST ECCS Sump Strainer

Non-Proprietary

October 2013

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1 INTRODUCTION

If a loss of coolant accident (LOCA) were to occur, it is postulated that this LOCA could generate and transport debris to the Emergency Core Cooling Suction (ECCS) strainer. The debris that could accumulate on the strainer may form a debris bed and increase the head los across the strainer. The purpose of these tests is to develop data to validate the IRWST strainer performance using conservative assumptions. Flow sweeps were also conducted to adjust the head loss over the range of fluid temperatures required for the strainer operation. Acceptance evaluation will be performed separately from this report.

The tests were conducted following test plans [1, 2] developed by Structural Integrity Associates. The principal difference between the tests was that the first test was based on a plant strainer area of 600 ft^2 and the second test was based on a strainer area of 500 ft^2, 100ft^2 was assumed blocked by tags [1, 2].

2 TEST FACILITY DESCRIPTION

2.1 Flow Loop

The test facility consists of an approximately 15 ft (4.5 m) diameter tank that is 7 ft (2.1 m) deep. The flow returns into the tank from a 6 inch pipe with a tee that is pointed at the floor in the center of the tank. The exit of the tee is approximately 2 in (0.05 m) above the floor so that the return flow sweeps along the floor then up the tank walls to help suspend debris. The tank can hold approximately 9500 gallons of water.

The test strainer is located next to the return pipe with the strainer plenum mounted 6 in (0.15 m) above the tank floor. The top of the strainer elements are 46-3/4 in (1.2 m) above the tank floor. Six agitators (trolling motors) are located at approximately every 60 degrees at an approximately 12 ft (3.7 m) diameter (see Figure 2-1).

The suction pipe is attached to the strainer and runs to the Godwin CD150M pump. The discharge of the pump goes to a flow meter, flow control valve, and then back into the tank (see photographs in Figure 2-2 and a schematic in Figure 2-3).

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Figure 2-1 Photograph of strainer in test tank

Flow rate can be controlled by a combination of a variable frequency drive (VFD) that drives the pump, the gate valve, or a bypass line which provides a short circuit path between the suction and discharge of the pump. Typically, the VFD is used to control the flow rate during a test, unless very low flow rates need to be achieved.

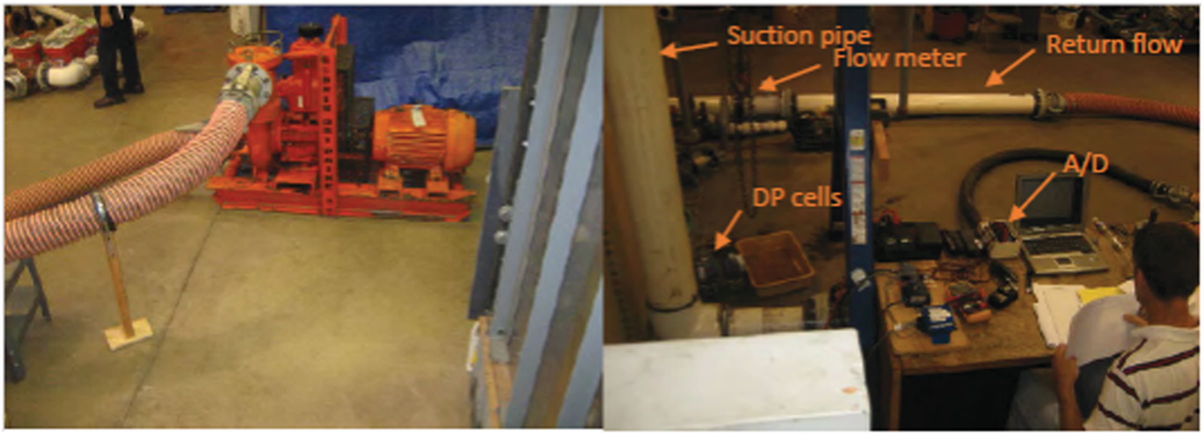


Figure 2-2 Pump on left, data acquisition flow meter and DP cells on right

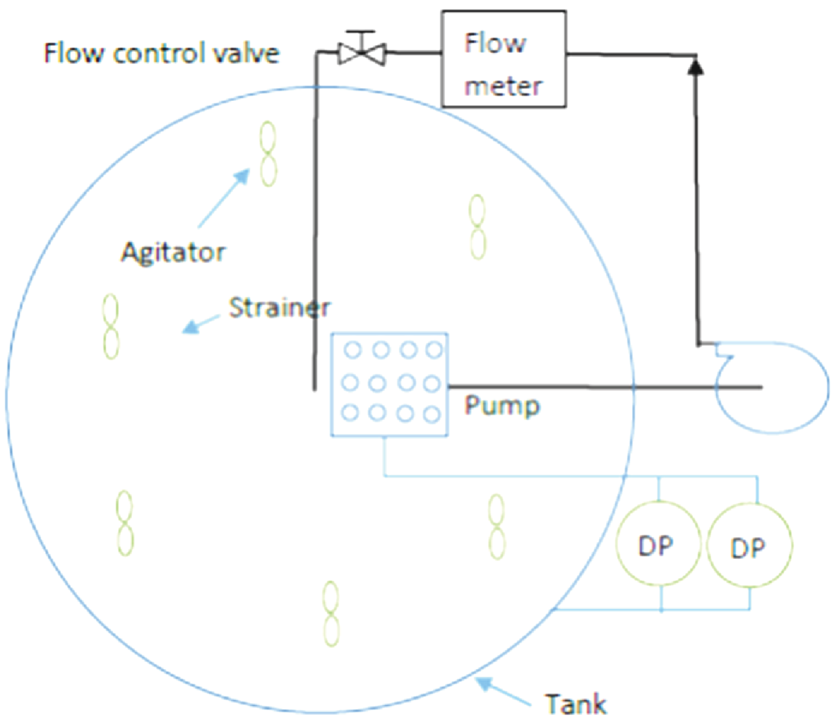


Figure 2-3 Flow schematic of test setup

2.2 Instrumentation

Head loss across the strainer was measured by two independent Rosemount model 1151 differential pressure transducers. One transducer was scaled to 0-100 in of water and the second was scaled to 0-300 in of water. These transducers were calibrated to +/-0.125% of their range. The low side of the differential pressure transducer was connected to the pressure tap on the strainer plenum and the high side of the pressure transducers was connected to a tap on the tank wall.

Flow rate was measured by a six-inch Omega model MG1000 electromagnetic flow meter. The flow meter was installed on the discharge side of the pump more than 50 diameters upstream of the pump with a straight section of pipe upstream and downstream of the flow meter. A flow control valve was installed downstream of the straight section of piping.

Water temperature was measured with a type T thermocouple installed in the tank near the water surface. The thermocouple was connected to an Omega DP-41 TC-A process meter.

All of these instruments were connected to a Dataq DI-220 data acquisition system running LSP60 software. This software records data every two seconds to disk in tab delimited format in engineering units. The software also provides plotting and digital displays of all of the instrumentation being recorded.

3 TEST PROTOTYPE

A prototype Transco strainer was tested (see Figure 2-1 and Figure 3-1). The strainer consists of three strainer cartridges each with four tubes bolted to a plenum that allows a flow path from each tube to the pump suction pipe. The three cartridges were labelled as C4570-004, C4570-005, and C4570-006. The surface area of this configuration is 75.1 ft^2 with perforated plate hole size of 3/32 in [1]. The plenum was mounted six (6) in (0.15 m) above the tank floor.

TS

Figure 3-1 Drawing of the test strainer

4 DEBRIS DESCRIPTION

Four types of debris were used in the test. Aged Nukon fiberglass was prepared as fines to simulate latent fiber, silicon carbide to simulate epoxy paint, sand mixture to simulate latent particulate, and aluminum oxy-hydroxide to simulate chemical debris [1,2].

4.1 Latent Fiber

For this test fiber, fines were tested to simulate latent debris. Fiber was prepared from aged Nukon fiberglass. The fiberglass was obtained heat treated from Performance Contracting Inc. lot number J-006-12HT*LN-1840. The heat treating process followed PCI procedure DPP-01 which heated one side of the insulation on a hot plate at 300 °C for 6 to 8 hours. The received insulation was inspected visually to confirm that the heat treatment produced a color gradient appropriate for aged fiber (see Figure 4-1).

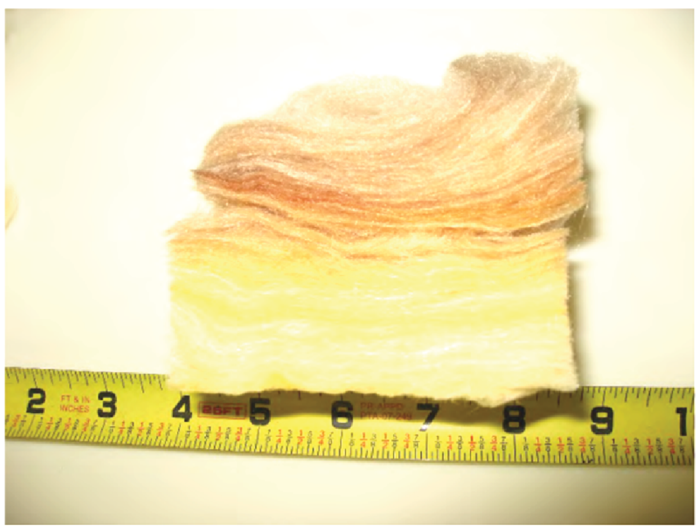


Figure 4-1 Sample of aged fiber

The use of fiberglass insulation, such as Nukon is recommended as a surrogate for dry latent debris [3]. The fiber was processed into fines. For test APR1400-HL-0813-1, the fiber was shredded once, then separated by a pressure washer, and stirred with a mixer. Typical fiber is shown below in Figure 4-2. These fibers have a significant amount of class 1 and 2 fibers, but also significant amount of class 3 fibers as defined in [4]. For test APR1400-HL-0913-2, the fibers were triple shredded, separated by a pressure washer, and stirred by a mixer in a more dilute fiber water mixture. The suspended fibers are shown in Figure 4-3 which are nearly all class 1 and 2 [4].

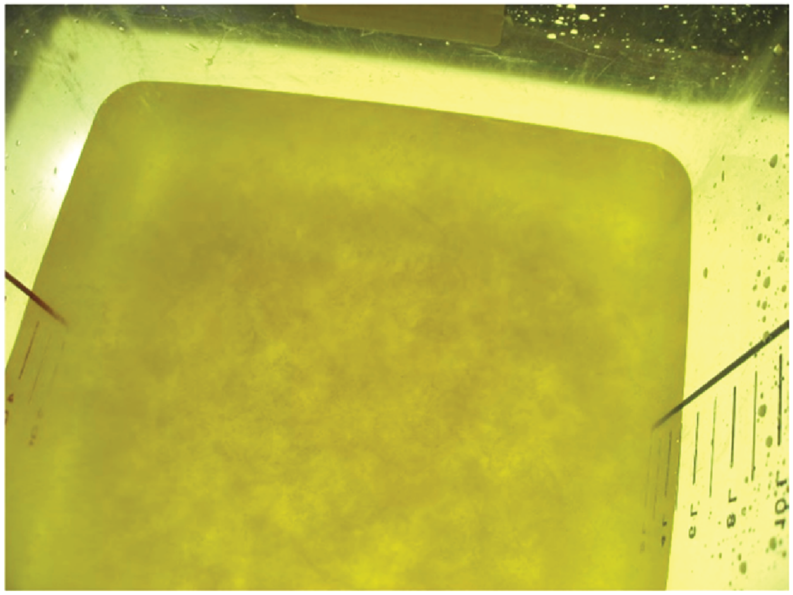


Figure 4-2 Photograph of fiber used in test APR1400-HL-0813-1

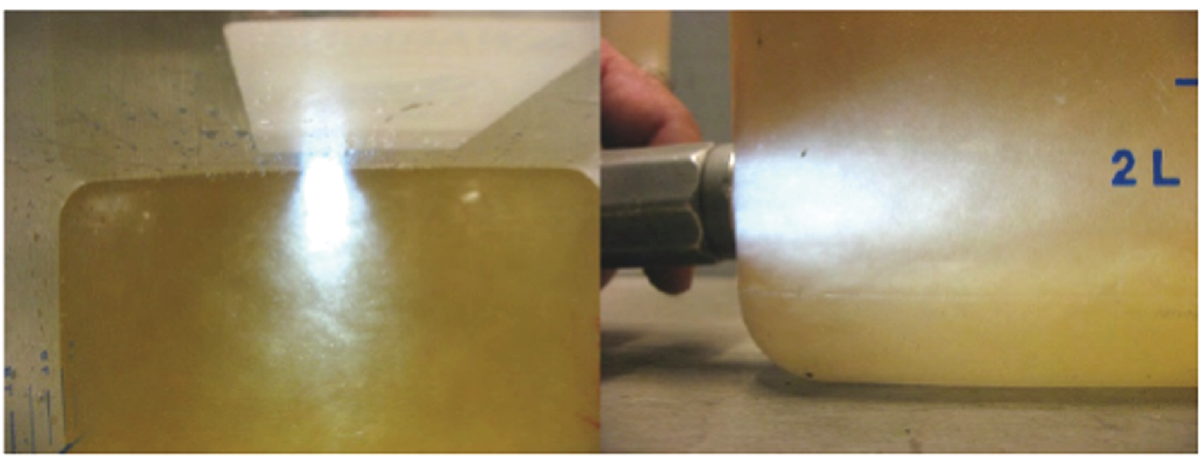
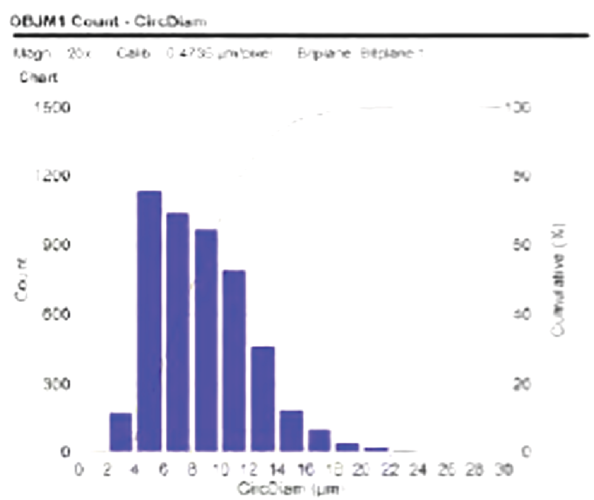


Figure 4-3 Photographed of fiber used in test APR1400-HL-0913-2

4.2 Silicon Carbide

ElectroCarḅ black silicon carbide (size 800) was obtained from Electro Abrasives in Buffalo NY. These particles have an average diameter of approximately 10 microns as measured by the manufacturer. A sample of the silicon carbide was microscopically measured and had an average diameter of 8.64 microns (Shoemaker, Kevin, M&P Lab Report 0929, January 13, 2009).



Values

CircDiam Intervals (µm)		Count	%	Cumul%
0	- 2	0	0	0
2	- 4	172	3.53	3.53
4	- 6	1128	23.13	26.66
6	- 8	1036	21.24	47.90
8	- 10	962	19.73	67.62
10	- 12	787	16.14	83.76
12	- 14	461	9.45	93.21
14	- 16	182	3.73	96.94
16	- 18	95	1.95	98.89
18	- 20	32	0.66	99.55
20	- 22	16	0.33	99.88
22	- 24	3	0.06	99.94
24	- 26	1	0.02	99.96
26	- 28	1	0.02	99.98
28	- 30	1	0.02	100

Statistics

Minimum	3.3	µm
Maximum	28.5	µm
Mean	8.64	µm
Std Dev	3.40	µm
Sum	42125.7	µm
Count	4877	
Under	0	
Over	0	
Accepted	100	%
Field Count	100	
Field Area	293847.6	µm²
Total Area	29.4e+06	µm²

Figure 4-4 Measured size distribution of black silicon carbide

4.3 PWR Sand Mix

PWR sand mix is defined to have a target distribution as shown in Table 4-1. The PWR mix was made by combining three types of sand. Paver leveling sand from Home Depot was used for the coarse sand. It was passed through a 2,000 micron sieve and no material passed through a 500 micron sieve. Glass bead blasting media was obtained in two different size ranges from Potters Industries in Pottsdam, New York (through McMaster Carr). The size labelled 40-60 mesh, lot number 1052713PO-2236 was all medium classification, all the sand passed through a 500 micron sieve and did not pass through a 75 micron sieve. The second size was labelled 170 - 325 mesh, lot number 1072313PO-3118 and was a combination of fine and medium sizes. 75.94 percent of the sand passed through a 75 micron sieve (fine) and 24.06 percent passed through a 500 micron sieve but was captured on the 75 micron sieve (medium). To create the sand mixture 28 percent of the total amount was weighed out from the paver sand. To create the fine sand 48.7 percent of the total amount was weighed out of the 170 - 325 mesh, which produced 37% fines and 11.7 percent medium. The rest of the medium sand, 23.3 percent of the total, was weighed from the 40-60 mesh sand.

Table 4-1: Target Size distribution [1,2]

Sand Recipe	Target (%)	Classification
<75 microns	37	Fine
>75 microns and <500 microns	35	Medium
>500 microns and <2000 microns	28	Coarse

4.4 Aluminum Oxy-hydroxide

Aluminum Oxy-hydroxide was fabricated following WCAP-16530-NP-A and the associated safety evaluation [5, 6]. The chemicals to make the aluminum oxy-hydroxide, aluminum nitrate and sodium hydroxide were obtained from Fisher Scientific.

The aluminum oxy-hydroxide was made at a concentration of 11g/l immediately prior to the test and a settling test was performed to ensure the chemical surrogate met the requirements in [6].

5 TEST PROCEDURE SUMMARY

5.1 Debris Preparation

5.1.1 Particulate Preparation

The particulate, sand mixture and silicon carbide, was split into buckets with approximately 10 pounds in each bucket. About 3 gallons of water was carefully added to each bucket and the mixture was agitated with a propeller agitator attached to a drill motor. The particulate and water was mixed to suspend the debris to facilitate pouring the mixture into the tank.

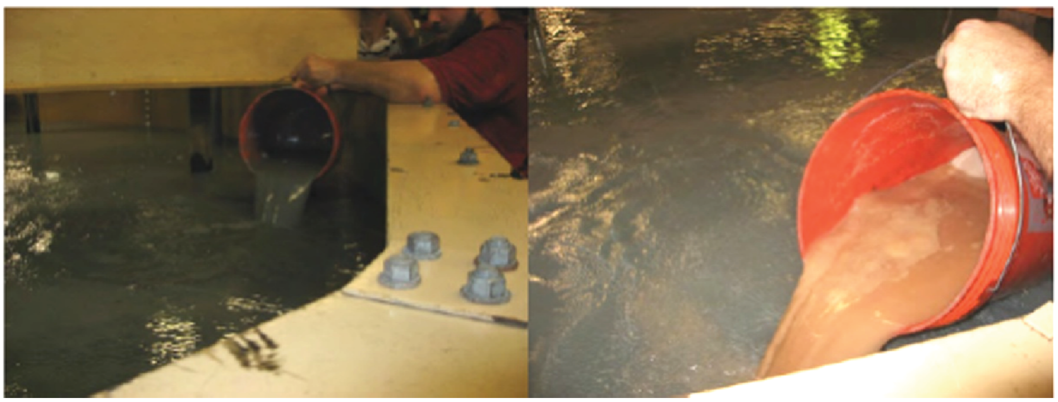


Figure 5-1 Typical particulate addition (silicon carbide left, sand mixture right)

5.1.2 Fiber Preparation

Fiber fines were prepared based on NEI guidance [7]. For both tests the debris preparation was similar, but the second test ARPR1400-HL-0913-2 did additional shredding and fiber dilution to ensure the fiber added to the tank was nearly all class 1 and 2 [4] and had no agglomeration as it was added.

For both tests, aged Nukon fiberglass insulation was cut into approximately 3 inch by 3 inch pieces. The cut pieces were then shredded in a leaf shredder/chipper, separated by a pressure washer, put into buckets, agitated by a mixer, and then poured into the tank.

For test APR1400-HL-0813-1, the fiber was shred a single time. The fiber was weighed into batches of 0.95 lbm. A batch of fiber of 0.95 pounds was placed in 4 gallons of water in a 32 gallon plastic container. The fiber was thoroughly wet and then separated using a pressure washer with a fan nozzle for approximately 4 minutes. The fiber was then separated into buckets. The fiber water mixture was then agitated with a propeller mixer at high speed for one minute, and the fiber water mixture was

added to the tank around the perimeter where the flow turbulence and upwelling diluted the fiber mixture (See Figure 4-2 for a photograph of the typical fiber size distribution). Photographs and video were taken of the fiber addition (for example see Figure 5-2).

Figure 5-2 Typical fiber fines addition for test APR1400-HL-0813-1

For test APR1400-HL-0913-2, the fiber was shredded three times. The shred fiber was then weighed into 2 batches of 1.15 lbm. A batch was split into three approximately equal portions and each third was placed into plastic container (approximately 32 gallons) with approximately 2 gallons of water. The fiber was thoroughly wet. The fiber was then separated using a pressure washer with a fan nozzle for 4 minutes. The water fiber mixture was then further diluted into 8 five gallon buckets with a total of 3 gallons of water in each bucket. Immediately prior to adding the fiber, the fiber was agitated with a propeller mixer on high for one minute. A sample of this fiber water mixture was taken to ensure the process produced fines that were nearly all class 1 and 2 fines [4] (see Figure 4-3). The fiber mixture was added to the tank and there were no fiber clumps as the fiber was poured into the tank. Photographs and video were taken of the fiber addition (for example see Figure 5-3).

Figure 5-3 Typical fiber fines addition for test APR1400-HL-0913-2

5.1.3 Aluminum Oxy-hydroxide Preparation

Aluminum Oxy-hydroxide (ALOOH) is made following the WCAP16350 recipe [5]. Given the volume of ALOOH required the amount of water is determined from the concentration (11g/l or 10.9 gal/lb).

Water is added to a clean plastic tank. Aluminum nitrate nonahydrate is added slowly to the water at 6.25 lb/lb of ALOOH. The water is mixed by a stirrer. After the aluminum nitrate has all dissolved sodium hydroxide is added at 2.0 lb/lb of ALOOH. The suspension must be mixed for at least one hour. A sample is taken and placed undisturbed in a graduated cylinder for an hour to perform a settling test. After one hour, greater than 60% of the volume must remain cloudy.

The ALOOH is mixed in a plastic tank. The required amount of volume is weighed out into plastic containers and poured into the tank around the perimeter.

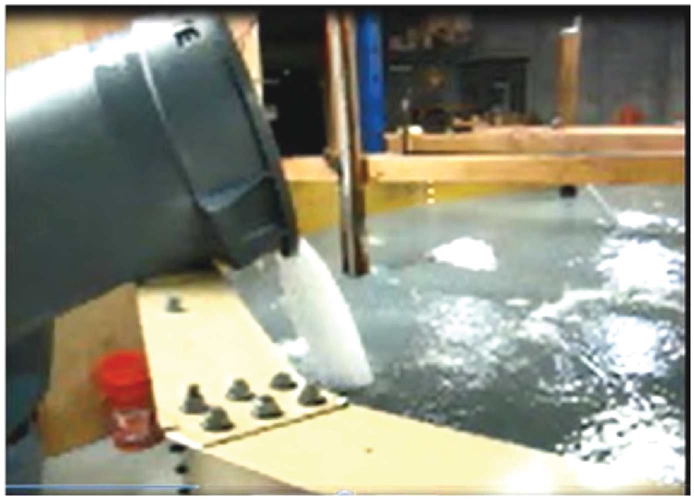


Figure 5-4 Typical chemical debris addition

5.2 Test Setup

The test setup consisted of cleaning the facility and cleaning and assembling the strainer as shown in Figure 2-1. The configuration is sketched in Figure 5-5. The strainer was checked to ensure there were no gaps greater than 3/32 in. The tank and piping were filled with water at 80 °F, the minimum temperature required in the test plan. The water level was set at 24 in above the top of the strainer tubes.

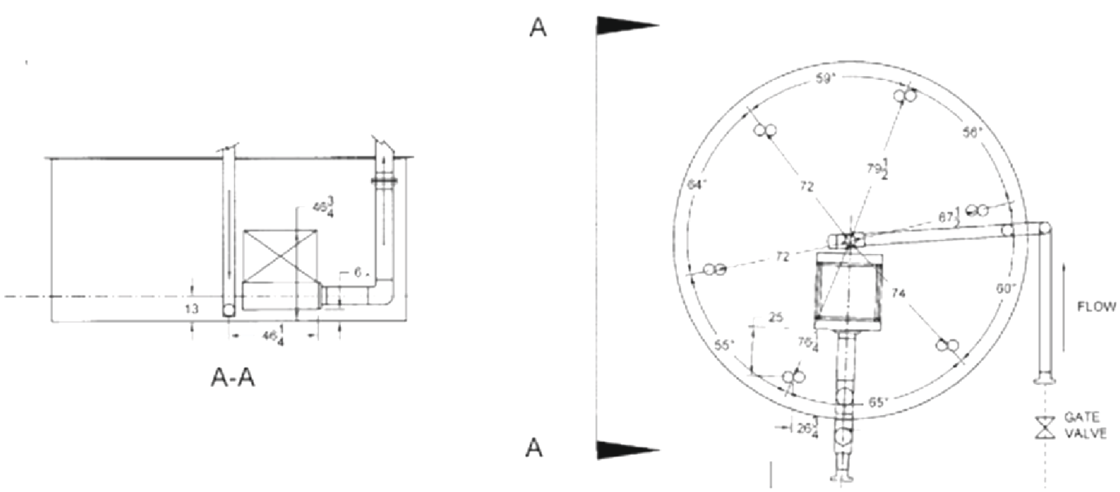


Figure 5-5 Layout of test facility

5.3 Test Initiation

Both tests were initiated by conducting a clean flow sweep. Because they had different target flow rates the sweeps occurred at slightly different target flow rates. All 6 agitators were on for both tests.

5.4 Debris Addition

After the clean flow sweeps were completed, particulate was added to the tank. Particulate was distributed into 5 gallon buckets and mixed with water. The particulate was added as slurry to make it easier to add the particulate in the tank. The buckets were poured around the perimeter of the tank. For each test there was a single addition of particulate, see Figure 5-1 for typical addition. Several buckets were added at consecutively to complete the addition.

After the particulate was allowed to circulate for a minimum of 2 pool turnover times (PTOs), the first of two batches of fiber were added. Fiber was added as slurry around the perimeter of the tank (see Figure 5-2 and Figure 5-3). Several buckets were added at consecutively to complete the addition. The second batch of fiber was added after 10 PTOs and the head loss reached its stability criterion (<1% head loss change in one hour). The head loss was so low that a 1 percent change in one hour was difficult to determine, but the head loss essentially remained constant to meet this criterion.

Chemical debris was then added from plastic 30 gallon containers and poured around the perimeter of the tank. For test APR-HL-0813-1, three chemical additions of 50 gallons each were added. The head loss did not increase for the last two additions so no more additions were required. For test APR-HL-0913-2, the measured head loss increased slightly for the first three chemical additions so the total load of chemicals was added in five batches.

5.5 Test Termination

Each subtest was terminated by completing the required minimum time and reaching the head loss stability requirement, if applicable. Clean flow sweeps were conducted for the time required and then that test was terminated. Particulate additions were conducted for the time required and then that sub-test was terminated. Fiber and chemical addition sub-tests were terminated upon completing at least 10 PTOs and reaching head loss stability of < 1 percent/hour. Final flow sweeps were terminated after completing the required 2 PTOs at each flow rate.

5.6 Post Test Observations

5.6.1 Test APR1400-HL-0813-1

After the test, the suction and discharge vents were opened very slowly to minimize disturbance of the debris bed. Typically draining with heavy debris beds does disturb the debris bed because debris can easily fall off vertical surfaces, especially when there is little head loss across the debris bed.

Figures 5-6 and 5-7 show that the strainer in the water was being drained from the tank. Some open area appears to have remained during the test. There are areas where debris has fallen off the strainer perforated plate also. The debris bed is thinner at the top of the strainer elements. Both photos show each strainer element covered by differing amounts of debris.

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Figure 5-6 Photo of the strainer post-test during draining (suction pipe is at top of photo)

TS

Figure 5-7 Photo of the strainer post-test during draining (suction pipe is at right)

Figure 5-8 shows two opposite sides of the strainer. The photo on the left shows the left side of the strainer looking from the suction pipe (suction pipe is near the right side of the photo). The photo on the right is the right side of the strainer (suction pipe is on the left side of the photo). The cylinder nearest the suction pipe on the left side appears cleaner than the other cylinders because debris has fallen off the strainer. Figure 5-9 shows details of the bottom of those cylinders. Figure 5-10 illustrates typical inside of strainer tubes after drain down.

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Figure 5-8 Photos of left and right side of strainer, the suction pipe is toward the center in both photos

TS

Figure 5-9 Photo of bottom of cylinders on left side of strainer showing debris having fallen off strainer Photo on left is aaway from suction pipe and photo on right is near suction pipe (visible)

TS

Figure 5-10 Typical view inside strainer tubes after drain down

5.6.2 Test APR1400-HL-0913-2

After the test, the suction and discharge vents were opened very slowly to minimize disturbance of the debris bed, just as in the previous test. Typically draining with heavy debris beds does disturb the debris bed because debris can easily fall off vertical surfaces, especially when there is little head loss across the debris bed.

In this test, the debris did not fall off the left cylinder closest to the suction pipe. Based on this comparison between Figure 5-11 and the left photo in Figure 5-8, there is no effect of agitation on the debris build up to the strainer. Figure 5-12 compares the left side and right side of the strainer after drain down and it is clear that debris falls off of different cylinders in an unpredictable manner. Figure 5-13 shows the ends of the strainer and Figure 5-14 shows the typical inside of the strainer tubes after drain down, note that debris falls off in an unpredictable manner.

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Figure 5-11 Left side of strainer during drain down (suction pipe is on right of photo)

TS

Figure 5-12 Comparison of left and right side of strainer after drain down

TS

Figure 5-13 Comparison of ends of strainer after drain down

TS

Figure 5-14 Photograph of typical inside of strainer tubes after drain down

Similar to the previous test, no debris was found on the tank floor.

5.7 Test Discrepancies and Nonconformances

For test APR1400-HL-0913-2, the flow meter was used outside of its calibrated range, but well within its operating range. The meter was calibrated to 900 gpm, but can operate to 2,400 gpm. The flow meter has two outputs an electrical output that is recorded on the data acquisition system and a display on the meter itself. For the test, the electrical output was rescaled from 900 gpm to 1,200 gpm maximum. The electrical output was compared to the display at several flow rates and compared to within 1 gpm. No further action was required.

For test APR1400-HL-0913-2, five (5) chemical additions were used, instead of four (4), at the request of the test director. The third chemical addition was increased from 50 gallons to 100 gallons. The additional chemical addition was used to provide additional resolution in case head loss increased significantly.

6 RESULTS OF TESTING

Test APR1400-HL-0813-1 was started on 28 August 2013 and finished on 29 August 2013. Test APR1400- 0913-2 was started on 12 September 2013 and finished on 13 September 2013.

6.1 Clean Flow Sweeps

The clean flow sweep data are shown in Table 6-1 and plotted in Figure 6-1. The data for the two tests are very consistent and the higher flow point for test APR1400-HL-0913-2 fits the same second order polynomial curve as test APR1400-HL-0813-1.

Table 6-1 Clean Flow Sweep Results

Test APR1400-HL-0813-1		Test APR1400-HL-0913-2	
Flow Rate (gpm)	Head Loss (in water)	Flow Rate (gpm)	Head Loss (in water)
833	4.3	1003	6.2
739	3.4	738	3.4
660	2.7	665	2.8
582	2.1	573	2.1
493	1.5	495	1.6
658	2.7	662	2.7
833	4.3	1002	6.2

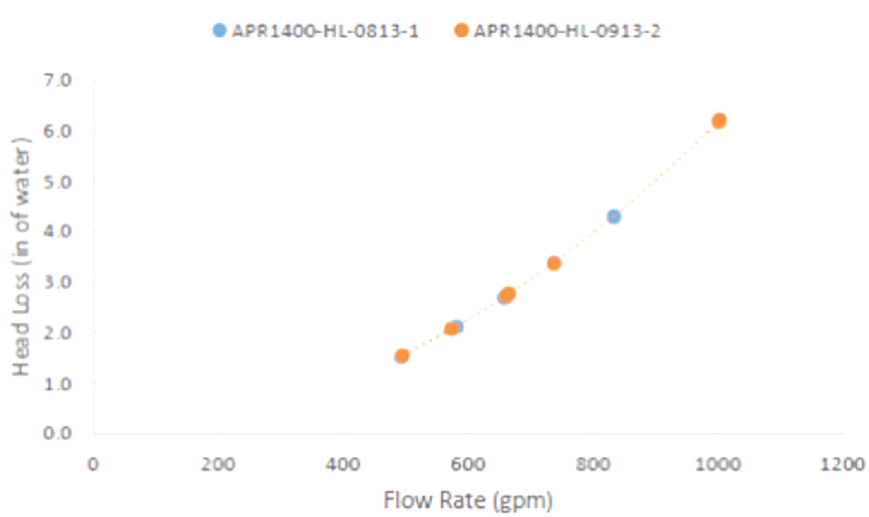

Figure 6-1 Clean flow sweep data

6.2 Test Conditions

Test APR1400-HL-0813-1 was run assuming a 600 ft^2 strainer and test APR1400-HL-0913-2 was run assuming a 500 ft^2 strainer (assumed blockage by tags and other debris) [1, 2]. The flow rate and debris amounts were scaled by the ratio of the test strainer area to the plant strainer area and therefore saw an increase for the second test of 20 percent.

Table 6-2 Comparison of head loss test conditions

Quantity	APR1400-HL-0813-1	APR1400-HL-0913-2
Flow rate (gpm)	834	1000
Silicon carbide(lbm)	77.4	92.9
Sand mix (lbm)	23.1	27.8
Fiber (lbm)(total)[1]	1.90	2.30
Chemical (gallons)(max)[2]	556.5	667.8

The as-tested test matrices are shown in Tables 6-3 and 6-4. The quantities in the tables indicate the amount of debris added during a particular subtest. Note that for test APR1400-HL-0813-1 only three chemical additions were required because head loss did not increase for the last two chemical additions. For test APR1400-HL-0913-2, the full chemical load was added in five additions.

Table 6-3 Test Matrix for APR1400-HL-0813-1

Subtest	Flow rate	Latent Fiber (lbm)	Dirt/Dust (lbm)	Coatings (lbm)	ALOOH (gal)
P.1	834	0	23.1	77.4	0
F.1	834	0.95	0	0	0
F.2	834	0.95	0	0	0
C.1	834	0	0	0	50
C.2	834	0	0	0	50
C.3	834	0	0	0	50
C.4	834	0	0	0	0
V.1	834	Water level was reduced to 2.0 feet above the strainer to check for vortexing			
FS	Various	Flow was reduced in 100 gpm increments to 234 gpm			

Table 6-4: Test Matrix for APR1400-HL-0913-2

Subtest	Flow rate	Latent Fiber (lbm)	Dirt/Dust (lbm)	Coatings (lbm)	ALOOH (gal)
P.1	1000	0	27.8	92.9	0
F.1	1000	1.15	0	0	0
F.2	1000	1.15	0	0	0
C.1	1000	0	0	0	50
C.2	1000	0	0	0	50
C.3	1000	0	0	0	100
C.4	1000	0	0	0	200
C.5	1000	0	0	0	267.8
V.1	834	Water level was reduced to 2.0 feet above the strainer to check for vortexing			
FS	Various	Flow was reduced in 100 gpm increments to 500 gpm			

6.3 APR1400-HL-0813-1 Debris Head Loss Results

Debris head loss results are shown in Table 6-5 for each of the subtests in Table 6-3 and plotted in Figure 6-2.

Table 6-5: Head Loss Results for APR1400-HL-0813-1

Subtest	Flow rate (gpm)	Temperature (F)	Head Loss (in water)
P.1	835	82	4.5
F.1	833	82	5.8
F.2	831	83	6.5
C.1	834	84	7.5
C.2	834	85	7.7
C.3	834	85	7.8
FS	729	85	6.0
FS	630	85	4.5
FS	536	85	3.4
FS	430	85	2.2
FS	333	85	1.4
FS	236	86	0.9

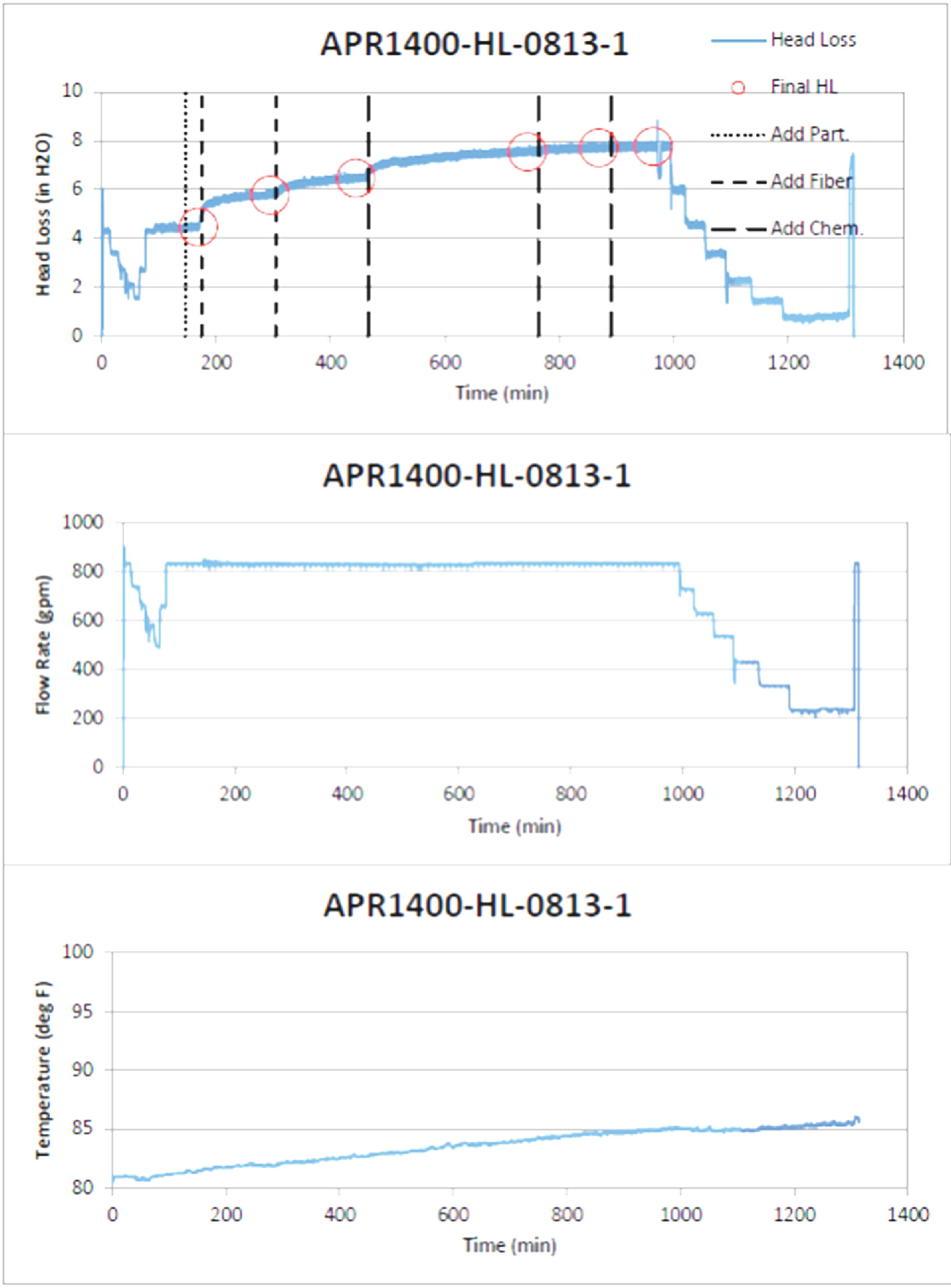

Figure 6-2: Head loss, flow rate, and temperature time history for APR1400-HL-0813-1

6.4 APR1400-HL-0913-2 Debris Head Loss Results

Debris head loss results are shown in Table 6-6 for each of the subtests in Table 6-4 and plotted in Figure 6-3.

Table 6-6 Head Loss Results for APR1400-HL-0913-2

Subtest	Flow rate (gpm)	Temperature (°F)	Head Loss (in water)
P.1	1009	81	6.4
F.1	999	82	8.1
F.2	998	82	8.4
C.1	996	84	9.0
C.2	998	85	9.4
C.3	999	86	9.6
C.4	1000	88	9.7
C.5	999	88	9.7
FS	899	88	7.9
FS	798	88	6.2
FS	700	88	4.9
FS	601	88	3.6
FS	496	88	2.5

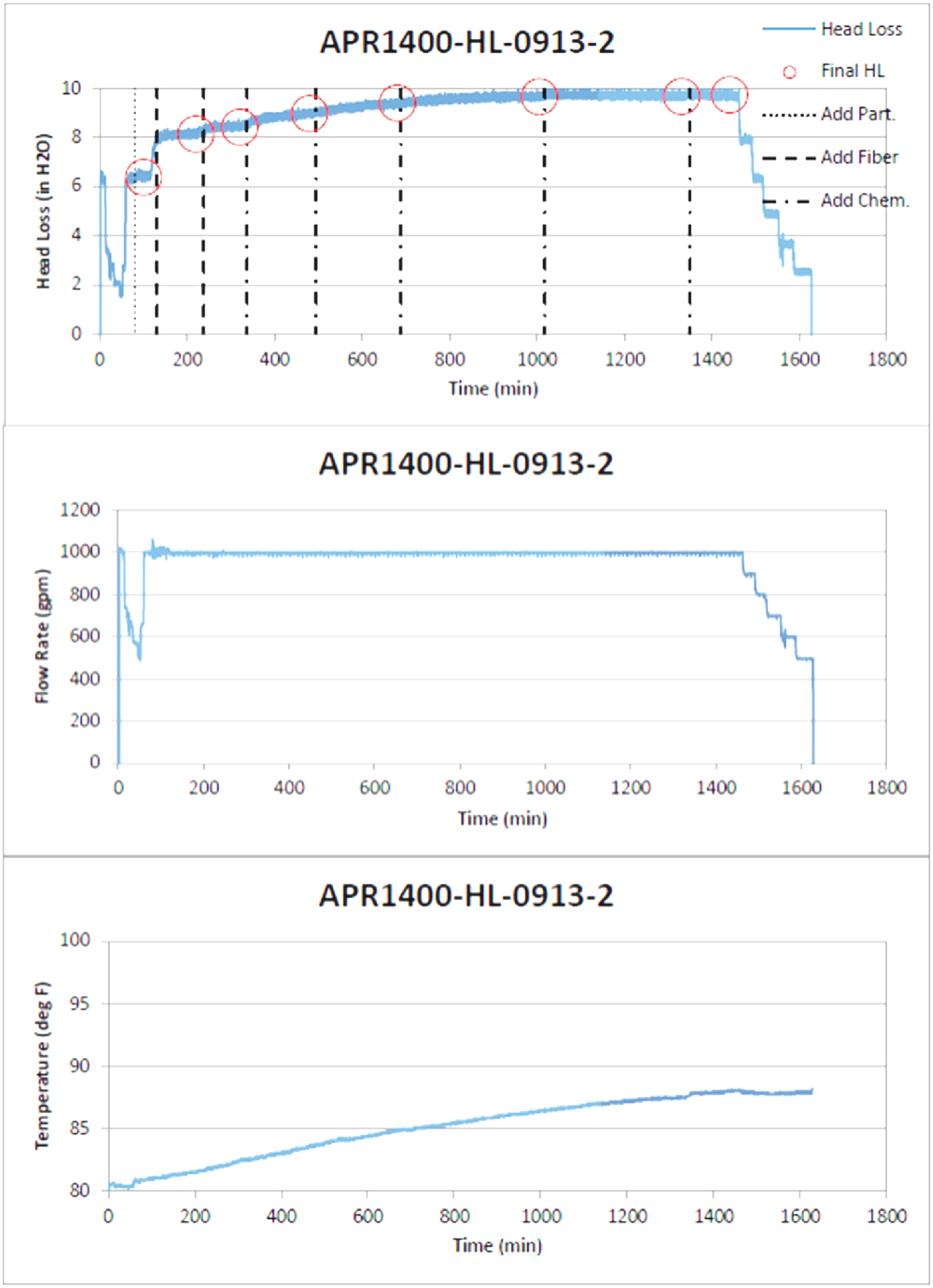

Figure 6-3 Head loss, flow rate and temperature results for APR1400-HL-0913-2

6.5 Vortex Tests

For both APR1400-HL-0813-1 and APR1400-HL-0913-2, no air entrainment or vortexing was seen. Photographs and video were taken of the strainer submerged at two feet of water at test flow rate. For test APR1400-HL-0813-1 after the flow sweep was complete, the flow rate was increased to the target flow rate to demonstrate the lack of vortex formation for test witnesses.

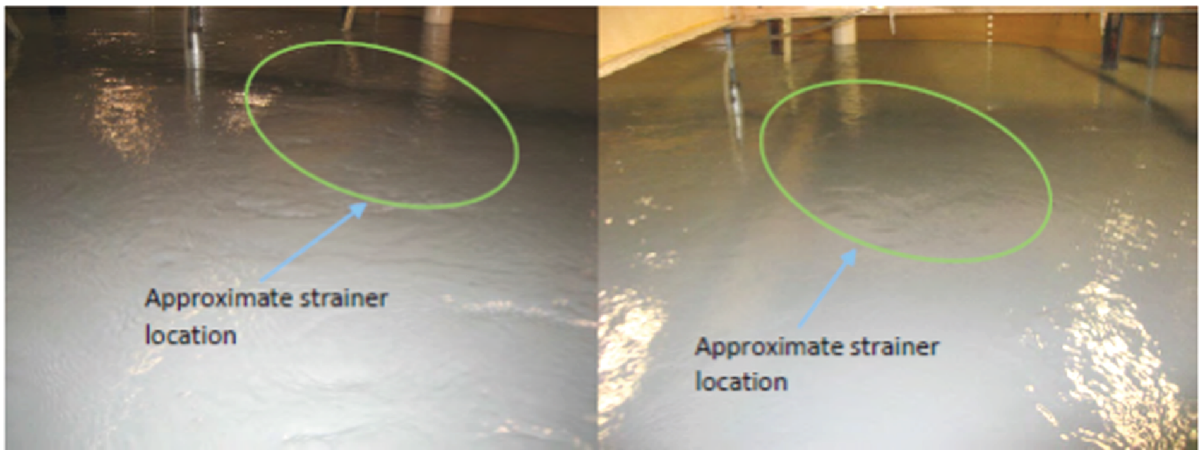

Figure 6-4: Photograph during vortex portion of tests APR1400-HL-0813-1 on left and test APR1400-HL- 0913-2 on right. No vortices visible

7 QUALITY ASSURANCE

All quality-related activities were performed in accordance with the Continuum Dynamics, Inc. Quality Assurance Manual [8]. Quality-related activities are those which are directly related to the planning, execution and objectives of the test. Supporting activities such as test apparatus design, fabrication and assembly are not controlled by the C.D.I. Quality Assurance Manual. C.D.I.'s Quality Assurance Program provides for compliance with the reporting requirements of 10 CFR Part 21. All instrument certifications, instrument calibrations, testing procedures, data reduction procedures, and test results are contained in a Design Record File which (upon completion) will be kept on file at C.D.I. offices.

8 REFERENCES

[1] Structural Integrity Associates, Test Plan No. 1300462.402, APR1400 IRWST ECCS Sump Strainer Prototype Hydraulic Qualification Test Plan," Rev. 1, July 2013

[2] Structural Integrity Associates, Test Plan No. 1300462.402, APR1400 IRWST ECCS Sump Strainer Prototype Hydraulic Qualification Test Plan," Rev. 2, September 2013

[3] NEI 04-07, Volume II, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02," Rev. 0, Appendix VII, page VII-3 December 2004 (SER)

[4] Los Alamos National Laboratory, Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance, NUREG/CR-6808, Feb. 2003, p 5-14

[5] Westinghouse, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," WCAP-16530-NP Revision 0, Feb 2006

[6] "Final Safety Evaluation by the Office of Nuclear Reactor Regulation, Topical Report WCAP-16530-NP- A 'Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191'," USNRC (ADAMS accession number ML073520891)

[7] NEI, "ZOI Fibrous Debris Preparation: Processing, Storage, and Handling," Revision 1 January 2012. [8] Continuum Dynamics, Inc., Quality Assurance Manual, Revision 14, February 2006

[8] Continuum Dynamics, Inc., Quality Assurance Manual, Revision 14, February 2006

Bypass Test Report for APR1400 IRWST ECCS Sump Strainer

Non-Proprietary

October 2013

Table of Contents

List of Tables

List of Figures

1 Introduction

If a loss of coolant accident (LOCA) were to occur, it is postulated that this LOCA could generate and transport debris to the Emergency Core Cooling Suction (ECCS) strainer. Some of the debris deposited on the ECCS strainer may pass through the strainer and could challenge the long term core cooling capability of the plant. The primary debris type of concern is fibrous material which potentially could form a debris bed downstream of the strainer, for example on the fuel grids. Particulate and chemical debris are assumed to pass through the strainer, and are therefore excluded from the bypass test.

The purpose of this test is to measure the quantity of fiber that can pass through the ECCS strainer. The test was conducted following a test plan [1] developed by Structural Integrity Associates.

2 Test Facility Description

2.1 Flow Loop

The test facility consists of an approximately 15 ft (4.5 m) diameter tank that is 7 ft (2.1 m) deep. The flow returns into the tank from a 6 inch pipe with a tee that is pointed at the floor in the center of the tank. The exit of the tee is approximately 2 in (0.05 m) above the floor so that the return flow sweeps along the floor then up the tank walls to help suspend debris. The tank can hold approximately 9,500 gallons of water. The tank was covered by a tarp to prevent dust and debris from falling into the tank.

The test strainer is located next to the return pipe with the strainer plenum mounted 6 in (0.15 m) above the tank floor. The top of the strainer elements are 46-3/4 in (1.2 m) above the tank floor. Six agitators (trolling motors) are located at approximately every 60 degrees at an approximately 12 ft (3.7 m) diameter (see Figure 2-1 and Figure 2-2).

The suction pipe is attached to the strainer and runs to the Godwin CD150M pump. The discharge of the pump goes to nine parallel filter housings, then to a flow meter, flow control valve, and then back into the tank (see photographs in Figure 2-2 and Figure 2-3 and a schematic in Figure 2-4).

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Figure 2-1 Photograph of strainer in test tank

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Figure 2-2 Photograph of filter housings.

Flow rate can be controlled by a combination of a variable frequency drive (VFD) that drives the pump, the gate valve, or a bypass line which provides a short circuit path between the suction and discharge of the pump. Typically, the VFD is used to control the flow rate during a test, unless very low flow rates need to be achieved.

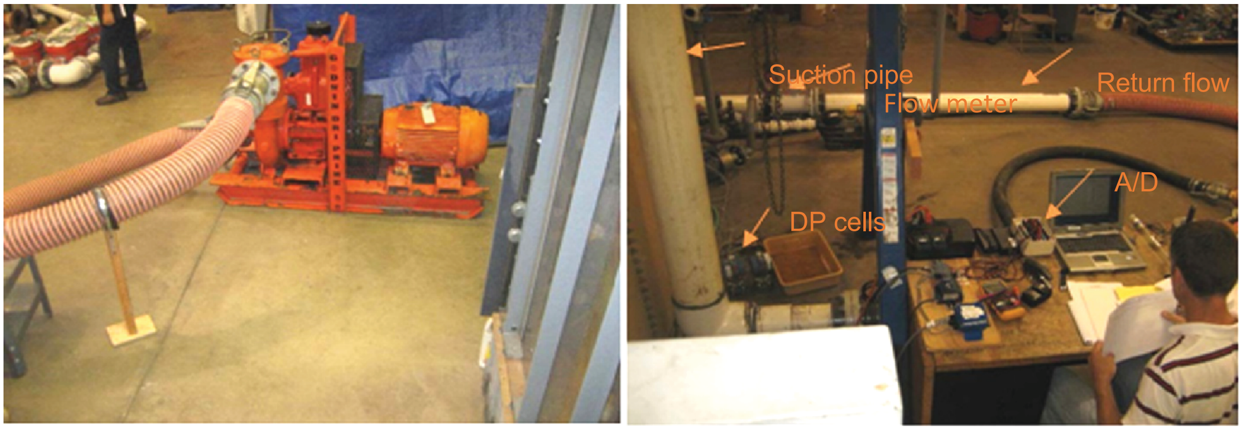

Figure 2-3 Pump on left, data acquisition flow meter and DP cells on right.

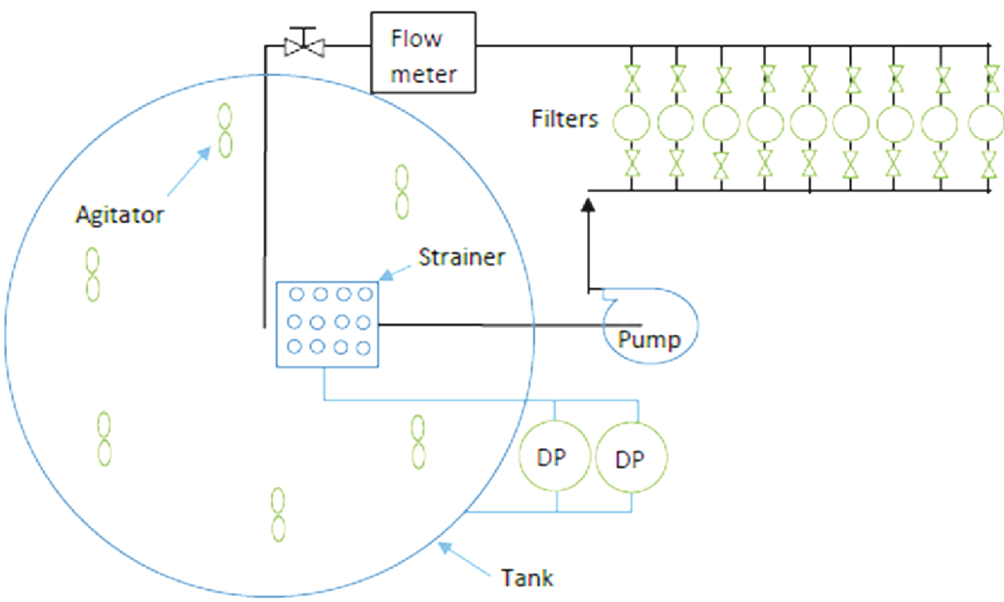

Figure2-4 Flow schematic of test setup.

2.2 Instrumentation

Head loss across the strainer was measured by two independent Rosemount model 1151 differential pressure transducers. One transducer was scaled to 0-100 in of water and the second was scaled to 0-300 in of water. These transducers were calibrated to +/-0.125% of their range. The low side of the differential pressure transducer was connected to the pressure tap on the strainer plenum and the high side of the pressure transducers was connected to a tap on the tank wall.

Flow rate was measured by a six-inch Omega model MG1000 electromagnetic flow meter. The flow meter was installed on the discharge side of the pump more than 50 diameters upstream of the pump with a straight section of pipe upstream and downstream of the flow meter. A flow control valve was installed downstream of the straight section of piping.

Water temperature was measured with a type T thermocouple installed in the tank near the water surface. The thermocouple was connected to an Omega DP-41 TC-A process meter.

All of these instruments were connected to a Dataq DI-220 data acquisition system running LSP60 software. This software records data every two seconds to disk in tab delimited format in engineering units. The software also provides plotting and digital displays of all of the instrumentation being recorded.

3 Test Prototype

A prototype Transco strainer was tested (see Figure 2-1 and Figure 3-1). The strainer consists of three strainer cartridges each with four tubes bolted to a plenum that allows a flow path from each tube to the pump suction pipe. The three cartridges were labelled C4570-004, C4570-005, and C4570-006. The surface area of this configuration is 75.1 ft^2 with perforated plate hole size of 3/32 in [1]. The plenum was mounted six (6) in (0.15 m) above the tank floor.

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Figure 3-1 Drawing of the test strainer

4 Debris Description

For this test only fiber fines were tested to simulate latent debris. Fiber was prepared from aged Nukon fiberglass. The fiberglass was obtained heat treated from Performance Contracting Inc. lot number J-006-12HT*LN-1840. The heat treating process followed PCI procedure DPP-01 which heated one side of the insulation on a hot plate at 300 °C for 6 to 8 hours. The received insulation was inspected visually to confirm that the heat treatment produced a color gradient appropriate for aged fiber (see Figure 4-1).

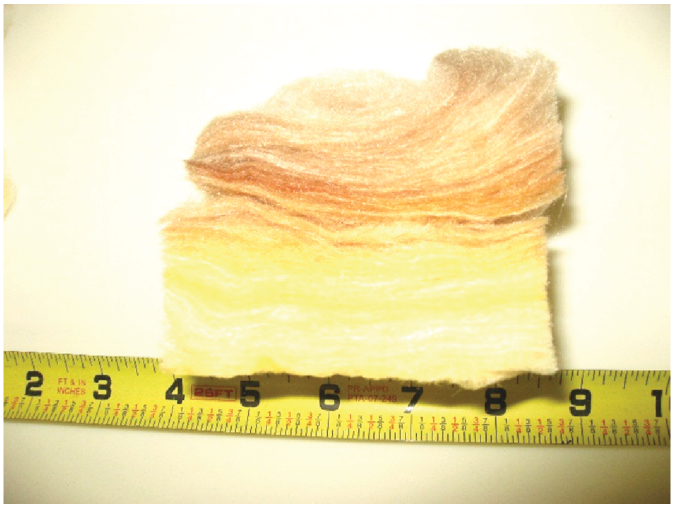

Figure 4-1 Sample of aged fiber

The use of fiberglass insulation, such as Nukon is recommended as a surrogate for dry latent debris [2]. The fiber was processed into fines, mostly class 1 and 2, as defined in [3] for use in the test. The processing steps are described in Section 5 and photographs of the end result of the suspended fibers are shown in Figure 4-2.

Figure 4-2 Photographed of simulated latent debris suspended in water.

5 Test Procedure Summary

5.1 Debris Preparation

Fiber fines were prepared based on NEI guidance [4]. Aged Nukon fiberglass insulation was cut into approximately 3 inch by 3 inch pieces. The cut pieces were then shredded in a leaf shredder/chipper, and the shredded fiber was then passed through the leaf shredder and additional two times. The fiber was shredded three times. The shred fiber was then weighed into 4 batches of 0.4 lbm. A batch was placed into plastic container (approximately 32 gallons) with approximately 2 gallons of water. The fiber was thoroughly wet. The fiber was then separated using a pressure washer with a fan nozzle for 4 minutes.

The water fiber mixture was then further diluted into 8 five gallon buckets with a total of 3 gallons of water in each bucket. Immediately prior to adding the fiber, the fiber was agitated with a propeller mixer on high for one minute. A sample of this fiber water mixture was taken to ensure the process produced fines that were nearly all class 1 and 2 fines [3] (see Figure 4-2). The fiber mixture was added to the tank and there were no fiber clumps as the fiber was poured into the tank. Photographs and video were taken of the fiber addition (for example see Figure 5-1).

Figure 5-1 Typical fiber fines addition.

5.2 Test Setup

The test setup consisted of cleaning the facility and cleaning and assembling the strainer as shown in Figure 2-1. The configuration is sketched in Figure 5-2. The strainer was checked to ensure there were no gaps greater than 3/32 in. The tank and piping were filled with water at 72 °F, which is above the 60 °F minimum required in the test plan. The water level was set 24 inches above the top of the strainer tubes.

All 9 filter housings were fitted with 1 micron felt filters to clean the water prior to the test starting. The data acquisition system was started and then the pump was turned on. The flow rate was set to 900 gpm, slightly greater than the target flow rate of 834 gpm, to improve pre-filtering. The water was filtered for greater than 10 pool turn over times (PTOs).

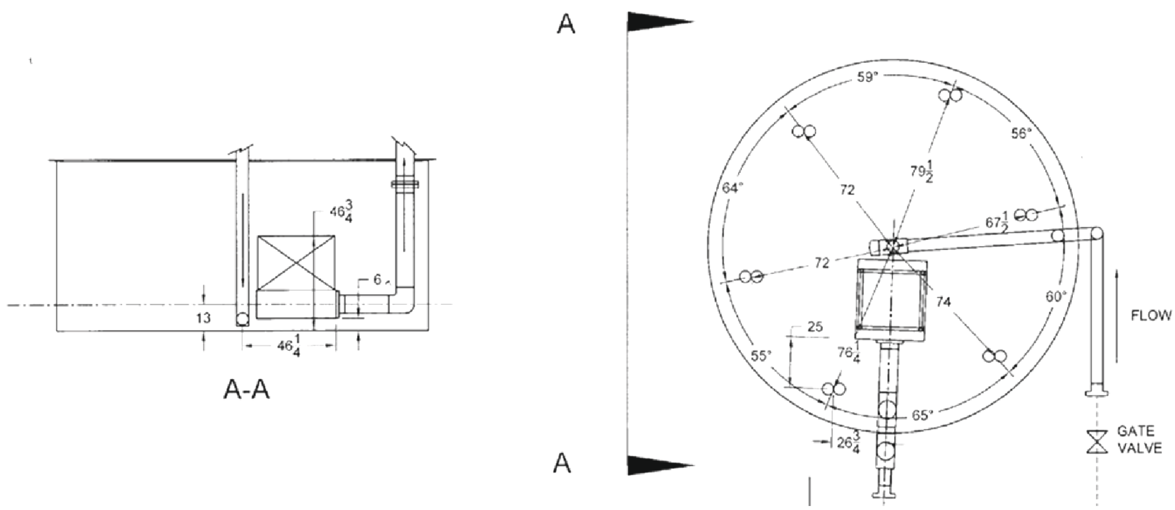

Figure 5-2 Layout of test facility

5.3 Filter weighing

Each filter was numbered to identify the filter. Filters were stored in a room at 35 percent relative humidity and 78 °F for several days prior to the test. The filters were weighed individually and in groups of eight, since they would be used in groups of eight. The filters were weighed in the same room in which they were stored.

After the test the filters were allowed to dry in lab conditions. After most of the water was removed from the filters, the filters were hung in racks in the filter weighing room at the same conditions they were initially stored and weighed.

The filters were allowed to dry for several days and then weighed three times over a period of several hours to ensure the weight was stable. The post-test filters were weighed in the same groups of eight that they were used (and originally weighed).

5.4 Test Initiation

The test was initiated by setting the flow rate to 834 gpm and swapping out the pre-filters for pre- weighed control filters. Data was already being acquired for head loss across the strainer, flow rate, and water temperature. Control filters were placed in eight of the filter housings with flow going through each of these eight filters. The ninth filter housing remained shut off and a pre-weighed, numbered filter that would be used to collect fiber was placed in that housing. No flow was going through that filter during the control filter portion of the test.

5.5 Filter Swapping

Filter swapping was performed to minimize flow disturbance and to avoid disturbing the debris bed on the strainer. Filters were swapped one at a time (only a portion of the flow could be disturbed). There were always eight filters active and one filter with no flow. To swap filters the valve on the downstream side of the unused filter was opened. Then the upstream valve of the unused filter was opened while the upstream valve of the neighboring active filter was closed. The new filter was now active.

The downstream valve on the used filter was closed completely isolating the filter. The vent valve on the filter was opened and then the drain valve was opened. The filter top was opened and when the water level in the filter housing was below the top of the filter, the drain valve was closed, the filter bag was removed and its number was recorded. Note that water draining from the filter housing drained through the filter bag and any fiber would be captured by the filter.

A new pre-weighed numbered filter (belonging to the same set of filters) was placed in the open filter housing. The filter number was recorded. The filter was sealed into the filter housing. Air was removed from the filter housing by cracking the upstream valve and allowing air to exit from the vent valve. Any water that exited through the vent passed through the removed filter to capture any fiber in the water. The filter was then hung up on a rack to dry.

This process was repeated for all filters and the last filter remained closed until the next filter change.

5.6 Debris Addition

After filter switching was complete fiber was added to the tank. Fiber fines were added from eight buckets and poured into the tank around the perimeter where the upwelling caused high level of turbulence. The fibers were suspended in the water and added to the tank without any visible fiber clumps.

There were four fiber additions of 0.4 lbm of fines.

5.7 Test Termination

The pre-filtering continued for a minimum of 10 PTOs prior to terminating this sequence and swapping filters for control filters. Filter swapping occurred after a minimum of 3 PTOs for the control filters. A minimum of 7 PTOs was used prior to terminating a fiber addition by swapping filters. After each fiber addition the pool was checked visually that all of the fiber was on the strainer. If no fiber was seen in the pool, then after 2 additional PTOs fiber swapping was started.

After the fourth batch of fiber was added and 7 PTOs were completed the test was terminated by stopping the pump. The tank was then drained while photographing and videotaping the debris on the strainer and the clean tank. The last set of filters were removed from the filter housings and allowed to dry.

5.8 Post Test Observations

The fiber debris was collected on the bottom of the strainer tubes on both the inside and outside. The fiber was built up to a height of 5 - 8 in (0.13 - 0.20 m) (see Figures 5-3 and 5-4). The debris bed was less than 1 in (0.025 m) thick at the bottom and tapered to a thin coating at the top of the fiber (see Figure 5-5). The debris remained on the strainer after the drain down.

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Figure 5-3 Strainer shown after test and drain down.

Figure 5-4 Photograph of the inside of the strainer tubes.

Figure 5-5 Detail of the fiber buildup outside of the fiber tube.

No fiber was found in the tank.

5.9 Test Discrepancies and Nonconformances

None.

6 Results of Testing

A single bypass test was run. The bypass test was identified as APR1400-Bypass-0913-1. Four batches of fines representing latent debris were added at the times shown in Table 6-1 and graphically in Figure 6-1. Note that time zero on the plot represents 9:36 AM when the data acquisition unit was started. A PTO during pre-filtering was 9 minutes and during the test was 10 minutes. Note that during filter switching and venting all water that might contain water still passed through the filters.

Table 6-1 Sequence of Events for Test APR1400-Bypass-0913-1

Event	Time	Number of PTOs
Pre-filtering	9:46AM to 12:31 PM	18
Switch filters	12:31 PM to 1:05PM	3.4
Control filter	1:10PM to 1:40PM	3
Switch filters	1:41PM to 2:05PM	2.4
First fiber addition	2:39PM to 2:45PM	0.6
Collect first fiber addition	2:45PM to 4:00PM	7.5
Switch Filters	4:13PM to 4:43 PM	3
Second fiber addition	5:00PM to 5:05PM	0.5
Collect second fiber addition	5:05PM to 6:18PM	7.3
Switch Filters	6:18PM to 6:45 PM	2.7
Third fiber addition	6:59PM to 7:04PM	0.5
Collect third fiber addition	7:04PM to 8:15PM	7.1
Switch Filters	8:16PM to 8:43 PM	2.7
Fourth fiber addition	8:51PM to 8:56PM	0.5
Collect fourth fiber addition	8:56PM to 10:10PM	7.4

6.1 Fiber Captured

Table 6-2 lists the amount of fiber fines added and the change in weight for the control filters and the filters that captured fiber after each fiber addition. Note that most of the strainer area remained open for all additions (see Figure 5-3). Each fiber addition was terminated after the tank appeared visually clear of fiber, which was confirmed near 5 PTO, then waiting two additional PTO for a minimum time of 7 PTO (see Table 6-1). PTO were counted from the end of each fiber addition.

Table 6-2: Summary of fiber bypass

Condition	Fiber added	Filter weight change (g)
Control filters	0	-0.18
After first fiber addition	0.4 lbm (0.18 kg)	37.16
After second fiber addition	0.4 lbm (0.18 kg)	29.66
After third fiber addition	0.4 lbm (0.18 kg)	28.04
After fourth fiber addition	0.4 lbm (0.18 kg)	29.08

6.2 Head Loss, Flow Rate, and Temperature

A plot of the head loss, flow rate and temperature are shown as a function of time.

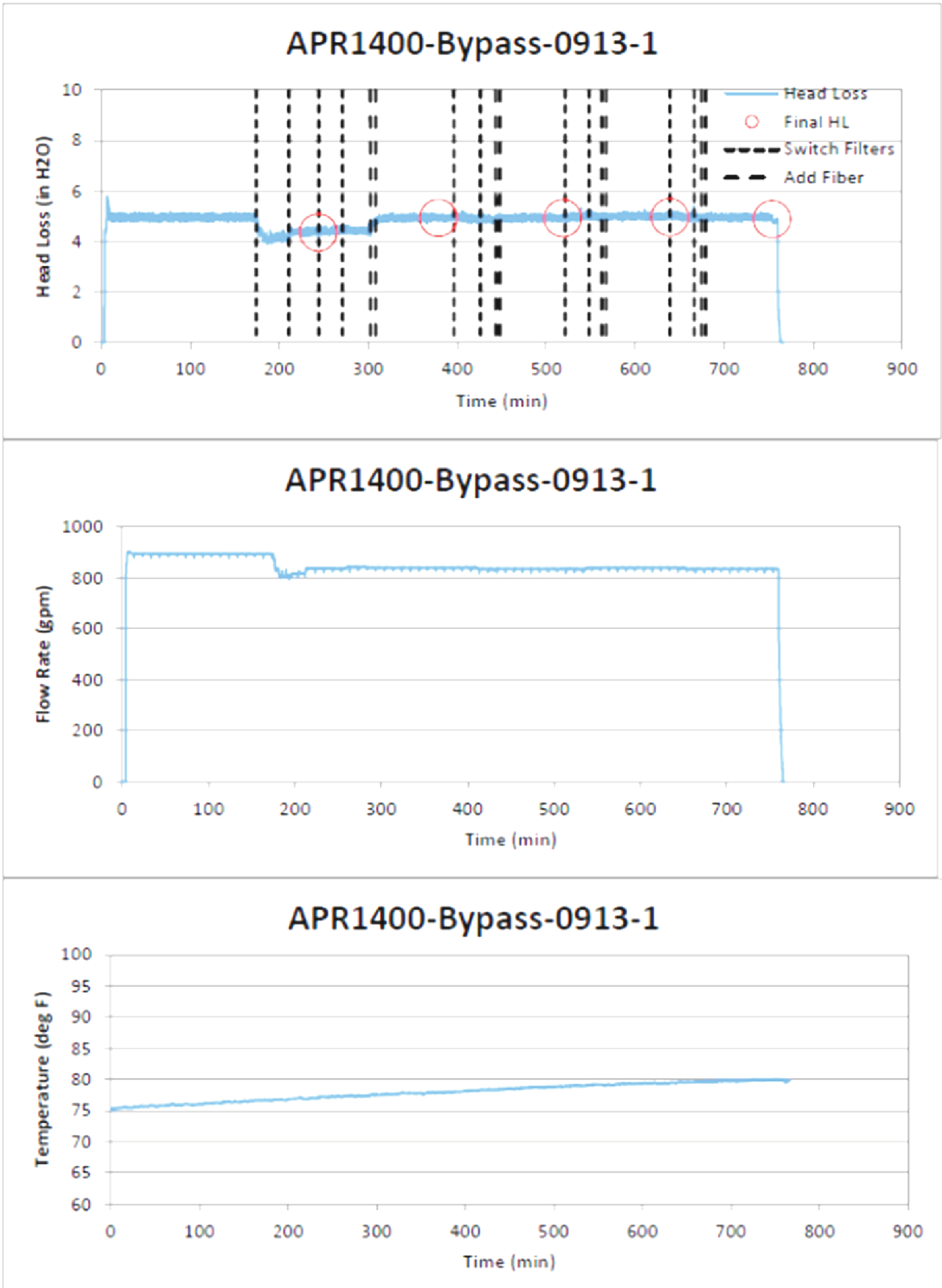

Figure 6-1 Time history of head loss, flow rate, and temperature. Pairs of lines on head loss plot indicate beginning and end of filter switch and fiber addition.

7 Quality Assurance

All quality-related activities were performed in accordance with the Continuum Dynamics, Inc. Quality Assurance Manual [5]. Quality-related activities are those which are directly related to the planning, execution and objectives of the test. Supporting activities such as test apparatus design, fabrication and assembly are not controlled by the C.D.I. Quality Assurance Manual. C.D.I.'s Quality Assurance Program provides for compliance with the reporting requirements of 10 CFR Part 21. All instrument certifications, instrument calibrations, testing procedures, data reduction procedures and test results are contained in a Design Record File which (upon completion) will be kept on file at C.D.I. offices.

8 References

[1] Structural Integrity Associates, Test Plan No. 1300462.403, APR1400 IRWST ECCS Sump Strainer Bypass Test Plan," Rev. 1, Aug 2013.

[2] NEI 04-07, Volume II, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02," Rev. 0, Appendix VII, page VII-3 December 2004 (SER).

[3] Los Alamos National Laboratory, Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance, NUREG/CR-6808, Feb. 2003, p 5-14.

[4] NEI, "ZOI Fibrous Debris Preparation: Processing, Storage, and Handling," Revision 1 January 2012.

[5] Continuum Dynamics, Inc., Quality Assurance Manual, Revision 14, February 2006.

Appendix C

Structural Drawings

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Figure C.1 Reactor Containment Building Section "A-A"

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Figure C.2 Reactor Containment Building Section "B-B"

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Figure C.3 Reactor Containment Building-Concrete Outline Dimensional EL. 81’-0”

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Figure C.4 Reactor Containment Building-Concrete Outline Dimensional EL. 100'-0"

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Figure C.5 Reactor Containment Building-Concrete Outline Dimensional EL. 114'-0"

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Figure C.6 Reactor Containment Building-Concrete Outline Dimensional EL. 136’-6”

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Figure C.7 Reactor Containment Building-Concrete Outline Dimensional EL. 156'-0"

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Figure C.8 Primary Shield Wall (Plan EL.69'-0")

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Figure C.9 Primary Shield Wall (Plan EL.100'-0")

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Figure C.10 Reactor & ICI Cavity Detail (Plan EL.69'-0")

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Figure C.11 Primary Shield Wall (Plan EL.117'-4")

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Figure C.12 Primary Shield Wall (Plan EL.130'-0")

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Figure C.13 Primary Shield Wall (Plan EL.130'-0")

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Figure C.14 Internal Structure (Plan EL.100'-0")

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Figure C.15 Internal Structure (Plan EL.114'-0")

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Figure C.16 Internal Structure (Plan EL.136'-6")

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Figure C.17 Internal Structure (Plan EL.156'-0")