ENCLOSURE 2

Non-Proprietary Version of BWROG ECCS Suction Strainers Benchtop Test #4 (BT4) Debris Bed Uniformity Test Plan, R0 [1140BWRBT-304-03], (GEH Class I - Public)

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BT4 – Debris Bed Uniformity
Test Plan – Revision 03

Non-Proprietary Version

1140BWRBT-304-03-NP

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ALDEN Research Laboratory, Inc.
30 Shrewsbury Street, Holden, Massachusetts 01520-1843

508-829-6000/phone • 508-829-5939/fax
info@aldenlab.com • www.aldenlab.com

INFORMATION NOTICE

This is a non-proprietary version of the BT4 - Debris Bed Uniformity Test Plan, which has proprietary information removed. Portions of the document that have been removed are indicated with space inside open and closed brackets as shown here [[ ]].

Record of Revisions

Revision No.	Revision Date	Change Description	Reason for Change
00	4/14/2015	Initial Issue	
01	4/15/2015	Proprietary information marks throughout document.	For consistency with proprietary version changes.
		Section 3.1 and Appendix A, changed "demineralized" to "deionized"	Consistency with remainder of document
		Section 3.2.2, penultimate paragraph, added "manifold" after "air introduction"	Clarity
		Appendix A, Water flow conditions, bundle flow conditions.	Corrected the inadvertent switch between submerged and unsubmerged conditions.
		Corrected several typographical errors throughout document	Editorial
02	4/20/2015	Removed stray " } " marking in text on p. 13, removed underlining on several brackets	Consistency with rest of document for removed proprietary information.
03	4/21/2015	Increased blank space between brackets	Consistency with proprietary version

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1.0 Objectives

Benchtop Test 4 (BT4) must be designed to meet a variety objectives to help address Requests for Additional Information (RAIs) [4][3] provided by the NRC to the Boiling Water Reactor Owner's Group (BWROG) in response to their submission of a Licensing Topical Report (LTR) titled: "Boiling Water Reactor Emergency Core Cooling Suction Strainer In-Vessel Downstream Effects" [3]. BT4 specifically must evaluate the following, as described in Attachment B of BWROG-13032[5]:

1) Verification that core spray modeling does not influence the ability of core spray to cool the fuel bundle or, alternatively, if core spray modeling is shown to have an influence, the identification of conservative core spray flow characteristics to employ to maximize any detrimental effects on the ability of the core spray flow to cool the fuel bundle.
2) Determination of the conditions, if any, leading to non-uniform debris bed development on the spacer grids that could impede cooling locally.
3) Evaluate and finalize full height bundle test approaches for:
   a. Steam simulation using air flow (evaluate introduction and distribution).
   b. Debris bed characterization, including optical blockage evaluation.
   c. Water hold-up measurement.
   d. Evaluate whether spacer grid differential pressure measurements can be reliably related to spacer grid blockage.
4) Variation of recirculation debris concentration with flow rate and the determination of a lower limit below which the recirculated debris concentration no longer changes as a function of flow rate (see Section 2.7).

2.0 Approach & Basis

The objectives outlined in Section 1.0 relate exclusively to concerns in the long term core cooling phase when water level has been recovered in the fuel bundle but the lower tie plate flow path is assumed to become blocked due to debris. The primary cooling path considered under these conditions is via core spray [1]. The Test 4 [3] full height bundle test series is targeted at confirming that the required cooling function from core spray can be maintained, as assumed in the parent LTR analysis [3]. In order to define the boundary conditions for the full height bundle Test 4 test series correctly, core spray must also be modeled. The fundamental approach to BT4 must therefore also include core spray modeling and must evaluate conditions as they might be expected at the bottom of the fuel bundle for the full height fuel bundle Test 4. In order to preserve the desired simplified approach of the benchtop test program (Attachment B [5]), a shortened fuel bundle assembly will be developed that incorporates a sufficient portion of the full height fuel bundle assembly characteristics to meet the objectives of the test outlined in Section 1.0.

2.1 Geometry

The BT4 shortened fuel bundle assembly must represent the interface between core spray and the fuel bundle and will therefore include a prototypical upper tie plate including the integral fuel bundle handle. Core spray is provided to the fuel bundle via the core spray headers in the region above the top of the fuel bundles [8]. The modeling approach for core spray is discussed in Section 2.4. One of the main objectives of BT4 is to evaluate the possibility of formation of non-

uniform debris beds. The upper tie plate (UTP) contains non-uniform openings across the fuel channel section and will generate some degree of non-uniform flow below the upper tie plate. The next [[ ]] spacer grids in a prototypical GE-14 fuel bundle [6] are partially rodded spacer grids (PRSGs) that have additional openings in the lattice and therefore may also influence the degree of non-uniform flow within the bundle. When the clean flow distribution is expected to be non-uniform the development of a non-uniform debris bed is more likely.

Therefore, the shortened fuel bundle will include a PRSG below the UTP. The non-uniform flow field will likely persist through all PRSGs in a similar fashion. Another possibility for non-uniform debris bed development is on the first fully rodded spacer grid (FRSG) below the bottom-most PRSG. The final spacer grid in the shortened assembly will therefore consist of a FRSG. A single PRSG is sufficient to simulate the incident flow distortion on the first FRSG since the distance between PRSGs is appreciable and the PRSGs are identical. The discharge flow pattern from the final fully rodded spacer grid must remain as prototypical as possible. Debris hold-up below the last fully rodded spacer grid should be avoided to allow debris to recirculate. Recirculation of debris with as little settling as possible is important to evaluate wash-down (see Section 2.7).

2.2 Flow conditions

Test 4 in the full height bundle test program addresses long term core cooling under both dry and submerged conditions [3]. Non-submerged long term core cooling conditions are acceptable for certain BWR designs [3]. For these designs, the fuel bundle never refills with water and the corresponding test conditions are referred to as being "unsubmerged". Later-model BWR reactor designs will end up with submerged cores under expected long term core cooling conditions. These conditions are referred to as "submerged". For dry conditions the flow rate incident on the fuel bundle depends only on the core spray flow distribution. For submerged conditions, the core spray supply exceeds what is required. The net in-flow into the bundle is only equal to what is required to replace evaporation or what is drawn in via natural convection currents. The water level may not rise appreciably above the top of the fuel channel since water can drain down to the lower plenum through unblocked bundles, bypass holes in the lower tie plate or other leakage paths [3]. The flow pattern into the bundle is therefore still affected significantly by core spray.

It is not clear whether blockage is more or less likely due to counter current steam flow. On the one hand the counter current flow is likely to disrupt debris bed formation. On the other hand the upward flowing steam reduces the available area through which water can flow downward, potentially making debris bed formation more likely. The full height fuel bundle test program will evaluate blockage both with and without simulation of the counter-current steam flow. The simulation of steam flow is discussed separately in Section 2.7. It is important to evaluate both conditions with and without simulation of counter current steam flow in BT4 as well.

2.3 Debris

The presence of debris in the core spray flow could allow blockage of the spacer grids, whether localized or global. The potential debris sources from containment consist of both fibrous and particulate sources. Fibrous insulation and the fibrous component of latent debris are the two dominant sources of fibrous debris that could potentially penetrate the strainer and challenge cooling of the fuel bundles in the reactor vessel. Particulate debris consists of iron oxide from the suppression pool, containment coatings and latent dirt and dust in containment. Various debris mixtures are possible depending on plant inventory, location of the pipe break, condition of the

suppression pool and the condition of the coatings within containment. A representative range in both quantity and composition must therefore be examined to ensure the conclusions drawn with respect to the objectives of this test are not sensitive to a particular debris source term that does not adequately represent the possible debris conditions across the fleet of BWR reactors.

However, it is not necessary to consider the possibility of sequential debris arrival since Test 4 is concerned with long term core cooling starting several minutes after the initial LOCA. Chugging and blow-down transport ensure a well-mixed suppression pool (see Section 4.4 in NUREG/CR-6224, [33]). Therefore a uniformly mixed debris mixture will be used in testing.

The fibrous debris characteristics targeted for the test must be representative of the fibrous debris characteristics expected downstream of the strainers based on test results obtained elsewhere [13]. The finer particulates that could transport to the strainer cannot be excluded from consideration downstream of the strainer. The debris characteristics of particulate therefore remain unchanged from upstream strainer conditions.

The debris concentration for the test must be considered carefully since higher debris concentration could lead to agglomeration and change the manner in which debris interacts with the spacer grid [5]. Prototypical suppression pool concentrations represent an adequate basis for core spray flow debris concentration since core spray flow draws from the suppression pool. The debris concentration in the suppression pool will decrease in time after incremental debris transport to the suppression pool has stopped. Higher concentrations should be evaluated for possibly affecting the development of non-uniform blockage (see Section 2.6) and wash-down (see Section 2.7). However, debris concentration will not affect the choice and method of counter current steam simulation or the development of adequate full height bundle measurements (see objective 3). Higher debris concentrations will also not be used to develop the method chosen to model core spray.

2.4 Core spray modeling

The headers discharge spray radially inward to cover the entire cross-section of active fuel. Since the tests must verify the ability to maintain cooling of the fuel bundle regardless of core position, any detrimental influence of a particular core spray trajectory must be bounded by the modeling method used for full height bundle testing. A range of spray trajectories and the resulting development of any blockage must be evaluated. In addition to spray flow supply, the possibility of all flow entering the fuel bundle at the perimeter of the fuel channel from the bypass region should be evaluated as this also constitutes a possible flow path with significant radial non-uniformity. While injection into the bypass region is supplemented by core spray, supplying flow from the bypass region alone is the worst case in terms of non-uniformity and will therefore also be considered for submerged bundle testing. Un-submerged bundle testing with bypass region flow injection is not necessary since the reactor types where un-submerged bundle testing is applicable are not equipped with injection directly into the bypass region. The evaluation of the core spray modeling approach will consider the spray momentum, flow rate and direction. The droplet size distribution is not important relative to the objectives of this test or the full height bundle test program and will not be considered in the test. The important effects of droplet size distribution will be evaluated in the evaluation of the core spray momentum. Since some geometrical details of the upper tie plate are not symmetrical (e.g. handle), some circumferential variation in the incoming spray must also be considered in developing a proper model for core-spray flow.

2.5 Steam flow simulation

The flow conditions relevant to Test 4 in the full height bundle test sequence were addressed in Section 2.2. Steaming could reduce blockage concerns via debris bed disruption but also emphasizes the effect of any remaining blockage because the area available for down-flow of water is reduced. Under the desired cooling conditions, phase change is limited in the lower region of the fuel bundle and increases gradually through the middle of the fuel bundle. The upper regions of the fuel bundle see the greatest void fraction of steam.

The prototypical bundle conditions therefore range from water solid to relatively high void fraction. Testing will be conducted both with and without counter current steam flow simulation to cover the range of expected conditions. In addition, the range of counter current steam flow will be sufficient to demonstrate how blockage behavior changes as a function of counter current steam flow rate. Since a range of counter current steam flow is investigated, the possible effects of how steam flow is distributed along the height of the bundle do not have to be evaluated further.

To simulate the effects of steam flow on debris bed development, actual phase change is not required. A gaseous injection method is therefore also acceptable. However, in order to adequately simulate the steam produced, the gaseous phase must be distributed approximately uniformly across the cross-section of the fuel bundle. These requirements also apply for the shortened bundle test bed that is described in the present test plan.

Air is being used as a suitable gaseous flow to simulate steam in the full height bundle testing [3] and will therefore also be employed in BT4.

2.6 Blockage evaluation

The evaluation of blockage is critical in determining the acceptability of any flow resistance that forms as a consequence of debris addition to the bundle. The analysis implemented a bounding envelope of acceptable losses across the spacer grids as a bounding development of blockage of cross-sectional area of the spacer grid. Debris bed formation on the spacer grid was therefore represented simply as a reduction in the available cross-sectional flow area at certain times after the accident. Test 4 must show that the various blockage fractions used in the analysis at certain times after the accident bound the experimentally determined blockage of the spacer grids. A difficulty exists however in determining blockage experimentally when the developed debris bed may be quite porous but occupies a large fraction of the cross-sectional area of the spacer grid.

Reliable blockage evaluation methods must therefore be developed that address the implementation of blockage in the analysis and is quantitatively possible from an experimental standpoint. Both flow resistance as well as optical methods (e.g. light transmission) should be used in developing a relationship between the debris bed characteristics in the experiment and the blockage values used to represent the bounding acceptable debris bed characteristics in the analysis.

In addition to deriving global blockage measures, local blockage must also be examined to evaluate whether or not it is possible to degrade cooling locally via a concentrated area of blockage while still meeting the overall success criteria for flow blockage. Blockage measurement methods should therefore also evaluate various measures of cross-sectional variation of debris deposition to help identify whether non-uniform blockage is a concern that warrants further evaluation. While criteria for unacceptable non-uniform blockage have not been

defined, the prime objective of BT4 in this regard is to quantify the potential magnitude of the non-uniformity for further evaluation.

2.7 Wash-down effect evaluation

The wash-down effect is due to the lack of phase change simulation in Test 4. The lowest portions of the prototypical fuel bundle have very little boiling and therefore have very little downward flow of water through the spacer grids. In Test 4, the same flow rate that is added to the bundle at the top will also be withdrawn from the bundle at the bottom. It is possible that a fragile debris bed that might form under very low flow conditions will not form in the execution of Test 4 because the flow rate range to be evaluated is not low enough. The fragile debris bed in this case would be "washed down" non-prototypically.

In order for wash-down to occur, the amount of debris held up within the bundle must be a function of the flow rate through the bundle. BT4 will therefore evaluate the relative concentration of debris downstream of the bundle as a function of the flow rate. It is expected that at some lower flow rate limit, the amount of debris that is held up at the spacer grids will no longer increase as flow is decreased. BT4 will determine this limit by monitoring the relative debris concentration downstream of the lowest spacer grid in BT4.

2.8 Assumptions

a) **Unverified:** The maximum fiber quantity per fuel bundle is limited to 50g. While this assumption is without direct basis, it is expected that 50g will be sufficient to form blockage fractions greater than 33% within the fuel assembly in the absence of counter-current steam flow simulation, allowing the objectives of the present test to be met. The assumption is therefore expected to be verified in testing.
b) **Unverified:** The water chemistry of a BWR suppression pool is best modeled using deionized water.

3.0 Experimental Setup

3.1 Overview

The fundamental approach to the test is outlined in Section 2.0. The outline of the flow loop that will allow the described approach to be executed is provided in Figure 3-1. The schematic shows a shortened fuel bundle assembly with a prototypical upper tie plate (UTP), partially rodded spacer grid (PRSG) and fully rodded spacer grid (FRSG). The lower tie plate (LTP) and LTP cover block are also part of the assembly to allow the flow to exit. Note that the LTP need not be prototypical since its main purpose is to anchor the fuel rods, tie rods and water rods. Nevertheless, it will be referred to by the acronym LTP within this document. The bundle assembly is further described in Section 3.2. Flow delivery will occur via spray nozzle or via the spray basin. The loop will be designed to account for overspray and the debris in the overspray will be washed down to the recirculation water tank using pump bypass flow and the spray flow itself. The recirculation water tank serves as the holding tank for the debris slurry. Over-spray will be returned to the recirculation water tank to make sure debris contained in the overspray will have an opportunity to be transported back to the spray nozzles and possibly transport into the fuel channel. The spray basin is described further in Section 3.4. The recirculation water tank is described in Section 3.5. The spray flow and pressure are measured independently from the bundle suction flow. The requirements for the spray flow are further described in Section 3.3.

Level indication in the spray basin will be used to indicate that a proper equilibrium between flow into and out of the spray basin has been reached. The vent may be actuated to compensate for water hold-up in the bundle in unsubmerged conditions. Two pumps operate in the loop. The bundle pump controls the bundle flow rate independently of the spray flow. Bypass flow from the bundle pump is recirculated to the area below the air introduction manifold to help increase the velocity at the bundle exit and help prevent settling in this area. For submerged conditions, where the water inventory does not change, the spray flow pump will not require control after initially setting up the desired conditions. The bundle pump speed may be varied to compensate for pressure losses inside the bundle or for water hold-up in the bundle in order to maintain a positive water level in the bottom of the bundle. The air supply system is designed to provide independent control over the simulated steaming flow rate. The debris concentration of the bundle outlet flow is monitored before the fluid is returned to the recirculation water tank (see Section 3.8 and Section 5.6). The loop shares many characteristics with the Test 4 loop set-up [18] but is in some ways simpler and in other ways more complex. The BT4 loop is simpler since it uses a single recirculation water tank rather than two collection tanks. The BT4 loop is more complex since BT4 must be designed to accommodate overspray.

All materials exposed to flow in the test must be corrosion resistant to deionized water (see Section 4.4). Corrosion resistance will be verified during inspection. Acceptable materials include: CPVC (chlorinated PVC), PVC (polyvinyl chloride), acrylic, polycarbonate, stainless steel, PTFE (Teflon), Polyethylene, Zirconium and Inconel alloys, etc.

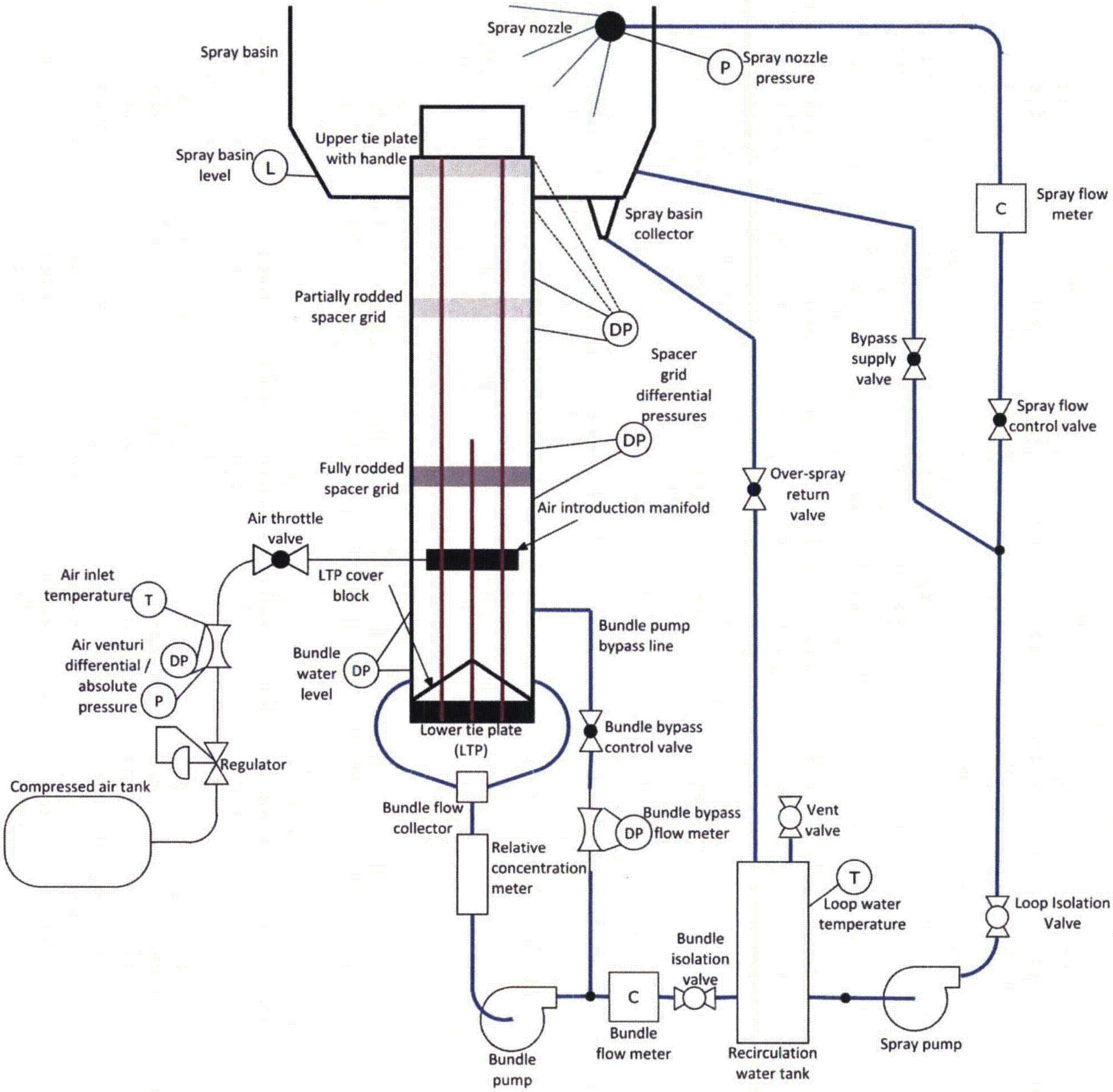

Figure 3-1. BT4 loop layout

3.2 Shortened fuel bundle geometry

3.2.1 Overview

The shortened fuel bundle geometry will consist of a prototypical UTP, a PRSG and a FRSG and will be terminated by an LTP model that provides the required anchoring and mounting spots for the dummy fuel rods, tie rods and water rods. The shortened bundle will be surrounded by a fuel channel model that provides a conservative internal flow passage area and contains the proper interface at the upper tie plate.

3.2.2 Fuel channel

The shortened fuel bundle geometry will employ a prototypical UTP with handle. The inner dimensions of the fuel channel and its interface to the UTP will be represented prototypically. Two clips (tabs) on the fuel channel catch the top of the UTP and fasten the fuel channel to the UTP. The geometry of the top of the fuel channel is shown in Figure 3-2, which shows the two clips that form the interface between the UTP and the fuel channel. The clip geometry is provided in Reference [26] and the location of the mounting hole is defined in Reference [22]. The inner cross-section of the fuel channel has a critical dimension of [[ ]] (square) with an asymmetric tolerance of at most [[ ]] [26]. The critical internal radius of curvature of the fuel channel is [[ ]]. These characteristics must be met by the fuel channel model employed in testing. [[ ]].

[[

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Figure 3-2. Top of Fuel Channel [21]

In addition to these geometric requirements, the fuel channel must have transparent sides that are equipped with measurement ports for differential pressure measurement approximately 1" above and below the spacer grids and UTP. Only one pair of ports is required at each elevation but additional ports may be added on other sides to provide flexibility for differential pressure diagnostics. The ports should terminate flush with the internal surface but should have a downward pitch of 10°±3° to prevent the water in the tap from exiting during counter current steam flow simulation. The transparent fuel channel must be able to be disassembled from the shortened fuel bundle without pulling the fuel assembly through the fuel channel. The main requirement is that the disassembly of the fuel channel results in little disturbance to debris beds

that are on the spacer grids. Horizontal removal of panels that make up the fuel channel is one method that can minimize debris bed disturbance and would satisfy this requirement.

The fuel channel must seal at the bottom to the modeled LTP and any leakage from the overall fuel channel must amount to less than 1% of minimum flow rate through the bundle. Bundle flow rates are discussed further in Section 4.1.2. The fuel channel must also contain four outlets that interface with the LTP cover block which guides flow to the outlets. Four inlets below the air manifold are required to introduce the bundle pump bypass flow. The inlets must be sized and located so that the pump bypass flow does not disturb the flow above the air introduction (see Section 3.6). Adequate sizing of the bundle pump bypass flow inlets will be verified during the facility inspection. Additional requirements for the bypass flow inlet lines are provided in Section 3.7. The bundle discharge diameter will be 1". Section 3.7 discusses requirements relative to how the four outlets must be combined to a single line and then interface with the recirculation water tank, described in Section 3.5.

The fuel channel must accommodate the air introduction manifold to simulate counter-current steam flow. Requirements for the air introduction manifold are provided in Section 3.6.

Finally, the fuel channel must interface with the spray basin to provide a seal between the spray basin and the fuel channel (see Section 3.4). Leakage must be less than 1% of the minimum bundle flow rate.

3.2.3 Fuel bundle

As discussed in Section 3.1, the fuel bundle itself will consist of a prototypical UTP, a PRSG, a FRSG and an LTP and corresponding cover block, where the LTP is not required to be a prototypical component, other than to provide adequate anchoring for fuel rods and water rods. The spacing between the UTP and the PRSG will match the prototypical distance between the UTP and uppermost PRSG [[ ]] The distance from the PRSG to the FRSG will match the distance between the lowest PRSG and the top FRSG [[ ]] [27]. The distance between the FRSG and the model UTP will match the distance between the top FRSG and the next lowest FRSG [[ ]] [27]. These distances must be maintained to within 0.25". By arranging the spacer grids in this manner, important prototypical distances are being maintained that will allow evaluation of key objectives of the test such as the potential development of non-uniform debris beds. The distance between the FRSG and the model LTP is less critical since flow develops relatively quickly downstream of FRSGs and well within the distance provided in the shortened fuel bundle assembly.

The LTP need not be prototypical. The critical requirements for the LTP are as follows:

- Sealing against the fuel channel
- Capturing the dummy fuel rods, tie rods, and water rods to provide lower structure to the fuel bundle
- Providing the lower seal of the shortened fuel bundle

The LTP therefore does not need to be equipped with the inlet geometry that is prototypical and would allow flow through the LTP. This includes the nose piece and the bypass flow holes. The LTP cover block will be the same one developed for Test 4 in the full height bundle testing [18], as shown in Figure 3-3. The LTP cover block must minimize debris settlement on the LTP and

the LTP cover block itself and help guide the flow out of the fuel bundle. Settlement on the LTP and the LTP cover block will be measured at the end of the test via weight gain measurement.

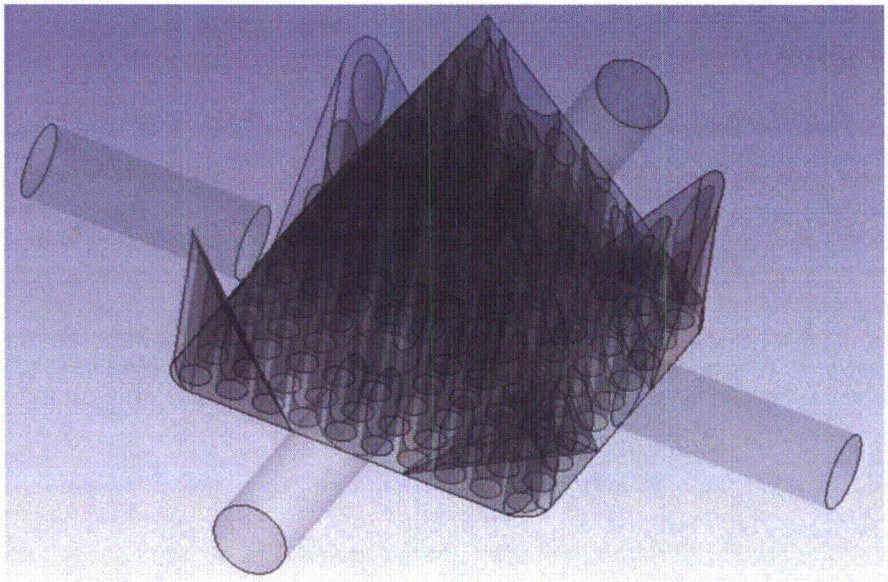

Figure 3-3. LTP Cover block, shown with 4 outlet pipes [18]

The dummy fuel rods need not be internally weighted but should be sealed sufficiently to prevent flow through the potentially hollow tubes. The same requirements apply to the tie rods. Fuel rods and tie rods must have prototypical top end fittings to allow a prototypical assembly with the top of the UTP, including prototypical springs and associated hardware. The part length rods (PLR) will have a length such that they reach above the FRSG in the assembly by the same amount as in the top most FRSG in the prototypical fuel bundle, [[ ]] [6][28] The arrangement of tie rods, full length fuel rods and PLRs will be prototypical within the fuel assembly. The perpendicularity requirements implemented for full height fuel bundles must also be adhered to as documented in Reference [20].

The water rods for the shortened bundle must have prototypical top end fittings as well as a prototypical top end diameter transition ([[ ]]) [6]. The bottom ends of the water rods must also be equipped with the same thickness transition but the location of the transition is not as precise. The transition must occur at least 6" below the FRSG and at least 6" above the LTP, so the water rod does not interfere with the LTP cover block. The water rod flow holes must be blocked. While the water rod flow holes are prototypical, the flow through the water rods is difficult to predict prototypically and it is conservative to block this alternative water flow path. Since a prototypical water path through the water rods does exist prototypically, any through-flow is sufficiently suppressed if the available clearances represent less than 1% of the prototypical openings in the water rod lower inlet ([[ ]]). The lower total water rod inlet flow area is [[ ]] [6]. Applying the 1% criterion to this area limits the total possible clearance area in the test water rod to one [[ ]] penetration or four [[ ]] penetrations. This information will be applied when inspecting the adequacy of

the test water rod hardware during the facility inspection. Prototypical water rods have small tabs that help locate the spacer grids. For ease of assembly and disassembly, these tabs can be replaced by set screws that have the same function.

In a prototypical bundle assembly, fuel rods are installed after the spacer grids and water rods are in place. The shortened test bundle will be assembled by mounting the fuel rods and water rods to the LTP and then sliding the FRSG and PRSG into place. The spacer grids will be located along the height of the bundle by set screws on the water rods which replace the welded tabs on a prototypical bundle. This assembly method will also allow the spacer grids to be removed from the top after testing before the fuel rods or water rods have been removed, helping to limit any alteration to the debris bed on the spacer grids. The position of the set-screw should be arranged such that it remains accessible from outside the bundle after all fuel rods are installed.

3.3 Spray flow nozzles

Core spray header nozzles on BWR reactors are designed to pass at least a [[ ]]. BWR 6 core spray nozzles are designed to pass a [[ ]] [8]. Two spray nozzles are common, the first is a [[ ]] type, as shown in Figure 3-4, consisting of a flared exit with a deflector to break up the stream of water. The [[ ]] nozzles are illustrated in Figure 3-5.

[[

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Figure 3-4. [[ ]] Nozzle

[[

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Figure 3-5. [[ ]] Nozzle

The [[ ]] nozzle has a much greater flow capacity than the [[ ]] nozzle [8]. The nozzles are alternated around the circumference of the spray header (inferred from Figure 5-4 in [8]). For both the upper core spray and lower core spray headers, nozzles are oriented toward the reactor vessel center [8]. The nozzles are angled vertically downward in each core spray header. For the upper core spray header, the downward angle of the [[ ]] spray nozzles was [[ ]] whereas the [[ ]] nozzles are oriented at [[ ]] downward. For the lower core spray header the orientations are [[ ]] downward for the [[ ]] and [[ ]] nozzles, respectively [8]. The supply pressure to the nozzles is relatively low. An internal orifice helps balance the flow among spray nozzles but only the header pressures are reported in Reference [8]. The minimum reported header pressure is approximately [[ ]] which represents an upper bound to the true nozzle supply pressure since all other reported pressures do not represent the true driving pressures but rather the flow control orifice upstream pressure.

The prototypical core spray nozzle headers are mounted less than [[ ]] above the top of the fuel channel [9]. The angle between the top of the fuel channel and the core spray nozzles is therefore relatively shallow, as shown in Figure 3-6. Figure 3-6 shows an arrangement typical of the fleet. The dimensions used for the test setup are not specific to any particular unit but representative of the BWR fleet.

[[

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Figure 3-6. Arrangement of core spray headers and nozzles relative to fuel channel [9]

The prototypical spray nozzles provide a full cone spray pattern with relatively large droplets on the order of [[ ]] ([8], answer to question #3 of the additional information requirements provided in the appendix of the document). The cone angle of the spray is sufficiently wide to provide sufficient flow to both peripheral and center fuel bundles.

To represent the described core spray characteristics in BT4, a spray nozzle ring containing 5 nozzles will be implemented. The nozzles will consist of a simple tee with a deflector similar to that found in the [[ ]] nozzles. The nozzles will be able to be arranged at downward angles between [[ ]], bounding the prototypical range. The relative distance between the nozzles and the fuel channel will be varied between 25% and 100% of the range of the spray, which will be designed to be less than 4 ft. The range of the spray will be limited by restricting the orifice of the spray nozzle and its driving pressure. The minimum spray nozzle diameter allowed will be 1/8" to ensure the nozzle does not produce a non-prototypical atomizing spray. The minimum flow rate per spray nozzle is obtained from the maximum bundle flow requirement of [[ ]] [7], for the unsubmerged bundle case). Accounting for a possible overspray of 50%, each spray nozzle must be designed to provide at least [[ ]] at a supply pressure of no more than [[ ]].

The arrangement of the five spray nozzles will be altered to reflect the possible positions of the fuel bundle within the core. The angle encompassed by the five nozzles will be considered as one of the experimental variables. Figure 3-7 shows a schematic of the various nozzle test parameters. When the angle between each nozzle (Parameter C in Figure 3-7) is set to 72°, the nozzles are arranged symmetrically around the circumference. The evaluation of these nozzle arrangements is further described in Section 4.2.

Each nozzle mount is required to provide the ability to characterize the rotational position of the nozzle relative to the horizontal plane (Parameter D in Figure 3-7). The nozzle position must allow the nozzle direction to be repeated reliably in the range of angles to be evaluated ([[ ]]).

The nozzle mounts must be designed to achieve at least three distinct positions in this range of angles. Other nozzle parameters vary the rotational position of the spray nozzle array relative to the fuel bundle (Parameter A) and also the fuel bundle position relative to the center of the spray nozzle array.

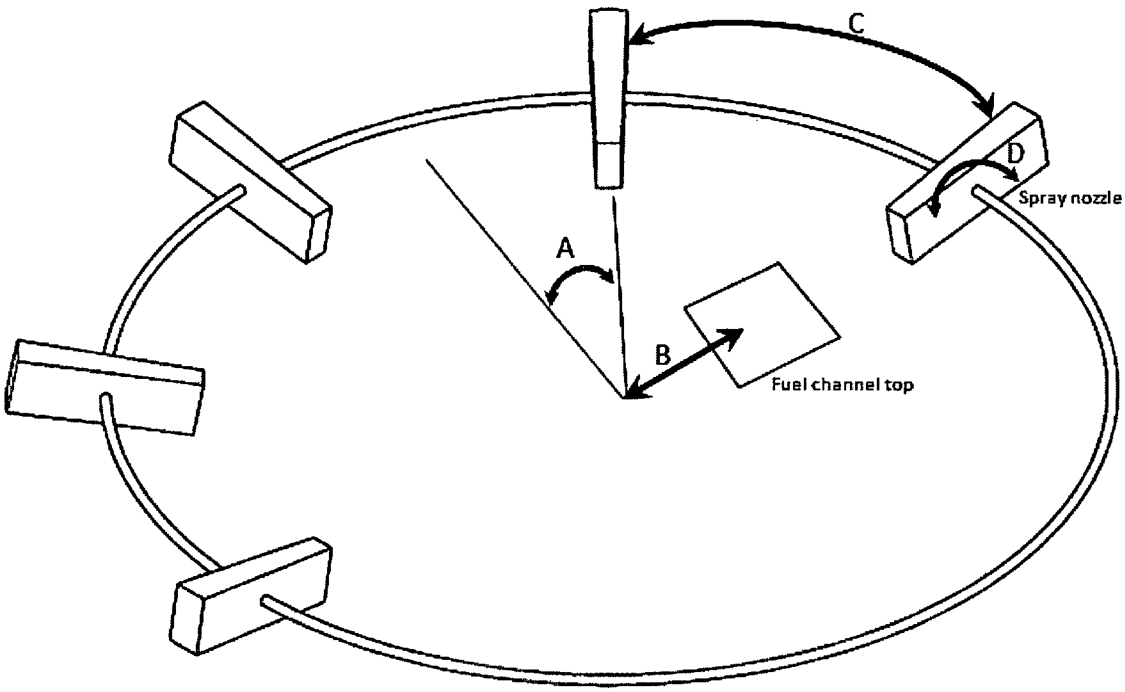

Figure 3-7. Spray nozzle arrangement parameters

Simplified single source flow delivery methods will also be evaluated once the range of spray conditions has been evaluated. The simplified single source flow delivery method must result in less than 1% over-spray since overspray collection is difficult to incorporate into the Test 4 full height bundle test setup. The simplified single source flow delivery method must be verified to provide the bounding behavior observed among the range of evaluated spray flow conditions. Section 4.2 and 5.9 will further discuss how the test results will be interpreted for bounding behavior.

3.4 Spray basin

The spray nozzle configurations to be evaluated drive the required radial extent of the spray basin. Since the spray range will be limited to 4 ft, a spray basin with a diameter of just over 8 ft will be sufficient to encompass the spray nozzles. The spray basin will be equipped with at least one bypass flow inlet to help ensure any debris contained in the overspray is swept back into the recirculation water tank. The bottom of the spray basin will be contoured to guide the bypass flow and overspray flow to at least one collection point to bring the water back to the recirculation water tank.

The collection point(s) will be equipped with a conical section to slowly accelerate the flow into the pipe leading back to the recirculation water tank. The bottom of the conical section must be designed to achieve a velocity of at least 1 ft/sec to avoid settling in the pipe. The minimum over-

spray flow rate will be [[ ]], based on the considerations of Section 3.3. For a single conical collection point, the maximum cone discharge diameter is [[ ]] whereas it is [[ ]] for two collection points. One conical collection section must be equipped with a pressure tap near its base to provide level indication for the spray basin. Level indication in the spray basin is discussed further in Section 5.2.1.

The spray basin must be sufficiently enclosed to prevent any spray flow from leaving the test. The spray basin must also seal against the fuel channel bundle at a location at least 6" below the UTP but at least 4" above the PRSG. These clearances will maintain the possibility of visual access to areas of interest within the shortened fuel bundle while the test is running.

The spray basin must be able to hold a water level that exceeds the fuel channel by approximately 1". A high spray basin water level is required for the evaluation of debris bed development when cooling flow is supplied from the bypass region alone (see Section 2.4).

3.5 Recirculation water tank

The recirculation water tank must have sufficient size to contain the entire volume of debris slurry at the target debris concentration. A bounding debris concentration for the suppression pool immediately following the accident was calculated in the test plan for BT2 [2]. For BT2, the calculated concentration of 1.0g of fiber per gallon was further increased to 1.5g of fiber per gallon. In addition sensitivity testing will be conducted using concentrations down to 0.2 g/gallon. To provide a conservatively large estimate for the required volume of the recirculation water tank, the lower concentration will be used. For the limiting assumed quantity of fiber of 50g, Assumption (a), the required volume of the recirculation tank is 250 gallons. The test debris concentration may be increased to a maximum of 2 g/gallon (see Section 4.6.3). The minimum recirculation water tank volume is therefore 25 gallons. The recirculation water tank must be designed to support both the minimum and maximum possible operating water level.

The recirculation water tank requires two inlets. The first inlet is for flow from the test bundle. The second is from the spray basin. The inlet from the spray basin is the largest contribution, possibly exceeding [[ ]] (see Section 3.3 and 3.4). The momentum from this flow will be used to maintain an even debris concentration in the recirculation tank and ensure debris settling does not occur. The spray basin inlet must therefore not be larger than [[ ]]. To aid in debris suspension, multiple spray basin inlets can be used for the recirculation tank. The minimum flow rate from the bundle is [[ ]] and the peak flow rate could be as high as [[ ]] (see Section 4.1). To ensure no settling occurs at the smallest flow rates and flow losses remain reasonable for larger flow rates the bundle flow inlet to the recirculation tank will be sized at [[ ]] with appropriate reducers available to reduce the inlet size to [[ ]] or below for the lowest flow rate test. The inlet velocity must be kept above 1 ft/sec to ensure full debris transport.

The recirculation tank also requires a vent. The vent will be used to control the water level within the recirculation tank. For tests with unsubmerged bundles, head-loss across the spacer grids will likely result in water hold up in the bundle. To ensure the loop flow rates can be maintained (even while temporarily reducing the bundle flow rate), the vent valve must be able to be actuated. When the vent valve is opened during the test, the water level within the recirculation tank will drop to account for the volume held up inside the test bundle. Vent valve management is further discussed in Section 3.7 and 4.1.2. The water level in the recirculation tank must be able to be visually monitored during testing.

The discharge from the recirculation tank must be from the bottom of the tank since this will further discourage settling of debris. The recirculation water tank must also be equipped with a port that allows the test water temperature to be monitored.

3.6 Air manifold

The requirements for the air injection manifold are as follows:

- Air injection should be as non-intrusive as possible.
- Any elements protruding into the flow path must be evaluated for debris retention after the test.
- The air injection must result in a visibly uniform distribution of void fraction throughout the bundle cross section. The uniformity of the air distribution must be documented during the facility inspection.
- The air injection must not be injected with upward momentum.

3.7 Piping & Valves

All pipes used in BT4 have the potential of carrying debris and must therefore be verified to have a velocity above 1 ft/sec. The velocity of 1 ft/sec is above the tumbling velocity of all debris types reported in NEI 04/07 [29] and therefore sufficient to ensure full transport of all debris.

The spray flow and bypass flow remain relatively constant and piping configuration changes will not be necessary to accommodate the range of tests to be conducted. The facility inspection will verify that the chosen design always maintains the required velocity within this portion of piping.

Piping changes will be necessary for the piping that connects the recirculation water tank to one of the outlets of the tee downstream of the bundle pump which contains only the bundle flow rate (pump flow – pump bypass flow). The anticipated flow range is twenty to one or greater, depending on whether an extended flow range is required to address debris wash-down (see Section 4.1.2.). The peak flow rate from the bundle will be [[ ]]. A reasonable minimum piping size for this flow rate is [[ ]] to keep piping losses in a reasonable range (~0.1-0.2 psi dynamic head). A flow rate of [[ ]] requires an internal diameter of at most [[ ]] to ensure a velocity of 1 ft/sec. Lower flow rates would require a further reduction. The piping configuration must therefore be adapted throughout testing to ensure the minimum velocity of 1 ft/sec is met without inducing excessive piping losses. Two bundle piping diameters will be used for bundle flow between the bundle pump bypass tee and the recirculation water tank. For flow rates between [[ ]], piping with an internal diameter between [[ ]] will be employed whereas for flow rates below [[ ]], piping with an internal diameter between [[ ]] will be used. The peak velocities in the piping will be between [[ ]] for flow rates just below [[ ]] and the lower flow limit where the 1 ft/sec criterion is satisfied is below [[ ]], providing some margin to the expected low flow rate test limit of [[ ]] (see Section 4.1.2). The maximum velocity for high flow rates will be below [[ ]].

At the discharge of the bundle, four outlets are used (see Section 3.2.2 and 3.2.3). The bundle pump bypass flow will ensure settling does not occur in the bundle discharge lines by ensuring the total discharge flow from the bundle is always above 10 gpm ensuring the 1 ft/sec velocity criterion is met for all experimental conditions. To verify an adequate discharge flow rate has been reached, the bundle bypass flow will be measured. The range for the bypass flow rate will be from 5 gpm to 10 gpm. To ensure no settling occurs in the bypass line and the pressure drop

remains reasonable, it will be sized with an internal diameter between 0.625" and 1.4". When the bypass line splits to return flow to the bundle without disturbing the flow field above the air introduction point, a minimum velocity of 1 ft/sec must be maintained in the line. If four lines are used the maximum internal inlet diameter is 0.71".

The losses for flow from the spray basin to the recirculation water tank do not change throughout the course of the test. However, the losses through the bundle that may develop through the test could decrease the outlet pressure from the test bundle as the test progresses. To maintain the same flow from the bundle and the spray basin, the bundle pump speed will be controlled. In this manner, the inlet pressure for the spray flow pump should never change for submerged test conditions and ongoing control of the pump speed is not necessary. For un-submerged conditions, water hold-up could lead to the spray pump needing adjustment since the water level in the recirculation water tank could decrease.

Valves in the pipe loop should be of the full port ball valve type. For throttling valves a V-ball design should be considered to eliminate potential debris sequestration in the bodies of loop valves. Globe valves are more likely to offer opportunities for debris drop-out and will therefore not be used in the loop.

3.8 Relative debris concentration meter

In order to assess whether or not debris wash-down is occurring, the debris concentration at the outlet of the bundle must be monitored. The measurement technique and output requirements are discussed in Section 5.6. However, the geometry of the relative debris concentration meter must also ensure that no settling occurs in the meter. To accomplish this goal, the meter will be set up such that the through-flow direction is downward. The same size cross-section meter must be used for all bundle flow rates. The length of the concentration meter must be sufficient to achieve uniform flow at the measurement point. The measurement point must be located at least 5 meter internal flow diameters downstream of the inlet and at least 2 meter internal flow diameters upstream of the exit of the meter. The concentration meter diameter must match the maximum diameter employed for the range of bundle flow rates. Since the relative debris concentration meter is located in the line from the bundle that contains the bundle bypass flow, the flow rate through the meter will be relatively constant.

4.0 Experimental Conditions

4.1 Water Flow Conditions

The test is set-up to provide for essentially constant spray flow supply conditions through the 5 spray nozzles while bundle flow conditions will vary much more significantly.

4.1.1 <u>Spray flow supply conditions</u>

While the relative position of the spray nozzles with respect to the fuel bundle will change throughout testing (see Section 4.2), the spray characteristics themselves will remain invariant throughout testing. Both the flow rate and delivery pressure will therefore not be changed during testing. A flow rate of [[ ]] of spray will be produced by each of five nozzles for a total supply flow rate of [[ ]]. Flow can also be supplied directly to the spray basin to model the case where flow enters the bundle from the bypass region alone.

The case where flow enters the bundle from the bypass region alone will not be evaluated for the unsubmerged case since reactor types that may not re-flood are not equipped with direct injection into the bypass region. The range of flow rates for supply directly from the spray basin, is also lower, being limited to the submerged bundle flow rate range, [[ ]] (see Section 4.1.2).

The spray flow rate or bypass flow rate is expected to be maintained at a constant level throughout a given test. Water hold-up in the bundle during un-submerged tests could lead to a decrease in the water level in the recirculation water tank and may therefore require a pump speed adjustment, depending on the amount of hold-up. For submerged tests, no pump speed adjustment at the spray flow pump will be necessary.

The spray flow rate and driving pressure will be measured and monitored directly. For the case where flow is supplied from the bypass alone, the inlet flow rate is of lesser importance and it is sufficient to maintain a constant water level in the spray basin. The supply pressure is implicitly monitored by measuring the water level in the spray basin.

4.1.2 Test fuel bundle flow rate

The test bundle flow rate is provided as a design input based on the condition of the bundle. For unsubmerged cases, the bundle flow rate is based on the possible range of incoming core spray flow which varies greatly across the core from [[ ]] [7]. For submerged cases the bundle flow rate is based only on the possible bundle cooling flow requirements with a provided range between [[ ]] [7]. Depending on test results it may be necessary to extend the test flow rate range to a lower flow rate to determine the limit for debris wash-down (see Section 2.7).

Test bundle flow rates must be measured independently downstream of the bundle pump bypass tee since the spray or bypass supply flow rate will always exceed the test fuel bundle flow rate. The bundle pump bypass loop flow rate itself will also be measured. The flow rate will be in the range between 5 gpm and 10 gpm.

For un-submerged tests, the target test fuel bundle flow rate may be difficult to maintain at a constant value during testing, depending on whether or not water hold-up develops during testing. If an attempt is made to withdraw water from the test bundle at the target flow rate while hold-up develops, the discharge piping may be emptied, including the relative debris concentration meter. Therefore, the water level in the discharge piping will be monitored for un-submerged tests. When hold-up is indicated by a loss of level in the discharge piping, the vent valve in the recirculation water tank is opened to allow the water level in the recirculation water tank to decrease to make up for the water hold up. At the same time, the bundle pump speed will be temporarily decreased to maintain a submerged water level for the relative concentration meter. When the test bundle discharge piping water level has recovered, the vent valve is closed again. To prevent control instability, a minimum vent valve open time will be determined during shakedown testing. At the end of the test, the reduction in recirculation water tank level can likely be directly related to water hold-up within the test bundle. Water hold-up is a helpful additional diagnostic tool to help characterize blockage.

4.2 Spray nozzle arrangement

One of the spray nozzle arrangement parameters that was introduced in Section 3.3 was the angle between each of the five nozzles (Parameter C in Figure 4-1). The potential influence of a

variation in the relative circumferential position of the fuel spray nozzles relative to the fuel bundle must be evaluated since the fuel bundle is square and has 180 degree symmetry due to the fuel bundle handle and water rod arrangement (Parameter A in Figure 4-1).

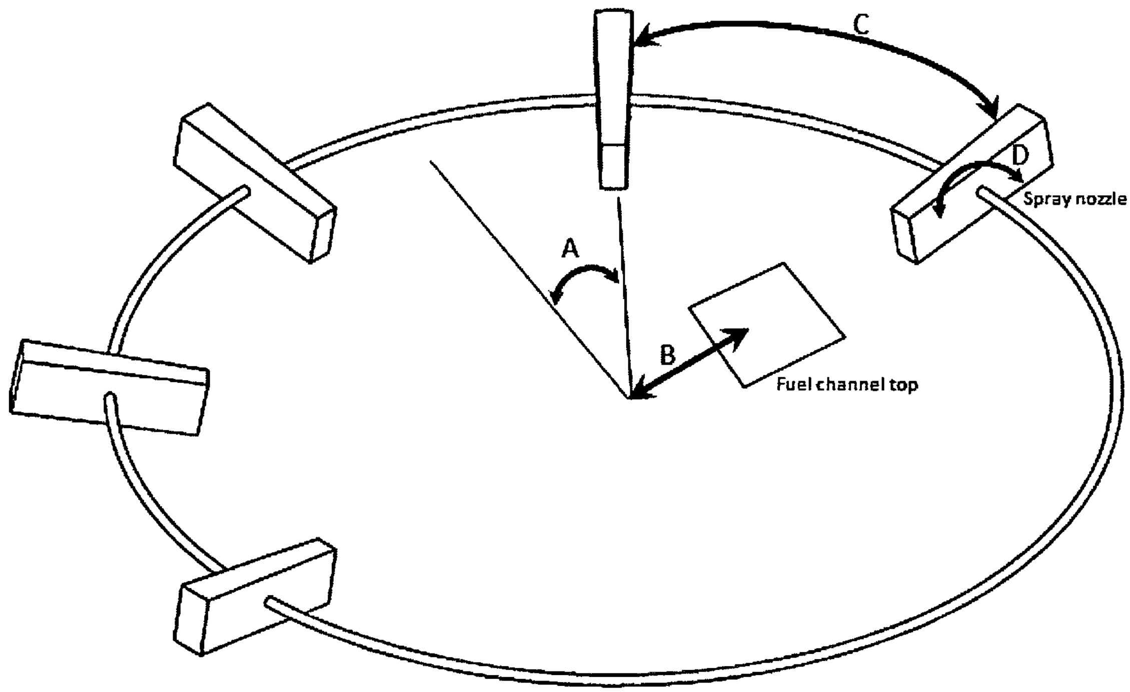

Figure 4-1. Spray nozzle arrangement parameters (repeated Figure 3-7)

The circumferential angle through which the nozzle arrangement can be rotated without duplicating alignments depends on the spacing between the nozzles and can be limited by the symmetry of the fuel bundle and the spacing between the nozzles. All five nozzles will be in operation at all times, regardless of nozzle arrangement.

In addition, the position of the spray arc center point relative to the test fuel bundle center point will be varied (Parameter B in Figure 4-1). The arrangement of the nozzle array will directly determine the flow rate into the bundle in the un-submerged case. For the submerged case, the spray nozzle configuration and bundle flow rate are not coupled. The angle of the spray nozzle (Parameter D in Figure 4-1) as well as the radial position of the test bundle in the spray arc will be used to evaluate the effect of spray flow momentum on debris bed formation, independent of the flow rate for the fuel bundle, which is determined by thermal conditions inside the bundle for the submerged bundle case.

In summary, Table 4-1 presents the spray flow related parameters to be evaluated. The minimum circumferential nozzle spacing will be 22.5° causing the five nozzles to occupy a 90 degree quadrant. The maximum circumferential nozzle spacing will be 72°. The circumferential position of the nozzle array can be varied between the reference 0° position and the remaining arc angle not occupied by the five nozzles. The circumferential position can be varied by 270° when the five nozzles occupy a 90° quadrant and only 72° when the nozzles are spaced by 72°. The symmetry of the fuel bundle UTP is such that a circumferential rotation past 90° is not

necessary. Since it is unlikely that the circumferential spray position will become an important parameter that needs to be resolved to increments of less than 18°, it makes sense to set the circumferential spray nozzle position parameter range to between 0° and 72° regardless of the circumferential nozzle spacing.

The downward angle of the spray nozzle is limited to within the prototypical range of between [[ ]]. For unsubmerged tests, the spray flow angles are directly tied to the incident bundle flow rate and the bundle flow rate will not be an independent parameter.

The radial position of the fuel bundle relative to the spray arc center will also be varied between 0 (center of the arc) and 75% of the radius of the arc (Parameter B in Figure 4-1).

It is important to also add that an additional configuration will be evaluated where all the spray flow is supplied through the bypass line and enters the fuel bundle from the periphery of the fuel bundle.

Table 4-1. Spray nozzle parameter summary

Parameter	Minimum Value	Maximum Value	Figure 4-1 Parameter ID
Angle between spray nozzles	22.5°	72°	C
Circumferential angle range	0°	72°	A
Radial position of fuel bundle in spray nozzle arc	0	75%	B
Spray nozzle downward angle	[[ ]]	[[ ]]	D

Once the response to the range of spray conditions has been identified, additional single nozzle or simplified water delivery methods will be evaluated for application to full height bundle testing, verifying that the simplified spray application method provides a bounding response to those measured over the range of evaluated spray conditions. Section 5.9 further discusses the evaluation of spacer grid blockage and how bounding behavior will be identified.

4.3 Counter-current Steam Flow

The steaming of the fuel bundle causes an upward flow of gas against the downward flow of liquid. When the core spray flow distribution was analyzed [8], its sensitivity to steam updraft was also evaluated. Specifically air and steam similarity was based on the similarity of the flow dynamic pressure. The similarity analysis compares the drag on an identically sized droplet using equal drag coefficients in steam and air. Dynamic pressure is defined by Equation 4-1. For air, the density is determined using the ideal gas law, Equation 4-2 with a gas constant determined using a molecular weight of 28.97 lbm/lb-mol [30] to be 53.33(ft-lbf)/(lbm-R). The steam density is taken at saturated conditions for standard atmospheric pressure, P = 14.696 psia, 0.0373 lbm/ft^3 [30].

$$P_{dyn} = \frac{1}{2} \cdot \rho \cdot V^2 \qquad 4\text{-}1$$

$$\rho = \frac{P}{R \cdot T} \qquad 4\text{-}2$$

Where:

P_{dyn} – dynamic pressure

ρ – density

V – velocity

P – absolute static pressure

R – gas specific ideal gas constant

T – absolute temperature

Using these relationships it is possible to conclude that equivalent air performance for a steam flow rate of [[ ]] [5] will be achieved with an air mass flow rate of [[ ]] when air is supplied at 77°F. The lowest flow rate that will be evaluated will be 10% of the maximum flow, or [[ ]]. The low flow rate limit will present a significant reduction from the maximum flow while still allowing the instrumentation to remain common between high and low flow.

4.4 Water chemistry

To best capture the water chemistry characteristics in a BWR suppression pool, deionized water will be used in testing (see Assumption b). The starting water characteristics must correspond to better than "Type IV" laboratory reagent water (ASTM Standard D1193 [31]), as confirmed by a conductivity at or below 5 micro-S/cm.

4.5 Temperature

Testing will be conducted at a target temperature of 80°F ± 5°F to match the temperature conditions at which the full height bundle tests will be conducted under [18].

4.6 Debris

4.6.1 Fibrous Debris

Fibrous debris will be prepared according to the NEI fibrous debris preparation protocol [12] but then modified further to represent the finer debris that is expected to bypass the suppression pool sump. In particular the generated NEI fiber slurry will be allowed to settle. The water will be poured slowly over a perforated plate with 1/8 in holes. The same pressure washer used in the initial debris preparation will then be used to rinse any fiber caught on the perforated plate through the perforated plate to further reduce any remaining fiber entanglements and also provide additional dilution. The perforated plate matches the maximum hole diameter of the BWR strainer fleet [13] therefore providing a conservatively large debris size distribution. Biasing the debris size distribution to greater sizes is expected to make the test more likely to develop debris beds and allow the objectives of BT4 to be achieved. A sample of the prepared debris will be

compared to the length distribution obtained in BWROG sponsored bypass testing [13] to demonstrate that the obtained debris distribution is acceptable. Note that a separate ongoing effort will provide additional details on the required debris preparation for full height bundle testing. It is expected that the debris form utilized for BT4 will be very similar while not identical to the final debris specification currently being finalized. The debris characteristics employed in BT4 will be compared qualitatively and quantitatively to provide a basis for the similarity assessment.

4.6.2 Particulate Debris

The particulate debris composition will match representative conditions in the BWROG fleet. Sludge and ZOI particulate debris will be represented by silicon carbide with a size distribution bracketing the data provided in the Utility Resolution Guide (URG) [14]. Bracketing of the size distribution will generate a broader size distribution than prototypical and thereby bias the results to the conservative side. In order to bracket the size distributions, the distribution laid out in Table 4-2 will be employed. Wider size distributions are conservative to narrower size distributions since pores of a wider range of sizes can be plugged with a wider range size distribution. Table 4-2 also provides the reference sludge size distribution [14][15] and the widest plant size distribution data [15].The width of the BT4 size distribution is even wider to account for the fact that coatings particulate could have a broader range of sizes. The largest size is trimmed at 108μm since a reasonable number of particles at a larger size would quickly make up a large fraction of the mass of particulate and thereby become non-conservative. The particulate will be slowly wetted with water to prevent the formation of foam.

Table 4-2. Debris size distribution

Particle size (μm)	Percentage of weight of particles smaller		
	BT4 Size distribution	URG reference [14] (interpolated)	URG widest size distribution [15] (interpolated)
4	34%	65%	42%
12	56%	95%	74%
36	78%	97%	84%
108	100%	100%	100%

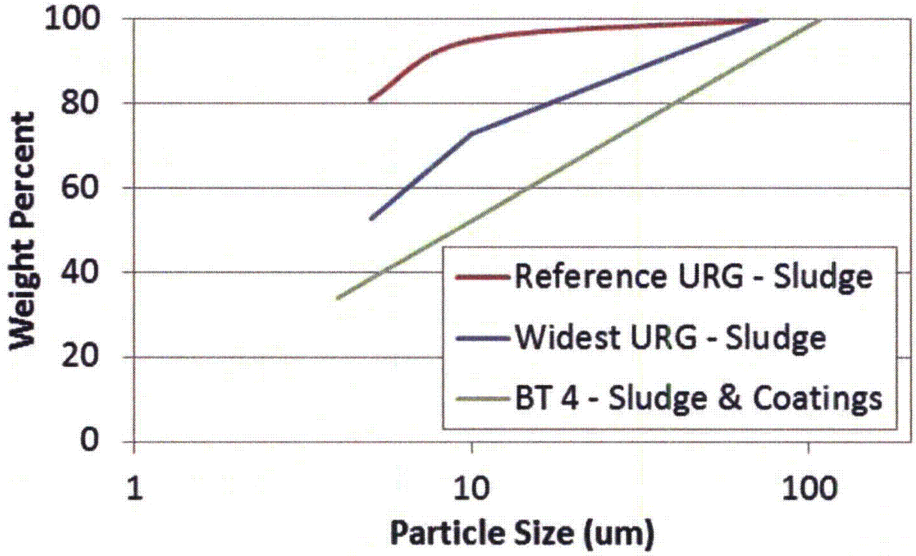

Figure 4-2. Particle size distribution comparison

4.6.3 Debris slurry

The fiber and particulate mixtures are combined to form one debris addition slurry. Three particulate to fiber (P/F) ratios will be investigated: 1:1, 3:1 and 10:1 (by mass), representing a wide range of possible debris mixtures that could occur post-accident at the fuel bundle. For each P/F ratio, the maximum fibrous debris quantity of 50g will be used (see Assumption a).

A fibrous debris concentration of 1.0 g/gallon was developed as the upper range of fuel bundle debris concentration for the BWR fleet for BT2 [2]. Fiber concentrations in the water leaving the strainers are likely significantly lower. The concentration in BT4 will be maintained at 1 g/gallon with sensitivity tests for lower concentrations down to 0.2 g/gallon. Should debris bed formation not be observed the fiber concentration will be increased but not above 2 g/gallon. The minimum recirculation water tank volume will therefore be 25 gallons.

4.6.4 Debris transport

The goal of the test setup is to only allow debris deposition with the bundle. Deposition on the LTP and LTP cover block will be tracked. The velocities in other components will be managed to ensure no settling occurs (see Section 3.7). The spray basin is expected to provide sufficient agitation to maintain debris in suspension. Spray flow incident on the spray basin could entrain air and cause some debris to float. The spray basin will be monitored for floating debris during the course of the test. If floating debris is observed it will be removed from the test, stirred to remove attached air bubbles and re-introduced to the test.

5.0 Instrumentation

The testing described above will involve a variety of instrumentation. The requirements will be described in the following subsections.

5.1 Flow meters

Flows will be measured with an uncertainty of better than 1.5%, considering the entire measurement train, including contributions from the meter calibration and any associated instruments (e.g. differential pressure cells, absolute pressure cell). The bundle flow instrumentation will achieve the required accuracy over the required range between [[ ]]. Since deionized water will be used as the test fluid, magnetic flow meters are not acceptable for the present testing. Spray flow rates will also be measured with an uncertainty of less than 1.5%. The nominal spray flow rate for BT4 is [[ ]]. For differential pressure water flow meters Equation 5-1 describes how the flow rate is calculated from the differential pressure measurement and the meter characteristics. Using a differential pressure flow meter for the lower bundle flow rates is challenging since it is important to keep the minimum clearance of the meter above 0.25" - 0.375" to ensure clogging of the meter does not occur.

The air flow meter will be able to measure flows between [[ ]] (see Section 4.3). The air flow rate measurement will require an absolute pressure transducer to properly measure the inlet density of the air (see Section 5.3). The measurement will also require a dedicated temperature probe for the same reason. The verification that a given test setup meets the uncertainty requirements should follow the analysis provided in Reference [18]. The mass flow rate and associated uncertainty requirements are detailed in Equations 5-2 to 5-4 [18]. Equation 5-4 may be used to calculate the uncertainty fraction in the differential pressure water flow rate measurements if the final two terms are dropped.

$$Q = C_d A_t \sqrt{\frac{2\Delta p}{\rho(1-\beta^4)}} \qquad 5\text{-}1$$

$$\dot{m} = C_d A_t \sqrt{\frac{2\rho_1 \Delta p}{1-\beta^4}}\, Y \qquad 5\text{-}2$$

$$Y^2 = r^{2/\gamma}\left(\frac{\gamma}{\gamma-1}\right)\left[\frac{1-r^{(\gamma-1)/\gamma}}{1-r}\right]\left(\frac{1-\beta^4}{1-\beta^4 r^{2/\gamma}}\right) \qquad 5\text{-}3$$

$$\frac{\delta \dot{m}}{\dot{m}} = \sqrt{\left(\frac{\delta C_d}{C_d}\right)^2 + \left(\frac{1}{2}\frac{\delta \Delta p}{\Delta p}\right)^2 + \left(\frac{1}{2}\frac{\delta p}{p}\right)^2 + \left(\frac{1}{2}\frac{\delta T}{T}\right)^2} \qquad 5\text{-}4$$

Where:

Q – volume flow rate

$\dot{m}$ – air mass flow rate

C_d – meter discharge coefficient

A_t – throat area

ρ_1 – inlet density

Δp – differential pressure measurement

β – Ratio of throat to inlet diameter

Y – Expansion factor

γ – ratio of specific heats (1.4 for air [18])

r – ratio of throat to inlet pressure

p – absolute inlet pressure

T – air temperature (absolute temperature scale)

δ – uncertainty

5.2 Differential pressure transducers

Differential pressure will be measured at several locations, serving various functions. The following subsections describe the location, function and requirements for the instruments.

5.2.1 Level instrumentation

In order to help diagnose spray flow supply variations and potential issues with overspray flow returning to the recirculation flow tank, the spray basin level will be monitored for each test. The spray basin level instrumentation also provides feedback on the bundle inlet flow rate when bundle flow is supplied only from the bypass region outside the fuel channel. The range of the spray basin water level must encompass the head difference between the minimum collector water level and a water level up to 1" above the fuel channel inlet height. An accuracy of better than 0.25 $inH_2O_{re68°F}$ for the water level is required.

Level instrumentation is also required for the bundle exit water level during un-submerged tests. The water level read-out will be used to diagnose hold-up of water within the bundle. Depending on the water level reduction, the bundle flow rate may be temporarily decreased until hold-up has reached equilibrium. A range of 6 $inH_2O_{re68°F}$ is sufficient for the level instrumentation in this region with an accuracy of better than 1 $inH_2O_{re68°F}$.

5.2.2 Spacer grid and UTP differential pressure measurement

The differential pressure across the PRSG and FRSG as well as the UTP must be able to be monitored. For this purpose, the fuel channel is equipped with pressure taps above and below each spacer grid as well as the UTP. The expected pressure differentials are small. A maximum range of 24 $inH_2O_{68°F}$ is sufficient. Pressure drops must be measured to within an uncertainty of better than 1/16 $inH_2O_{68°F}$. Two differential pressure cells must be dedicated to measuring differential pressures. The pressure drop across the FRSG must be continuously monitored. The taps for the PRSG and the UTP must be connected together to allow either the UTP or the PRSG pressure drop to be monitored. During testing, the UTP and PRSG pressure drops will be measured at regular intervals. Since the target conditions for the bundle are steady state conditions, the interval between measurements does not need to be very short and even an interval of 10 minutes is sufficient.

5.3 Absolute pressure transducer

An absolute pressure transducer is required to correctly measure the inlet density to the air flow meter. Since the supply pressure for air is expected to be on the order of 50-60 psig, an absolute pressure sensor with a range of greater than 80 psia is expected to be sufficient. A measurement accuracy of better than 0.3 psia will ensure that the inlet density measurement does not contribute significantly to the air mass-flow measurement uncertainty (see Section 5.1).

5.4 Gauge pressure transducer

A gauge pressure transducer is required to monitor the spray flow supply pressure relative to atmosphere. The target spray flow supply pressure is between [[ ]]. A gauge pressure transducer with a minimum range of at least 5 psig will therefore be sufficient. The uncertainty of the pressure measurement must be better than 0.05 psig to allow the maximum spray driving pressure to be properly characterized.

5.5 Temperature probes

The test temperature will be monitored in the recirculation water tank. The range of the temperature measurement for BT4 need only encompass the range between 75°F and 85°F. Based on the desire to keep the test temperatures constant within 5°F, a measurement accuracy of 1°F is sufficient.

The air supply temperature is required to determine the air mass flow through the differential air flow meter. The temperature is expected to be in the range between 70°F and 100°F. To ensure the air temperature measurement uncertainty does not affect the flow rate measurement significantly, a measurement uncertainty of 1°F is sufficient.

5.6 Relative debris concentration meter

The relative debris concentration meter will be used to provide a relative measure of the debris concentration at the outlet of the test fuel bundle. It is not required for the relative debris concentration measurement to be calibrated quantitatively against debris concentration. The prime motivation for the measurement is to examine the variation of the measurement during the course of a single test and between tests of the same debris mixture to evaluate debris wash-down. To accomplish this goal a simple transmission light measurement is sufficient. The repeatability of the meter is its most important characteristic and must be within 5%. To evaluate the repeatability of the meter, the relative debris concentration meter will be filled with a representative debris slurry mixture and an initial reading taken. The same debris slurry is then diluted down to 10% of its original concentration and an additional reading is taken. Another two samples of the same debris slurry are then taken and the process is repeated two additional times to verify that the reading remains within 5% of the average of all three readings. The measurement point along the height of the meter and meter diameter must meet the criteria outlined above in Section 3.8.

5.7 Data acquisition system

A data acquisition board will be used to acquire the data generated by the electronic sensors in the test and used to control the over-spray return flow valve and the pump speed. The key requirements for the data acquisition board are to measure the inputs to an accuracy of better than 5mV. Since the envisioned sensors will generate voltages above 5V at full range, the accuracy requirement ensures that the sensor uncertainty will dominate the overall measurement

uncertainty. The data acquisition board will need to have the capability to acquire at least ten sensors at the same time, not counting the air flow meter inlet temperature. The air flow meter inlet temperature will be measured electronically and in real time. It is not necessary to acquire the test water temperature electronically in real time. The temperature will be noted in the test log at regular intervals throughout testing.

The data acquisition board must be able to issue control signals to the valve positioner as well as the pump VFD to maintain control during changing loop conditions. The adequacy of the control algorithm for both the valve position and pump speed must be evaluated during the facility inspection.

5.8 Scales

Debris weights will be determined to an accuracy of better than 0.3% for weights above 10g, which is expected to encompass all required debris weights. The weight gain of the LTP and LTP cover block will also be measured to determine any debris loss in these elements of the loop. The weight gain of each component will be determined to within 0.2g. This accuracy is sufficient relative to the total weight of debris added which is planned to exceed 50 g (particulate to fiber ratio of 1 with a 25g mass of fiber).

To perform gravimetric measurements of flow rate during spray nozzle flow tests (see Section 6.1.1), a scale capacity of at least 85 lbf is required. The accuracy of the scale should be such that the flow rate can be determined to within 1%.

5.9 Blockage evaluation

One of the key metrics that must be evaluated in BT4 is spacer grid and UTP blockage. As discussed above in Section 2.6, it is important to relate the loss characteristics measured in BT4 to the method of implementation of loss in the analysis that is the backbone of the LTR [3]. In the experiment, the loss may be difficult to measure since the flow rates are generally low. The analysis implements blockage as a local area reduction increasing the velocity and therefore the losses. However, since the velocity is low, the blockage fraction may be difficult to measure with differential pressure measurements alone. The equation that describes losses with the area term included is provided in Equation 5-5. The equation can then be manipulated to provide loss as a function of the open area fraction, as shown in Equation 5-6. The open area fraction can easily be related to the blockage fraction via Equation 5-7. The main purpose of this development is to show that any loss increase measured in the test can be directly related to an equivalent blockage fraction.

$$\Delta P = \frac{K}{2 \cdot \rho \cdot {A_{open}}^2} \cdot \dot{m}^2 \qquad 5\text{-}5$$

$$\Delta P = \left(\frac{K}{\xi^2}\right) \cdot \frac{\dot{m}^2}{2 \cdot \rho \cdot {A_{ref}}^2} \cdot \qquad 5\text{-}6$$

$$BF = 1 - \xi \qquad 5\text{-}7$$

Where:

ΔP – pressure loss

ρ – density

A_{open} – open area

A_{ref} – reference area when completely unblocked

K – loss coefficient

$\dot{m}$ – mass flow

ξ – fraction of area open

BF – fraction of area blocked

In order to allow the blockage fraction to be determined from the provided relationships, it is imperative that a clean spacer grid differential pressure measurement be obtained. If the clean spacer grid differential pressure is not measurable, then the assessment of blockage via differential pressure measurement becomes more difficult. However, in the case where the initial clean differential pressure is not measurable because it's too small, the development of any measureable head-loss after debris addition is associated with the development of significant blockage. For example, if it is assumed that a 10 fold increase in the spacer grid differential pressure is needed to take the spacer grid pressure differential measurement from too low to measure to just barely measureable, such an increase is associated with an open area fraction reduction to under 32% or equivalently 68% blockage. The blockage can therefore be significant even at differential pressures that are just barely large enough to measure, depending on the clean flow differential pressure. Similarly, Equation 5-5 to 5-7 can be used to show that a 50% blocked spacer grid generates a head-loss that is four times the head-loss of a clean spacer grid.

Since spacer grid blockage may be difficult to measure accurately using differential pressure diagnostics, other methods will also be evaluated. The alternate approach to blockage measurement will be optically. In order to optically evaluate blockage, the difference in the amount of light that is transmitted through the spacer grid is quantitatively compared. The measurement method is non-intrusive with the exception that the spacer grid needs to be removed from the test and short replacement fuel rod stubs and water rod stubs must be installed. The precise method will be developed in shakedown testing and will be captured in a separate procedure for execution during tests of record. The requirement for the developed method is that it is quantitative and that basic characteristics of the measurement are evaluated during the measurement process development such as accuracy and repeatability. The developed procedure must be exercised on a spacer grid that is blocked to a known extent to make these determinations. It is important to note that the blockage determination made optically can be directly related to blockage in the sense of Equation 5-7 when the differential pressure across the spacer grid can be measured in a given test at a given location. These occurrences will provide validation of the optical measurement against the idealized blockage fraction implemented analytically. The developed method must also produce a spatially resolved measurement of blockage. The spatial variation of blockage will be used to document the degree of non-uniformity of any blockage that develops, which is a key objective of BT4.

As a suitable method is developed for optical blockage determination outside the test bundle, the adaptation of the method to blockage assessment when the spacer grid is still installed in the bundle must also be considered. The comparison of blockage measurements made when the

spacer grid is still installed in the bundle and made outside the bundle is critical in the validation of the in-bundle measurement method and its reliable application in full height bundle testing.

One of the objectives of BT4 is the development of an alternative simplified spray flow introduction method that produces equivalent bounding debris bed formation behavior. Debris bed development can be bounding in two ways. The debris bed can generate a bounding blockage fraction but the debris bed can also be bounding in its non-uniformity. The interpretation of the bounding blockage fraction is relatively straightforward but the interpretation of bounding non-uniformity requires additional discussion. The spatial variation of blockage will be quantified by the optical blockage determination. The resolution of these characteristics must be approximately 1" x 1", or a 2 x 2 fuel rod area on the spacer grid. Smaller resolution is not required since blockage that is more localized than 1" x 1" would not have the ability to provide thermal challenges since flow structures within the assembly are able to mix at scales up to approximately 0.5" x 0.5". The non-uniformity of blockage will be characterized using the following metrics:

- Root-mean square (RMS) of blockage
- Ratio of peak blockage to mean blockage
- Largest contiguous area fraction above mean blockage

These metrics are expected to be sufficient to characterize non-uniformity and provide a traceable basis for what conditions are considered bounding. The simplified spray flow introduction method will be developed to produce the bounding measured mean blockage behavior. The bounding debris bed non-uniformity will be provided to GEH for evaluation as to whether the observed non-uniformity could cause concerns relative to local heat transfer limitations.

5.10 Calipers

Calipers will be used to verify that the bundle components maintain the correct tolerance with respect to prototypical requirements. The calipers will have an accuracy of 0.001" or better.

6.0 Testing Scope & Limitations

6.1 Scope

In preparation for all testing discussed below an extensive period of shakedown testing will be required. The following subsections describe only the tests of record to document the performance of the facility and the tests required to achieve the objectives of the test.

6.1.1 Spray flow arrangement

In order to validate the operating regime of the spray flow nozzle arrangements, a series of tests will be used to document the variation of the incident bundle flow rate as a function of the nozzle arrangement parameters (see Table 4-1). The tests will be conducted in clean water to improve test through-put. The switch from clean to debris laden water will not impact the spray flow distribution in the range of debris concentrations to be evaluated. The peak fibrous debris concentration that could be evaluated with the present setup would be 5g of fiber per 1gallon of water. At the highest particulate to fiber ratio, of 10:1, the percent by mass of debris in the water is still only 1.5% and will therefore not affect the water density appreciably nor the momentum

and behavior of the spray. In order to more precisely determine the spray flow rate incident on the bundle at each position, the flow rate from the fuel bundle will be measured gravimetrically. The discharge from the bundle will be collected in a vessel for timed weight measurement. Since the recirculation water tank level will decrease during these tests, the recirculation water tank vent valve and over-spray return valve will remain open. The spray flow rate will be maintained constant by controlling the pump speed.

The first condition to be evaluated will be the equal circumferential spacing of all spray nozzles (five nozzles spaced evenly around the circumference), since achieving the peak incident spray flow rate of [[ ]] is most difficult to achieve under these circumstances. This test will define the spray nozzle arc diameter. The diameter will be the maximum diameter at which the spray flow nozzles are able to provide [[ ]] of flow to the bundle or 8ft, whichever is smaller. At small spray nozzle arc diameters, the nozzles may significantly over-spray the fuel channel. At large spray nozzle arc diameters, the nozzles will no longer be able to reach the fuel channel.

6.1.2 Facility inspection

An extensive facility capability demonstration test sequence will be undertaken to document that the facility meets the geometric, instrumentation and performance requirements described in the test plan. These requirements are collected in Appendix A.

6.1.3 Clean water testing

In order to provide the best possible characterization of blockage through differential pressure measurements, the clean bundle spacer grid losses will be measured across the full range of bundle flow rates ([[ ]]) in a submerged condition with flow being provided from the spray basin. Supplying the flow from the spray basin will provide the most quiescent flow conditions allowing the clean flow resistances of the bundle to be determined more accurately. The flow range exceeds the submerged bundle flow rate range in order to ensure some measureable differential pressures will be realized. The flow resistance is unlikely to change significantly as a function of Reynolds number and the resistance determined at a high flow rate can also be applied at the low flow rate. Using the flow resistance, an estimate of the blockage can be developed if a measureable differential pressure across the spacer grid is observed during testing, even at low flow rates.

Testing will be repeated with counter-current steam flow simulation since the air flow significantly affects the flow losses across the spacer grid.

Differential pressures for the FRSG, PRSG and UTP will be measured for five flow rates in the range between [[ ]] both with and without counter-current air flow simulation. Three levels of air flow will be investigated to develop the required spacer grid behavior: [[ ]]. These air flow rates are significantly below the peak flow rates required but are expected to be sufficient to quantitatively establish the relationship between flow resistance and air flow. The outlined characterization of the clean flow resistance will provide the required database to determine whether significant blockage occurred based on debris test measured differential pressures.

6.1.4 Submerged bundle testing with debris

Considering counter-current steam flow and debris concentration there are a total of eight parameters to be evaluated: four spray flow configuration related parameters, bundle flow rate,

counter-current steam flow rate, particulate to fiber ratio and debris concentration. In order to determine which of the parameters have an important influence on the blockage characteristics of the spacer grids and UTP, a 16 run design of experiments (DOE) test matrix will be executed. Each parameter is evaluated at a low and high value and its sensitivity on the test outcome can be statistically determined through analysis of variance methods (ANOVA). The selected DOE test matrix is an eight parameter resolution IV partial factorial design [32]. A resolution IV design ensures that the effects of all parameters are not in any way confounded with interactions between two parameters. They are only aliased with higher order interactions which are extremely unlikely to influence results [32].

A resolution IV design makes it difficult to quantify and identify exactly how interactions among parameters may contribute to the observed experimental results. However, identifying the detailed parameter dependencies and interactions is not an objective of BT4. The results obtained from these 16 tests will be sufficient to determine what conditions are more likely to produce non-uniform debris bed formation (if any) and what spray flow configurations may be more likely to produce a greater degree of blockage. The results of these tests will also provide a preliminary assessment of whether or not debris wash-down occurs in the range of submerged bundle flow rates.

Table 6-1. Design of experiments test sequence for submerged bundle

Circ. Nozzle Spacing	Circ. array location	Radial position of test bundle	Downward nozzle angle	Bundle flow rate	Counter-current steam flow rate	Particulate to Fiber Ratio	Debris Concentration
-1	-1	-1	-1	-1	-1	-1	-1
1	-1	-1	-1	-1	1	1	1
-1	1	-1	-1	1	-1	1	1
1	1	-1	-1	1	1	-1	-1
-1	-1	1	-1	1	1	1	-1
1	-1	1	-1	1	-1	-1	1
-1	1	1	-1	-1	1	-1	1
1	1	1	-1	-1	-1	1	-1
-1	-1	-1	1	1	1	-1	1
1	-1	-1	1	1	-1	1	-1
-1	1	-1	1	-1	1	1	-1
1	1	-1	1	-1	-1	-1	1
-1	-1	1	1	-1	-1	1	1
1	-1	1	1	-1	1	-1	-1
-1	1	1	1	1	-1	-1	-1
1	1	1	1	1	1	1	1

The assignment of the low and high parameter settings is provided in Table 6-2. In general the low and high parameter values represent the extreme parameter ranges identified in Section 4.0. One exception to this is the air mass-flow rate. It is expected that very little counter-current steam flow is sufficient to provide a major disruption to the debris bed formation process. If counter-current steam flow produces more limiting blockage behavior, higher counter-current steam flow rates will be simulated in follow-on testing. The low and high levels for debris concentration

correspond to the extremes of concentration discussed previously in Section 4.6.3. Higher debris concentrations will only be employed if no measureable blockage is observed at the lower concentrations currently planned.

Table 6-2. Test parameter level description

Parameter	Low value (-1)	High value (+1)
Circumferential nozzle spacing	22.5°	72°
Circumferential array location	0°	72°
Radial position of test bundle	0%	75%
Downward nozzle angle	[[ ]]	[[ ]]
Bundle flow rate	[[ ]]	[[ ]]
Counter-current steam flow rate	[[ ]]	[[ ]]
Particulate to fiber ratio	1:1	10:1
Fibrous debris concentration	0.2 g/gallon	1 g/gallon

Prior to the execution of the large 16 run DOE test matrix three repeat tests will be executed with all parameters at the midpoint between the low and high value except that the tests will be conducted without counter-current steam flow simulation (low level for counter current steam flow rate) and at a particulate to fiber ratio of 3:1. These tests are important in demonstrating the repeatability of blockage measurements and the outlet relative debris concentration. All tests will be conducted using 50g of fiber. Should blockage above 80% be observed during these tests, the debris quantity will be reduced to 25g and the repeatability tests will be begun again. The reason for a debris reduction at 80% blockage is that the determination of the bounding spray flow parameters may be very difficult if all tests result in very high blockage. The debris reduction will therefore make it easier to satisfy the objectives of BT4 and is therefore justified.

Once the limiting parameter levels producing the greatest blockage and most non-uniform blockage have been identified, blockage development will be examined under the same conditions but at a particulate to fiber ratio of 3:1 to ensure these conditions are not more limiting than those evaluated as part of the design of experiments test matrix. As part of these additional tests, the corresponding tests at a particulate to fiber ratio of 1:1 and 10:1 will be repeated.

The evaluation of supplying bundle flow from the perimeter of the fuel channel will occur at the limiting condition for counter-current steam flow simulation. Four tests will be conducted varying the bundle flow rate and the particulate to fiber ratio from the low to high levels. An additional test will be conducted at the midpoint of bundle flow rate and a particulate to fiber ratio of 3:1. If fibrous debris concentration is determined to be important, it will be set to the value producing the most limiting blockage behavior. Otherwise the fibrous debris concentration will be set to 1 g/gallon.

If the results show that the relative debris concentration downstream of the bundle is a function of bundle flow rate, additional testing is required to determine if debris wash-down is occurring. The three tests producing the greatest blockage conducted at the low bundle flow rate will be repeated at a flow rate of [[ ]] (at their respective debris concentrations) to determine if the relative downstream debris concentration continues to be affected by the flow rate below [[ ]]. If the relative downstream debris concentration still depends on the flow rate the same three tests will be repeated at a flow rate of [[ ]]. If the relative downstream debris concentration is still shown to be a function of the bundle flow rate, a test plan revision is required to allow the examination of even lower flow rates.

The following is a list of all submerged bundle testing:

- (3) repeatability tests
- (16) DOE matrix tests
- (3-4) tests at P:F of 3:1 for worst conditions under P:F of 10:1 and 1:1, also repeating one P:F 10:1 test and one P:F 1:1 test
- (5) bypass region spray flow supply tests
- Conditional (3-6) tests to evaluate debris wash-down

A total number of tests between 27 and 34 will therefore be executed to evaluate the behavior of blockage in the shortened fuel bundle for submerged bundle conditions.

6.1.5 Un-submerged bundle testing with debris

A similar strategy to that employed for submerged bundle testing will be used in evaluating blockage development in an unsubmerged bundle. The primary difference is that the bundle flow rate is no longer an independent parameter and instead falls out from the spray flow configuration. Seven parameters therefore remain for evaluation. It is not possible to reduce the number of tests in a partial factorial DOE design relative to the eight parameter configuration and maintain a resolution IV design. However, the interactions in the sixteen run design are less confounded and it will be easier to discuss the potential influence of interactions in the DOE test matrix given in Table 6-3.

Table 6-3. Design of experiments test sequence for the un-submerged bundle

Circumferential Nozzle Spacing	Circumferential array location	Radial position of test bundle	Downward nozzle angle	Counter-current steam flow rate	Particulate to Fiber Ratio	Debris concentration
-1	-1	-1	-1	-1	-1	-1
1	-1	-1	-1	1	-1	1
-1	1	-1	-1	1	1	-1
1	1	-1	-1	-1	1	1
-1	-1	1	-1	1	1	1
1	-1	1	-1	-1	1	-1
-1	1	1	-1	-1	-1	1
1	1	1	-1	1	-1	-1
-1	-1	-1	1	-1	1	1
1	-1	-1	1	1	1	-1
-1	1	-1	1	1	-1	1
1	1	-1	1	-1	-1	-1
-1	-1	1	1	1	-1	-1
1	-1	1	1	-1	-1	1
-1	1	1	1	-1	1	-1
1	1	1	1	1	1	1

The level assignments remain the same as those developed for submerged bundle testing. The initial repeatability tests will also be conducted for the un-submerged bundle. The follow-on tests conducted after the DOE test matrix described above to confirm behavior at the intermediate particulate to fiber ratio of 3:1 will also be executed for the unsubmerged bundle, at the limiting debris concentration.

Since the bundle flow rate depends on the spray configuration, the DOE test matrix is likely to produce downstream concentration measurements across a wide range of bundle flow rates. The results must be examined carefully to determine whether wash-down was occurring. If wash-down is determined to have occurred, additional testing will be performed once the single source spray model has been developed (see Section 6.1.6). Once the single source spray flow model has been developed, the flow rate can be independently controlled and reduced in steps from [[ ]] in 0.25 gpm increments until the downstream bundle debris concentration is no longer affected by the flow rate or the limit of [[ ]] bundle flow rate has been reached. The evaluation will be repeated at low and high particulate to fiber ratios.

The following is a list of all un-submerged bundle testing:

- (3) repeatability tests
- (16) DOE matrix tests
- (3-4) tests at P:F of 3:1 for worst conditions under P:F of 10:1 and 1:1, also repeating one P:F 10:1 test and one P:F 1:1 test
- Conditional (4) tests to evaluate debris wash-down

A total number of tests between 22 and 27 will therefore be executed to evaluate the behavior of blockage in the shortened fuel bundle for un-submerged bundle conditions.

6.1.6 Single source spray flow model

The testing conducted under Section 6.1.4 and 6.1.5 provides an extensive database of experimental results. Experimental observations of how blockage develops under various spray flow configurations will be used to develop a spray flow model that does not cause overspray but still maintains bounding behavior with respect to the development of blockage. The developed single source spray flow implementation must be validated in reference tests that span the range of bundle flow rates ([[ ]] for submerged bundles, [[ ]] for un-submerged bundles) and the range of particulate to fiber ratios (1:1 to 10:1). A set of five reference tests will therefore be conducted for both submerged and un-submerged bundles to demonstrate that the developed spray flow model provides bounding behavior in terms of mean blockage behavior. The qualification test matrix is provided in Table 6-4. The qualification test matrix will be executed at the limiting fibrous debris concentration (either 0.2 or 1 g/gallon).

Table 6-4. Single source spray flow model verification test matrix

Bundle state	Flow rate (gpm)	Particulate to fiber ratio
Submerged	[[ ]]	1:1
	[[ ]]	1:1
	[[ ]]	10:1
	[[ ]]	10:1
	[[ ]]	3:1
Un-submerged	[[ ]]	1:1
	[[ ]]	1:1
	[[ ]]	10:1
	[[ ]]	10:1
	[[ ]]	3:1

6.2 Limitations

The following are limitations that apply to the test based on requirements and considerations developed in previous sections:

- The low flow rate limit for bundle flow is [[ ]].
- The maximum volume of debris slurry is 250 gallons.
- The minimum volume of debris slurry is 25 gallons.
- The maximum fibrous debris quantity is 50 g.
- The maximum bundle flow rate is [[ ]].
- No provisions are available to heat test loop water above ambient temperatures.
- The combined spray nozzle flow rate is limited to [[ ]].
- The pressure of the spray nozzle manifold is limited to [[ ]].

7.0 Test Procedure

7.1 Spray flow distribution

The spray flow distribution will be determined without counter-current steam flow modeling using a gravimetric method to measure the flow rate. The following steps outline the procedure for spray flow distribution testing, which is conducted with an un-submerged bundle without debris.

1) Perform instrumentation checks.
2) Set the proper spray nozzle configuration.
3) Ensure the bundle downstream piping is configured for high flow (large diameter).
4) Fill the recirculation water tank with clean water.
5) Open the over-spray return flow valve completely.
6) Maintain the vent on the recirculation water tank in the open position.
7) Vent the pump suction line.
8) Place two empty flow collection vessels with a minimum capacity of ten gallons side by side below the test bundle.
9) Align the discharge from the bundle to one of the two vessels.
10) Start the pump and control the spray flow to [[ ]] using pump speed and the bypass valve position.
11) When steady state conditions have been reached, simultaneously re-align the discharge from the bundle to the remaining empty collection vessel and start a timer.
12) When the collection vessel is nearly full or 180 seconds have elapsed, align the flow back to the first collection vessel.
13) Stop the pump.
14) Empty first collection vessel into spray basin.
15) Weigh contents of second collection vessel and then return its contents to the spray basin as well.
16) Record all measurements and observations in the log book.
17) Update spray flow configuration and begin another measurement at step 8).

7.2 Submerged bundle testing

The following steps broadly outline the test procedure steps for submerged bundle testing. The procedure steps are sufficiently general to cover both clean water and debris testing.

1) Perform instrumentation checks.
2) Set the proper spray nozzle configuration.
3) Ensure the bundle downstream piping is configured for the target bundle flow rate (either high or low flow).
4) Verify bundle isolation valve is closed.
5) Verify over-spray return valve and recirculation water tank vent valves are open.
6) Fill recirculation water tank with prepared debris slurry or clean water (depending on test).
7) Close recirculation water tank vent valve.
8) Start counter-current air injection if applicable to the test.
9) Fill bundle with clean water to the top of the fuel channel. Maintain air flow during filling.
10) Install shroud around fuel bundle to allow spray flow operation without any spray flow reaching the fuel bundle.
11) Fill spray basin collectors with clean water.
12) Set data acquisition software data collection interval to 1-2 seconds.

13) Vent pump inlet piping.
14) Verify loop isolation valve is open.
15) Start pump and control spray flow to [[ ]] using pump speed and bypass supply control valve.
16) Maintain a full water level in the spray basin collectors.
17) Circulate for 5 minutes to ensure recirculation water tank and spray basin water volume are well mixed.
18) Remove shroud from fuel bundle to allow spray flow to enter fuel bundle.
19) Once steady state conditions have been reached, start bundle pump with bundle bypass flow valve fully open and bundle isolation valve closed.
20) Open bundle isolation valve and adjust bundle pump speed and/or bundle bypass flow valve until desired bundle flow rate is achieved.
21) Monitor bundle outlet debris concentration and differential pressure across the FRSG.
22) Switch differential pressure monitoring between UTP and PRSG depending on experimental observations but at least every 10 minutes.
23) Continue test until steady state conditions have been reached as determined by downstream debris concentration observations as well as differential pressure measurements.
24) At the conclusion of the test, close loop isolation valve and stop pump.

For debris tests only:

25) Disconnect bundle tubing from bundle isolation valve and drain bundle at a rate not exceeding the test flow rate as indicated by the bundle flow meter.
26) Remove the fuel channel from the bundle and perform assembled bundle blockage measurements.
27) Disassemble bundle in the vertical position carefully to limit any potential debris bed disturbance. Bundle will allow removal of spacer grids from installed fuel rods which is not possible on a prototypical bundle but will be implemented for the shortened test bundle in BT4 (see Section 3.2.3).
28) Perform isolated UTP and spacer grid blockage measurements.
29) Perform weight gain measurements on LTP and LTP cover block.
30) Examine recirculation water tank, spray basin and loop piping for settled debris. Any debris must be collected and quantified.

7.3 Un-submerged bundle debris testing

Unsubmerged bundle testing proceeds in the same manner as submerged bundle testing with the following exceptions:

1) The bundle is not filled with clean water but sufficient clean water is added to ensure the relative debris concentration meter and flow meter are submerged.
2) Opening of the bundle isolation valve has to wait until a sufficient amount of flow has accumulated above the LTP to ensure water solid conditions are maintained in the flow meter and the relative debris concentration meter.

8.0 Test Acceptance and Termination Criteria

8.1 Test termination criteria

Deviations from the test termination criteria must be addressed in the test report but do not necessarily invalidate the entire test.

8.1.1 Clean bundle test termination criteria

Tests executed with a clean bundle do not require specific test termination criteria. These tests are terminated when the required measurements have been completed.

8.1.2 Debris test termination criteria

The test is terminated when the head-loss across the spacer grids and the relative debris concentration meter reading have stabilized (<1% change in 30 minutes).

8.2 Test acceptance criteria

The target test conditions (bundle flow rate, spray flow rate, spray flow header pressure, counter current air flow injection) must be maintained to within +/-3% of the target value for at least 95% of the test duration. The test temperature must remain within 5°F of the target test temperature of 80°F for the entire test. Deviations from these acceptance criteria must be addressed in the test report but do not necessarily invalidate the entire test.

9.0 Procedure List

Table 9-1 lists the project specific procedures that will be written based on the present test plan and the generic Alden QAP procedures that will be specifically invoked to support the execution of testing and the evaluation of test results.

Table 9-1. Procedures supporting testing

Procedure number	Title	Purpose
1140BWRBT-460	Spray flow distribution	Determine the amount of water incident on the fuel channel under the various spray flow arrangements.
1140BWRBT-461	Fuel bundle assembly inspection	Verify the shortened full bundle has been assembled correctly and is in a clean condition.
1140BWRBT-462	Facility inspection	Verify that the constructed facility (bundle and associated tanks, basins, pumps, etc.) perform as required by this test plan.

Procedure number	Title	Purpose
1140BWRBT-463	BT4 test procedure (covering both submerged and un-submerged bundle testing)	Run a test with debris-laden water conforming to the outline provided above and achieving the objectives of the test plan.
1140BWRBT-464	In-bundle spacer grid blockage evaluation	Will evaluate blockage optically before the spacer grid is removed from the bundle.
1140BWRBT-465	Isolated spacer grid blockage evaluation	Same as 464 but conducted after the spacer grids / UTP have been removed.
1140BWRBT-403	BT4 fuel bundle assembly & disassembly procedure	Step by step procedure for assembly and disassembly, as well as handling of the bundle and its parts.
QP-3201	DP cell check procedure	Verify proper operation of instrumentation
QP-3202	Temperature probe check procedure	
QP-3203*	Filter bag weighing procedure	Determines the weight gain of a filter bag. For these tests the procedure will be used to help evaluate any debris found in non-prototypical components.
QP-3205	Debris handling	General guidelines for handling and storing fibrous and particulate debris.
QP-3208*	Handling and storage of samples and filters	Guidelines for handling and storing filters that will be or were used in testing.
QP-3214*	Filter qualification	Procedure to verify the retention performance of the filter bags used in testing specific to the materials of concern for a given test.
*To support measurement of debris collected outside of bundle after testing.		

10.0 Safety

There are several aspects to BT4 that require careful attention in order to ensure a safe working environment.

1) The water to be used for BT4 is deionized water. Deionized water is very aggressive and must therefore be handled cautiously. Safety glasses and rubber gloves must be worn at all times when working with deionized water.
2) Sharp edges. Some of the components of BT4, primarily the spacer grids but possibly also other components contain thin enough metal to be sharp enough to pierce skin. Prototypical components (spacer grids, water rods, UTP, dummy fuel rods) should be handled with gloves at all times to prevent injury and also help protect the components.
3) Zircaloy. Some components will be made of Zircaloy (spacer grids, fuel rods). Fine metal shavings from this material are flammable. Clean-up in areas where fuel rods and spacer grids have been handled should therefore be performed using a dust-pan and broom, rather than a vacuum. Wetting down an area and then cleaning up the resulting slurry with a wet-vac is acceptable, as long as enough time has been given for any dust in the atmosphere to have settled out.
4) Pressurized air. Air is used to simulate counter current steam injection and will be supplied using an air compressor. While the actual delivery pressures are likely to be low (<20 psig), the original supply pressures may be elevated above 80 psig. When working with compressed air, it is most important to recognize when this energy source is turned on so that the energy isn't suddenly accidentally released. Materials used with the air supply must be rated for air. PVC must not be used in the piping to supply air. Safety glasses must be worn at all times when working with compressed air. When working with air lines, the state of an air line must always be verified, and personnel is to assume the line is pressurized unless the converse has been verified. When working on an air line, the supply must be locked out such that accidental pressurization cannot occur.

11.0 References

[1] 1120BWRFA-201, "BWR Fuels Hydraulic Test Program – Project Plan".
[2] 1120BWRFA-302-P, "BT2 Fuel Rod Roughness Effects".
[3] 1120BWRFA-106-00, BWROG-12016, "Submittal of Batch 2 Responses to RAIs Associated with Boiling Water Reactor Owners' Group (BWROG) Licensing Topical Report NEDC-33608P, "Boiling Water Reactor Emergency Core Cooling Suction Strainer In-Vessel Downstream Effects".
[4] 1120BWRFA-105-00, BWROG-12005, "Submittal of Batch 1 Responses to RAIs Associated with Boiling Water Reactor Owners' Group (BWROG) Licensing Topical Report NEDC-33608P, "Boiling Water Reactor Emergency Core Cooling Suction Strainer In-Vessel Downstream Effects"
[5] 1120BWRFA-141-00, "BWROG-13032, Submittal of Responses to Supplemental RAIs Associated with Boiling Water Reactor Owners Group (BWROG) Licensing Topical Report NEDC-33608-P, 'Boiling Water Reactor Emergency Core Cooling Suction Strainer In-Vessel Downstream Effects'", 06/28/2013.
[6] 1120BWRFA-107-00 Item 2, "GNF 2 Design Basis", DB-0011.03 Rev. 8, 2013*
[7] 1120BWRFA-109-00 Item 5, "Flow rate and/or driving head ranges for each of the tests".

[8] 1120BWRFA-109-00, Item 11, “Licensing Topical Report: BWR Core Spray Distribution”, NEDO-10846, April 1973.
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*The GNF 2 design basis document compares the fuel design to the reference fuel design for the full height bundle testing GE-14. The document therefore provides many useful technical inputs for GE-14 type fuel.

Appendix A

Items for Inspection / Control

- Experimental setup according to Figure 3-1
- Test loop materials exposed to flow must be corrosion resistant to deionized water. Verification to occur via operational facility inspection.
- Fuel channel requirements (Section 3.2.2):
  - Fuel channel provides prototypical interface with UTP, including clip geometry.
  - Inner cross section of [[ ]].
  - The internal radius of curvature is [[ ]].
  - Transparent sides
  - Measurement ports for differential pressure measurement 1" above and below the spacer grids and UTP. One pair of ports required, additional ports optional.
    - Flush termination of pressure ports.
    - Downward pitch of 10°±3°
  - Able to be disassembled without removing shortened fuel bundle with little disturbance to established debris beds.
  - Must seal at the bottom against the LTP with leakage less than 1% of the minimum flow through the bundle.
  - Must contain four inlets:
    - Sized and located so that bundle pump bypass flow does not disturb flow field above the air introduction manifold.
  - Must contain four outlets:
    - Interface with LTP cover block.
    - 1" discharge diameter.
  - Must interface with the spray basin and provide a seal between the spray basin and the fuel channel with leakage less than 1% of the minimum flow through the bundle.
  - The water level within the fuel bundle must be monitored and measured during un-submerged water testing.
- Fuel bundle requirements (Section 3.2.3)
  - Shortened fuel bundle assembly consisting of prototypical UTP, PRSG and FRSG as well as an LTP sufficient to terminate the fuel rods, tie rods and water rods.
  - Spacer grid locations (+/- 0.25"):
    - UTP to PRSG distance (bottom to bottom): [[ ]]
    - PRSG to FRSG distance: [[ ]]
    - FRSG to LTP distance: [[ ]]
  - LTP requirements:
    - Must seal against the fuel channel. See above for acceptable leakage requirements.
    - Must capture the fuel rods, tie rods and water rods.
    - Must not allow water flow out of the bottom of the fuel bundle.
    - Use LTP cover block as developed for the full height bundle Test 4[18].
      - Help guide flow out of the bundle.
      - Minimize debris settlement.
    - Settling of debris on LTP and LTP cover block must be quantified via weight gain measurement.
  - Fuel rod and tie rod requirements:

    - Must not allow through-flow.
    - Must have prototypical top end fittings, including springs and associated hardware.
  - PLRs will reach above the FRSG by [[ ]].
  - Arrangement of fuel rods, tie rods and PLRs will be prototypical within the bundle.
  - Fuel bundle assembly between UTP and bundle must meet prototypical perpendicularity requirements.
  - Water rod requirements:
    - Prototypical end fittings.
    - Diameter transition [[ ]] above the PRSG from [[ ]].
    - Lower end transition at least 6" below the FRSG but also at least 6" above the LTP.
    - Water rod openings / clearances must be smaller than one [[ ]] hole or smaller than four [[ ]] holes.
    - Tabs are replaced by set screws which must remain accessible even with fuel rods and tie rods installed.
- Spray flow nozzle requirements (Section 3.3):
  - 5 total spray nozzles.
  - Spray nozzles have form of a tee with a simple deflector.
  - Spray nozzles can be rotated between [[ ]] downward with at least three fixed positions.
  - Spray nozzle array can be moved such that fuel channel can be located between 25% and 100% of the range of the spray (as determined in spray flow distribution measurements at the start of testing), less than 4 ft.
  - Minimum spray nozzle diameter is 1/8".
  - Each spray nozzle must supply [[ ]] at a supply pressure of no more than [[ ]].
  - The circumferential spacing of the spray nozzles must be able to be controlled.
  - Configurations must address the ranges provided in Table 4-1.
- Spray basin requirements (Section 3.4):
  - Minimum diameter of just over 8 ft.
  - At least one bypass flow inlet to sweep debris to collection point(s).
  - Contoured bottom to guide flow to spray basin collection point(s).
  - Conical collection point(s) requirements:
    - Discharge must accelerate flow to at least 1 ft/sec.
      [[

      ]]
    - One collection point must be equipped with a pressure tap at base for level indication.
  - Must contain all spray flow.
  - Must seal against the fuel channel at least 6" below the UTP but at least 4" above the PRSG.
  - Must be able to hold water to a level of 1" above the top of the fuel channel.
- Recirculation water tank requirements (Section 3.5):
  - Must hold entire volume of debris slurry, minimum volume of 250 gallons.
  - Must support operation down to a volume of 25 gallons.
  - Overspray flow inlet:

        - No larger than 2".
        - Must maintain debris in suspension.
        - Bundle flow inlet sized to [[ ]] with available reducer down to [[ ]]. Must keep inlet velocity above 1 ft/sec.
    - Must be equipped with an actuated vent valve.
    - Water level in the recirculation water tank must be able to be visually monitored.
    - Discharge from bottom of tank to discourage debris settling.
    - Must be equipped with a port for temperature measurement.
- Air manifold requirements (Section 3.6):
    - Air injection should be as non-intrusive as possible.
    - Any elements protruding into the flow path must be evaluated for debris retention after the test.
    - The air injection must result in a visibly uniform distribution of void fraction throughout the bundle cross section. The uniformity of the air distribution must be documented during the facility inspection.
    - The air injection must not be injected with upward momentum.
- Piping and valve requirements (Section 3.7):
    - All piping carrying debris must maintain a velocity above 1 ft/sec.
    - Two piping diameters required for piping between the bundle pump bypass flow tee and the recirculation water tank:
        - [[ ]] or flows above [[ ]] gpm.
        - [[ ]] for flows below [[ ]] gpm.
    - Valves in the loop must either be full port ball valves or have a V-ball design. No globe valves are to be used in the loop.
    - Fuel bundle bypass line diameter:
        - 0.625" – 1.4" before split to return flow to bundle.
        - Maximum 0.71" after split.
- Relative debris concentration meter (Section 3.8):
    - Flow through meter is downward.
    - Measurement point at least 5 meter internal diameters downstream of inlet.
    - Measurement point at least 2 meter internal diameters upstream of outlet.
- Water flow conditions (Section 4.1):
    - Spray flow:
        - Total spray flow of [[ ]].
        - For flow supplied from bypass region, the flow rate range is [[ ]].
        - Spray flow supply pressure must be measured.
    - Bundle flow:
        - Un-submerged test flow range: [[ ]].
        - Submerged test flow range: [[ ]]. (Low limit could be reduced further depending on debris wash-down measurements)
        - Bundle pump bypass flow meter range: [[ ]].
        - For un-submerged test, must be able to reduce bundle flow rate temporarily.
        - Vent valve must be actuated. The actuation time must have a minimum value.
- Counter-current steam flow (Section 4.3):
    - Flow range of [[ ]].
- Water used for testing must have a conductivity of lower than 5 micro-S/cm.

- Temperature: 80°F ± 5°F.
- Debris (Section 4.6):
  - Fiber:
    - Prepared according to NEI fiber debris preparation protocol and then washed through a screen with 1/8" holes.
    - Size distribution collected and compared to debris specification and BWROG bypass test report results.
  - Particulate:
    - Silicon carbide
    - Size distribution according to Table 4-2
  - Slurry:
    - Use 1:1, 3:1 and 10:1 particulate to fiber ratios
    - Debris concentration between 0.2 and 1.0 g/gallon.
    - If debris bed formation is not observed, increase fibrous debris concentration to a maximum of 2 g/gallon.
  - Debris transport:
    - Settling on LTP and LTP cover block must be measured.
    - Agitation within spray basin sufficient to maintain suspension.
    - Any floating debris must be collected, mixed and added back into the test.
- Instrumentation requirements (Section 5.0):
  - Flow meters:
    - Accuracy of better than 1.5% considering entire measurement train.
    - Bundle flow meter range: [[ ]].
    - Spray flow meter operating point: [[ ]].
    - Air flow meter range: [[ ]].
    - No magnetic flow meters.
    - Minimum flow meter clearance above 0.25".
  - Level instrumentation:
    - Spray basin water level with range up to 1" above the fuel channel inlet height, accuracy better than 0.25 $inH_2O_{re68°F}$.
    - Bundle exit water level for un-submerged tests with range above 6 $inH_2O_{re68°F}$ at an accuracy of better than 1 $inH_2O_{re68°F}$.
  - Spacer grid and UTP differential pressure measurement:
    - Range of at least 24 $inH_2O_{re68°F}$ with an accuracy of better than 0.0625 $inH_2O_{re68°F}$.
    - Two transducers required. One for the FRSG and one to be aligned either to the UTP or PRSG with intervals between measurements of less than 10 minutes.
  - Absolute pressure transducer:
    - Range of greater than 80 psia with an accuracy better than 0.3 psia.
  - Gauge pressure transducer:
    - Range of greater than 5 psig with an uncertainty better than 0.05 psig.
  - Temperature probes:
    - Water temperature probe with a range of 75 - 85°F with an uncertainty of better than 1°F.
    - Air temperature probe with a range of 70 - 100°F and an uncertainty of better than 1°F.
  - Relative debris concentration meter:
    - Not calibrated against debris concentration on an absolute basis.

        - Repeatability of meter within 5%, evaluated as described in Section 5.6.
    - Data acquisition:
        - Measure voltage inputs to an accuracy of better than 5 mV.
        - Measure at least 10 inputs at the same time, not counting temperature probe inputs.
        - Air temperature measurement must be acquired together with other inputs.
        - Water temperature can be acquired via display only.
        - Capable of output signals to valve positioner and pump VFD.
    - Scales:
        - Accuracy of better than 0.3% of reading for weights above 10g.
        - Accuracy of weight gain determination for LTP and LTP cover block is better than 0.2g.
        - Scale with 85 lbf capacity with accuracy such that flow rate can be determined to within 1%.
    - Blockage determination:
        - Optical blockage determination method is required:
            - Must assess accuracy and repeatability. Demonstrate ability to measure blockage on a grid that is blocked to a known extent.
            - Method must provide for spatially resolved blockage assessment.
            - Method must be adaptable to measurement of blockage within the fuel bundle.
            - Blockage non-uniformity is characterized by: RMS of blockage, Ratio of peak to mean blockage, largest contiguous area fraction above mean blockage.
            - Resolution of blockage measurements better than 1" x 1".

- Simplified spray nozzle model requirements:
    - Replicate the worst case debris bed mean blockage conditions measured using 5 spray nozzles.
    - Execute qualification test matrix for demonstration (see Section Table 6-4).

ENCLOSURE 3

GE-Hitachi Nuclear Energy Americas LLC

AFFIDAVIT

I, Lisa K. Schichlein, state as follows:

(1) I am a Senior Project Manager, NPP/Services Licensing, Regulatory Affairs, GE-Hitachi Nuclear Energy Americas LLC (GEH), and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in Alden report 1140BWRBT-304-03-P, "BT4 – Debris Bed Uniformity Test Plan – Revision 03," Revision 03, dated April 2015. GEH proprietary information in 1140BWRBT-304-03-P is identified by a dotted underline inside double square brackets. [[This sentence is an example.{3}]]. In each case, the superscript notation {3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner or licensee, GEH relies upon the exemption from disclosure set forth in the *Freedom of Information Act* ("FOIA"), 5 U.S.C. §552(b)(4), and the *Trade Secrets Act*, 18 U.S.C. §1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for trade secrets (Exemption 4). The material for which exemption from disclosure is here sought also qualifies under the narrower definition of trade secret, within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975 F.2d 871 (D.C. Cir. 1992), and Public Citizen Health Research Group v. FDA, 704 F.2d 1280 (D.C. Cir. 1983).

(4) The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a and (4)b. Some examples of categories of information that fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by GEH's competitors without a license from GEH constitutes a competitive economic advantage over other companies;

b. Information that, if used by a competitor, would reduce its expenditure of resources or improve its competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information that reveals aspects of past, present, or future GEH customer-funded development plans and programs, resulting in potential products to GEH;

d. Information that discloses trade secret or potentially patentable subject matter for which it may be desirable to obtain patent protection.

(5) To address 10 CFR 2.390(b)(4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GEH, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GEH, not been disclosed publicly, and not been made available in public sources. All disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to regulatory provisions for proprietary or confidentiality agreements or both that provide for maintaining the information in confidence. The initial designation of this information as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in the following paragraphs (6) and (7).

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, who is the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge, or who is the person most likely to be subject to the terms under which it was licensed to GEH.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist, or other equivalent authority for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GEH are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary and/or confidentiality agreements.

(8) The information identified in paragraph (2) is classified as proprietary because it contains detailed methods, results, and conclusions regarding supporting evaluations of the effects on nuclear fuel performance of containment debris that bypasses the ECCS suction strainers for a GEH BWR. The analysis utilized analytical models and methods, including computer codes, which GEH has developed, obtained NRC approval of, and applied to perform evaluations of containment debris effects on the nuclear fuel for a GEH BWR.

The development of the evaluation processes along with the interpretation and application of the analytical results is derived from the extensive experience and information databases that constitute major GEH assets.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GEH's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GEH's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GEH. The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial. GEH's competitive advantage will be lost if its competitors are able to use the results of the GEH experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GEH would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GEH of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing and obtaining these very valuable analytical tools.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on this 22th day of April 2015.

Lisa K. Schichlein

Lisa K. Schichlein
Senior Project Manager, NPP/Services Licensing
Regulatory Affairs
GE-Hitachi Nuclear Energy Americas LLC
3901 Castle Hayne Road
Wilmington, NC 28401
Lisa.Schichlein@ge.com