# Attachment 2

# Strainer Test Plan in Support of STP Pilot Risk-Informed GSI-191 Pilot Licensing Application

South Texas Project Risk-Informed GSI-191 Evaluation

# Strainer Test Plan in Support of STP Pilot Risk-Informed GSI-191 Pilot Licensing Application

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# TECHNICAL DOCUMENT COVER PAGE

| Document No: ALION-REP-STP-8998-14 | Revision: 0 | Page 1 of 21 |
|---|---|---|

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Document Purpose/Summary:


In support of Risk-Informed-Resolution (RIR) arguments developed for closure of Generic Safety Issue-191 (GSI-191), South Texas Project (STP) is constructing a horizontal flume facility to conduct a limited-scope investigation of strainer performance at the University of New Mexico (UNM) Thermal Hydraulics Laboratory. The attached plan outlines test objectives and guiding assumptions, describes specific tests, and illustrates basic features of the facility including diagnostics. Intended application of the data is discussed. This test plan will motivate detailed procedures for each test that define final debris inventories and loading schedules.

This document is not considered safety related. However, it has been prepared, reviewed, and approved. Review was completed by the client.

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# Table of Contents

1 Background....5
2 Objectives of Strainer Module Testing for South Texas Project....7
3 High-Level Test Description....8
3.1 Test Matrix....8
3.2 Clean Strainer Characterization....9
3.3 Conventional Debris Approach....10
3.4 Chemical Product Approach....11
3.4.1 Stage 1: Corrosion and Leaching....12
3.4.2 Stage 2: Saturation and Product Formation....14
3.4.3 Stage 3: Accumulation and Head Loss....15
4 FIESTA Facility....16
4.1 FIESTA Facility Design....16
4.2 Flume Test Diagnostics....18
5 Test Descriptions....19
6 Application of Test Data....19
7 References....21
Appendix 1: Detailed Test Descriptions....1-1
FTA-000 (Shakedown)....1-1
FTA-100 (Clean Strainer)....1-2
FTA-200 (1/4th-inch contiguous bed)....1-5
FTA-300 (1/16th-inch contiguous bed)....1-6
FTA-400 (DBA debris load)....1-7

## List of Tables

Table 1. High-level test description....9
Table 2. Supporting Diagnostics and Data Collection....18

# List of Figures

Figure 1. Partial overview of the STP containment building, including one train of ECCS strainers, coolant buffer (TSP), and spray system flow path into the recirculation sump .......... 6
Figure 2. Notional stages describing formation of chemical products in the post-LOCA chemical environment .......... 12
Figure 3. Typical PWR large-break temperature and pH histories. .......... 13
Figure 4. Cumulative aluminum ion concentration computed for two pH histories and a common temperature history representative of a large-break LOCA with sprays never terminated. .......... 14
Figure 5. Schematic of the UNM Flume Integral Effects and Separate Effects Testing and Analysis (FIESTA) facility .......... 16
Figure 6. Series of strainer modules (left) and single strainer module (right) for STP .......... 17

# Strainer Test Plan in Support of STP Pilot Risk-Informed GSI-191 Pilot Licensing Application

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## 1 Background

During a LOCA, debris material such as insulation fibers, dirt, concrete, and paint are dispersed throughout the containment building, along with the coolant that is released as a result of the pipe break. The emergency core cooling system (ECCS) recirculates coolant that collects on the floor of the containment building using several pumps. Debris material collected by the coolant in the containment building may be transported to the ECCS strainers that prevent excessive amounts of debris material from entering the reactor core (Figure 1).

Over time, accumulation of debris can result in excessive head loss, which could potentially lead to an insufficient amount of coolant being recirculated through ECCS pumps. Additionally, the interaction of chemicals released during the LOCA (corrosion of structural materials, buffers used to regulate pH, etc.), the coolant, and debris material produced during the LOCA may also contribute to head losses at the ECCS sump strainers.

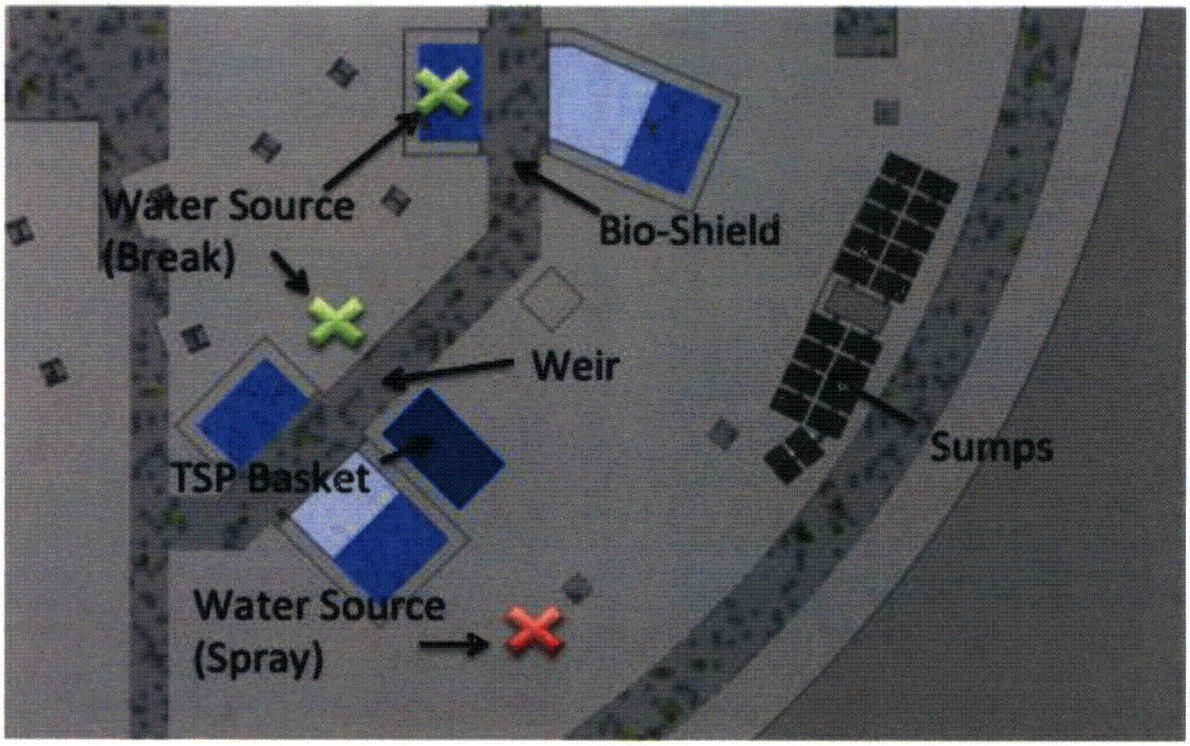


**Figure 1. Partial overview of the STP containment building, including one train of ECCS strainers, coolant buffer (TSP), and spray system flow path into the recirculation sump.**

During the July 2013 NRC visit to the University of New Mexico (UNM) Chemical Head Loss Experiment (CHLE) testing facility, the Staff questioned the possibly nonprototypic nature of the bed formation caused by the configuration of the CHLE vertical loop. More specifically, the Staff was concerned that inadequate application of the NEI fiber preparation methodology can preferentially result in small clumps of fiber (Class 3 fibers) [1]:

"The staff noted that the intent of the approval of the NEI fiber preparation methodology was to allow an alternate means of preparing (especially fine) fibrous debris without using methods that result in a non-prototypical amount of fiber shards. The intent is to create mostly individual fibers that are easily suspended (Class 2) with a lesser amount of Class 3 (small clumps) and Class 1 (shards) to match the NEI 04-07 fiber size distribution. Some of the photos in the test reports appeared to indicate that there was an excessive amount of Class 3 fibers in the prepared debris. The staff also stated that they were concerned that the use of NEI fiber in vertical loop testing would result in a non-prototypical bed because the fiber is allowed to settle by gravity onto the perforated plate instead of transporting with flow as it would in the plant."

Additional concerns have been raised regarding the estimation of chemical induced head loss using multiplicative factors and the use of the NUREG/CR-6224 head-loss correlation. The FIESTA test series is designed to span the range of known head-loss challenges from thin-bed to design basis debris conditions while providing data for calibration and validation of the L* additive chemical head-loss approach and the VISTA correlation for nonchemical debris head loss. Sections to follow present the objectives for strainer testing, describe the test matrix and prototypical test sequences, describe the test facility, discuss generic features of each test, and state the intended application of the test data for GSI-191 resolution.

# 2 Objectives of Strainer Module Testing for South Texas Project

In support of Risk-Informed-Resolution (RIR) arguments developed to address issues raised in Generic Safety Issue-191 (GSI-191), South Texas Project (STP) is constructing a horizontal flume facility to conduct a limited-scope investigation of strainer performance at the University of New Mexico (UNM) Thermal Hydraulics Laboratory. The Flume Integral Effects and Separate effects Testing and Analysis (FIESTA) facility is described below in detail (Section 4). Test conditions will emphasize total transport of specified debris (including fiber, particulates and chemical products) to a full-scale strainer module with corresponding time-dependent measurement of flow velocity, head loss, water temperature and volume, chemical concentration, and debris mass. These tests are intended to emulate the procedures and configuration used for deterministic STP strainer performance testing [2] while expanding the data base available for calibration and validation of both the L-star (L*) additive, chemical head-loss response envelope [3] and the VISTA head-loss correlation applied to a functional strainer module [4].

The planned flume tests will generate data in prototypical performance ranges for the STP ECCS strainer and help quantify the margin of uncertainty between actual behavior and semi-analytic approximations of head loss induced by chemical and non-chemical debris. Specific test objectives include:

1) Collecting strainer performance data across the full range of known head-loss challenges including thin-bed conditions with high particulate/chemical loads and design-basis conditions with maximum fiber and maximum particulate/chemical loads;
2) Maximizing the amount of information collected during the formation of each bed because intermediate loads represent unique accident conditions in the spectrum of possible Loss of Coolant Accidents (LOCAs);
3) Emphasizing thin-bed conditions that are most likely to occur *and* most likely to influence risk quantification if adverse responses exceed thresholds of concern;
4) Increasing data resolution in regions of low chemical loading (mass per unit area) where existing measurements are sparse;
5) Complementing existing strainer performance tests by filling data gaps rather than generating replicate information;
6) Employing familiar test procedures for debris preparation and transport, and familiar chemical product surrogates.

# 3 High-Level Test Description

## 3.1 Test Matrix

Traditional strainer performance testing emphasizes debris combinations that are known to cause large head losses including: (A) thin, uniform fiber beds with high particulate and high chemical loads; and (B) thick, uniform fiber beds with high particulate and high chemical loads. For STP, Condition A represents Medium Break LOCAs (MBLOCA) with high debris transport factors, and small-to-medium-sized Large Break LOCAs (LBLOCA) with lower debris transport factors. Condition B represents a design basis accident (DBA) with LBLOCA debris inventory and high transport factors. Previous strainer module testing emphasized Condition B [2], so the DBA strainer response is better understood for LBLOCAs than for the more likely cases represented by Condition A.

High particulate and high chemical loads will be tested because particulates and chemicals have been observed to reduce bed porosity and increase fiber-bed compression. However, particulate loads contributed by assumed failure of unqualified coatings at STP have been substantially reduced through recent reevaluation of coating-system application and maintenance records, so updated particulate loads will be used after NRC review. Similarly, recent aluminum corrosion data show compelling evidence of surface passivation that greatly reduces the amount of chemical product projected to form over a 30-day mission time. While the total chemical inventory introduced to each test will be calculated in the standard way using WCAP-16530 [5], the batch loading schedule will emphasize low concentrations needed for L* calibration and intermediate loads corresponding to potentially lower total inventories.

Debris combinations selected for the FIESTA flume tests emphasize most likely realistic behavior (risk-dominant) while recognizing uncertainties in the chosen conditions. Prior strainer module tests performed at Alden Research Laboratory (ARL) emphasized extreme debris loads. So in combination with an understanding of how infrequently extreme conditions occur, the ARL data can help quantify uncertainties with respect to prototypical results obtained from current FIESTA studies. The FIESTA test plan includes an option to perform a DBA loading condition if existing data are judged to be insufficient.

Flow conditions and water temperature will be chosen to represent conditions of maximum system vulnerability, namely, high strainer face velocity that generally induces higher head loss through a debris bed and elevated temperature where available Net Positive Suction Head ($NPSH_A$) is low. Debris head loss is not relevant until recirculation from the sump begins (as early as 20 min for a LBLOCA), and maximum flow rates exist prior to shutting off sprays (approximately 6.5 hr). Thus, pool temperature at the time of ECCS recirculation is considered a good target for representative test conditions. Often, facility limitations preclude achieving the actual desired target temperature, so lower test temperatures are accepted with the rationale that correspondingly higher fluid viscosity and density will induce higher head loss readings.

To quantify uncertainty introduced by temperature-biased head-loss observations, FIESTA tests support development of a temperature-dependent head-loss model. Therefore, a minimum temperature near 55C will be maintained for all tests to represent the minimum long-term cooling temperature, and excursions up to 85C will be conducted to validate models of temperature effects. Similarly, flow velocities will be varied down to 30% less than the maximum to collect data in the performance range when containment spray pumps are shut off.

Table 1 provides generic descriptions and a brief rationale for each of the tests. A narrative description of each test timeline is provided in Section 5 after the generic approach and general facility features are described. All material quantities will be scaled from the plant conditions to the test module surface area. Nonchemical debris will be introduced in a series of small batches of constant particle-to-fiber ratio until maximum specified debris loads are achieved. Objectives of introducing small mixed batches include: (1) allow the bed to form as uniformly as possible with no gaps or occlusions (cavities), (2) collect head-loss performance data at intermediate loadings up to the maximum specified for each test, (3) facilitate interpretation of surface-averaged Reynolds number for VISTA correlation of the full-scale strainer module. Chemical products will also be introduced in small batches to improve data resolution in the low-concentration range and near chemical loads of special interest.

## 3.2 Clean Strainer Characterization

Proper characterization of the clean strainer response has been undervalued as a diagnostic tool. The FIESTA tests emphasize strainer module response over a full range of temperature and velocity for three different fluid conditions including pure water, baseline buffered and borated solution, and baseline chemistry loaded with WCAP surrogate [5]. The purpose of isolating each fluid condition is to address long-standing questions about whether the density and viscosity of chemically loaded fluid affect head loss.

**Table 1. High-level test description**

| Test Series | Non-Chemical Conditions | Chemical Conditions |
|---|---|---|
| FTA-000 | Facility Shakedown:<br>- Temperature/flow control<br>- Debris intro/transport procedures<br>- Cleaning and transport calibration<br>- Diagnostic function and acquisition | Surrogate preparation and introduction procedures |
| FTA-100[a, b] | 110: Clean strainer, no solid debris | Pure water with no chemicals |
| | 120: Clean strainer, no solid debris | Baseline chemicals |
| | 130: Clean strainer, no solid debris | Baseline chemicals + WCAP surrogate [4] |
| | 140: Batch additions of solid debris | Optional continuation of FTA-130 |
| FTA-200 | 1/4th-in. total equivalent fiber, failed unqualified coatings + MBLOCA damaged qualified coatings + latent debris | WCAP surrogate with initial loading rates informed by UNM corrosion data.<br>Addition up to reduced 30-day inventory.<br>Addition up to full WCAP 30-day inventory. |
| FTA-300 | 1/16th-in. total equivalent fiber, all failed unqualified coatings + SBLOCA damaged qualified coatings + latent | WCAP surrogate with initial loading rates informed by UNM corrosion data.<br>Addition up to reduced 30-day inventory. |

| Test Series | Non-Chemical Conditions | Chemical Conditions |
|---|---|---|
| | debris | Addition up to WCAP 30-day inventory. |
| FTA-400 | DBA condition to confirm ARL data using new maximum loadings<br>OR, replicate one FTA test for variability<br>OR, improve thin-bed characterization | WCAP surrogate with initial loading rates informed by UNM corrosion data.<br>Addition up to reduced 30-day inventory.<br>Addition up to WCAP 30-day inventory. |

Notes: a. Clean-strainer tests may be performed in a single continuous run during shakedown.
b. Option FTA-140 would add solid debris at the end of FTA-130 (reverse-order loading)

The basic diagnostic obtained from each clean-strainer test is differential pressure as a function of fluid temperature and velocity. An array of three differential pressure cells is located along the centerline of the axial core tube. The array monitors fluid pressure as flow accumulates through the plates and exits from the module. Clean strainer traces can be compared to debris loaded traces to judge uniformity of the bed. The array is also essential to understand how network flow through the stacked plates leads to total hydraulic loss through the module. This information will be used to improve estimates of total hydraulic loss through the STP manifold that consists of several modules in series.

Comparison of strainer response to pure water and strainer response to chemical loaded fluid provides an opportunity to use the strainer itself as a diagnostic instrument to quantify the viscosity of the chemical fluids under actual flow conditions. Quantification of fluid viscosity as a function of temperature (and perhaps even of shear rate) is possible using a Reynolds correlation of pressure drop to describe the total response of the module. Because the characteristic geometry is fixed between tests, and flow rates are measured accurately, only the fluid properties vary. Diagnostics have been added to the facility to capture static pressure and fluid level so that actual fluid density can also be estimated; only the fluid viscosity remains unknown, so it can be determined from the data. Direct measurement of in-situ fluid properties under conditions specific to strainer performance may provide an important uncertainty reduction, and remove arguments about the applicability of bench-scale measurements to engineering-scale tests.

## 3.3 Conventional Debris Approach

Conventional, or nonchemical solid, debris consists of Nukon™ fiberglass and particulates including latent dirt and failed coatings. All debris types will be procured in bulk from approved vendors and order/ship records will be maintained.

All fiberglass debris will be prepared using the NEI procedure with extended application of a pressure-washer jet to ensure a dominant proportion of Class II debris sizes. A revised procedure, adapted from CHLE testing, will be developed for preparation and temporary storage of fiberglass debris batches, and training will be established to ensure consistency of the product. Visual, light-table verification will be performed at least once during each test by a person other than the debris preparer.

Particulate debris will consist of pre-sieved silicate to use as a latent debris surrogate, and degraded epoxy and acrylic coatings to use as failed coating surrogate. Amounts of each coating material will be specified consistent with plant inventory records and with ZOI damage estimates corresponding to the fiber loading in each test.

Fiber and particulate will be premixed together in small batches of constant mass ratio to support batch addition as specified in the test plan. Each batch will receive final pressure washer mixing just prior to introduction in the flume. Each batch will be introduced over a 5 – 10 minute time period in a manner that encourages vertical uniformity of debris that approaches the strainer module, and near 100% lateral transport in a flow regime not greatly dissimilar to the containment pool. Examples of unacceptably dissimilar flow regimes include: (1) pouring debris on top of the strainer module, and (2) highly agitated flow that disrupts uniform bed formation.

In general, flow velocities within ±20% of the maximum average face velocity will be used to form beds and monitor head loss. Similarly, fluid temperature will be maintained within ±20% of the 55C target during bed formation. Prior to the first addition of chemical products, a gradual temperature excursion up to 85C will be performed while the velocity is simultaneously decreased to 50% of target flow and then increased to 150% of the target flow. The velocity sweep can be performed gradually over a time span comparable to the temperature increase. The order of operation is designed to prevent impact on the established debris bed. Minimum temperature and minimum flow represent the lowest Reynolds condition that the bed will experience. Maximum temperature and maximum flow represent the highest Reynolds condition that the bed will experience. The velocity will finally be reduced gradually to the specified test condition while the fluid cools to the desired target near 55C. If measured head loss after the flow sweep is observed to be more than 10% below that measured prior to the flow sweep, additional solid debris will be added to meet or exceed the prior condition. A similar temperature and velocity sweep will be conducted at the very end of each test following complete chemical loading.

## 3.4 Chemical Product Approach

Chemical products that may form in the STP post-LOCA accident environment are presumed to evolve in a complex process involving several stages: (1) corrosion of metals and leaching from solid debris, which are collectively referred to as "material release;" (2) saturation of the aqueous solution (either homogeneous or local) and precipitation of semi-solid compounds that; (3) migrate to the strainer debris bed and increase head loss (Fig. 2). In these tests, Stage 2 will be simplified by conservatively assuming that all metal ions released during Stage 1 corrosion appear immediately as chemical product without credit for delayed saturation. Analytic projections of release rates in Stage 1 define the chemical loading rate for the tests, while the primary objective of testing is measuring head loss that occurs in Stage 3. A further simplification assumes that all possible compounds that might form in Stage 2 are adequately bounded by a mass-equivalent amount of surrogate product formed according to procedures outlined in WCAP-16530 [5]. The total amount of surrogate product added to each test will also be calculated using WCAP-16530 corrosion rates.

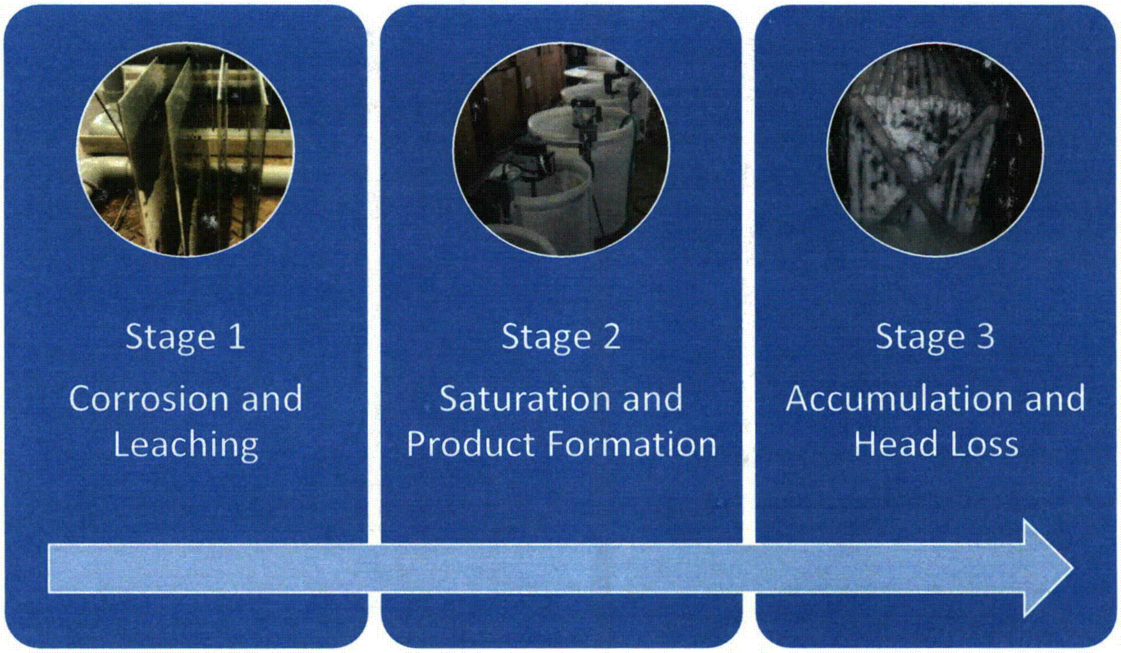


**Figure 2. Notional stages describing formation of chemical products in the post-LOCA chemical environment.**

### 3.4.1 Stage 1: Corrosion and Leaching

Two primary factors that affect time-dependent material release, and therefore the production of chemical product, are pH and temperature. Figure 4 presents prototypical temperature and two pH histories representing a large break at STP. Note that the pH changes rapidly when dry chemical buffering agent dissolves in the pool, but an artificial delay of 2 hours was built in to approximate the time needed to fully mix high-pH fluid. Specific temperature and pH histories will be selected to calculate chemical product source terms that are of interest for each flume test. The calculations only help identify concentration ranges of special interest for high-resolution chemical batch addition. Total chemical inventory for each test will be determined using WCAP-16530 corrosion rates.

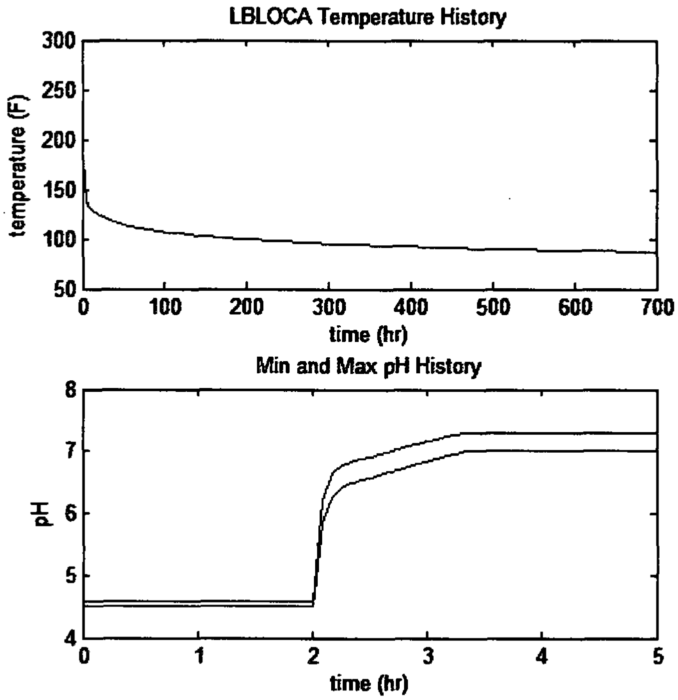


**Figure 3. Typical PWR large-break temperature and pH histories.**

Time-dependent pH and temperature are combined with models of aluminum corrosion to predict time-dependent cumulative chemical product that is presumed to form in Stage 2. WCAP-16530 [5] provides one such model that is characterized by a high corrosion rate determined from testing over a limited time period. A recent model based on UNM testing of aluminum over a longer duration provides strong evidence for passivation that limits the total amount of aluminum that can be released into solution. A minor variant of the UNM model produces the total integrated concentration of aluminum ions that would be released into solution shown in Fig. 5. The total amount of chemical product as a function of time can also be calculated from this history.

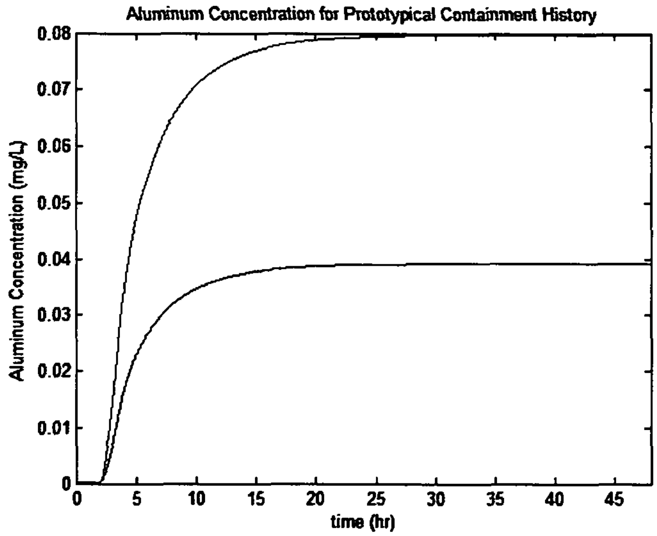


**Figure 4. Cumulative aluminum ion concentration computed for two pH histories and a common temperature history representative of a large-break LOCA with sprays never terminated.**

Similar chemical product histories can be calculated using the WCAP corrosion rates, but the total 30-day inventories are much higher. UNM data describing aluminum coupon passivation has not been fully reviewed by the NRC, but the conclusions are consistent with in-situ tank tests conducted under representative STP conditions, and therefore warrant consideration in the FIESTA test procedure. Chemical production histories will be calculated using both the WCAP corrosion rates and the UNM corrosion rates to assess uncertainty bounds on the head-loss response. The calculations only help identify concentration ranges of special interest for high-resolution chemical batch addition. Total chemical inventory for each test will be determined using WCAP-16530 corrosion rates.

### 3.4.2 Stage 2: Saturation and Product Formation

By neglecting any potential for solubility and saturation phenomena, product formation is presumed to occur immediately following release by corrosion and leaching. However, in-situ conditions dictate that very low concentrations of metal ions are gradually introduced into a very large system of pseudo-stable pH and temperature. Pseudo-stable means that changes in temperature and pH are much slower than the chemical reactions needed to release ions and form chemical products.

The WCAP-16530 procedure for producing chemical surrogate is not consistent with environmental conditions, because high concentrations of separately dissolved chemical salts are combined together at room temperature before the resulting precipitate is introduced into the stock buffered and borated (B&B) chemical solution at room temperature. Further, the suspension of chemical product is then often introduced to a flume of high-temperature B&B solution. Temperature shock, pH shock, and rate of combination are all important factors that can affect the morphology (size, shape, hydration) of the chemical precipitate, even if the stoichiometry of the compound is unchanged.

Despite the known nonprototypical aspects described above, chemical surrogate for the FIESTA tests will be prepared in accordance with WCAP-16530 procedures. All room temperature storage, mixing, and settling criteria will be satisfied. Small batches of predefined mass will be introduced into the high-temperature flume in a typical manner until the total inventory estimated using WCAP-16530 corrosion rates is present in the flume.

### 3.4.3 Stage 3: Accumulation and Head Loss

During the accident scenario, the bed of nonchemical debris will form within a few hours following switchover to recirculation; and, neither STP prototypical testing nor accelerated corrosion testing have produced significant precipitants during the first 5 days. These observations support sequential formation of a particulate and fiber bed followed by a phase of chemical addition within the same continuous test. This point is discussed because reality contradicts the assumption of immediate chemical product formation stated for simplification of Stage 2. Actual corrosion begins immediately, and chemical product inventory will be calculated directly from the release rate as if the product forms immediately. However, staggered addition of solid debris and chemical products by several hours is consistent with the actual chemical environment and with previous flume testing procedures. Sequential addition of solid debris and chemical products also supports collection of higher quality data for the L* additive head-loss correlation.

Figure 4 shows that metal concentrations, and hence assumed precipitate concentrations, can change rapidly in the first few hours of the accident. Initial introduction of chemicals will attempt to match observed rates of corrosion for a period of 12 hours before advancing the rate of product addition to achieve the total specified loading. Under the assumption of immediate product formation, these are the most rapid rates of precipitation and accumulation that can be tied to actual phenomena that occur in the pool, so it will be useful to monitor a representative bed response. If precipitation actually occurs during the accident, the rate of formation will be controlled by the rate of corrosion that exists at the time saturation is reached and equilibrium is established, so the assumption of immediate formation always provides the most rapid rate. A debris laden, agitated pool cannot support conditions of supersaturation needed to cause a catastrophic precipitation event in the STP chemical environment that is dominated by corrosion.

Beyond the initial 12 hours of chemical addition, the principle guiding chemical-product addition will be "as slow as practical." More data resolution is needed for low superficial concentrations (mass/area), so several small batches will be added until the 30-day inventory projected using UNM corrosion rates is reached. Larger batches can then be introduced until the 30-day inventory predicted using WCAP corrosion rates is reached. A stability hold of at least 2 pool turn overs will be observed between batches, and each batch will be introduced at a uniform mixing rate over 10-15 minute intervals.

# 4 FIESTA Facility

In support of experimental validation data for the STP RIR license submittal, UNM is constructing a confirmatory flume-test facility capable of simulating the dominant phenomenology affecting debris transport and chemical effects at the recirculation sump strainer under physically similar pool-refill and recirculation phase conditions immediately following a LOCA. The FIESTA experimental facility is designed to simulate fiber transport initiated by a primary RCS pipe break, continuing with fiber transport during the refill phase, and concluding with the fiber transport during the recirculation phase. The FIESTA facility will house a prototypical strainer at the sump side of the flume and will be instrumented to measure time-dependent pressure drop data. FIESTA is designed to be able to operate in both an integral effects testing (IET) *and* separate effects testing (SET) mode.

The FIESTA tests described here emphasize near 100% debris transport and uniform vertical mixing of finely divided debris. No quantification of near-field settling will be measured at this time.

## 4.1 FIESTA Facility Design

The FIESTA facility (Figure 5) will be a closed-loop insulated flume that is 32 ft (L) X 4 ft (W) X 6 ft (H) and will be capable achieving temperatures as high as 85 C, with an expected operating temperature near 55 C.

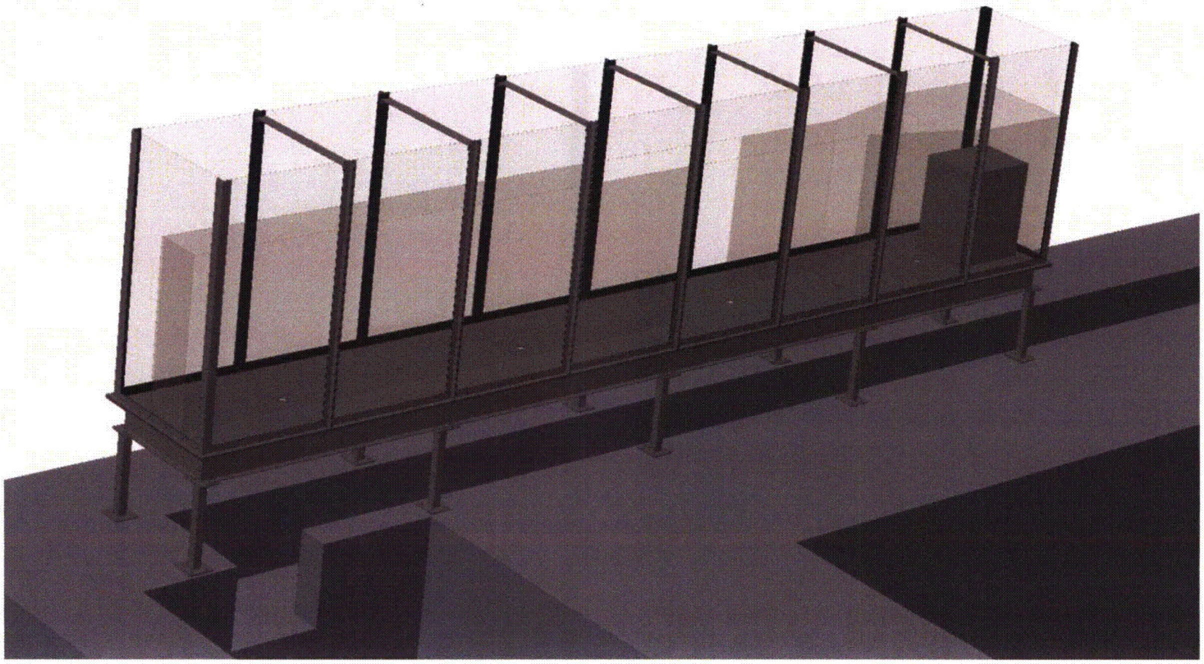

**Figure 5. Schematic of the UNM Flume Integral Effects and Separate Effects Testing and Analysis (FIESTA) facility**

Similar to the large flume tests previously performed at UNM, flow in the FIESTA facility will first enter the tank at the opposite end of the tank from the strainer. An internal polycarbonate channel will be installed interior to the open channel of the flume to encourage complete debris transport to the strainer. An example of the narrow transport channel used at ARL is shown in Figure 6. The FIESTA facility will take advantage of extensive existing infrastructure leftover from the original open-channel hydraulics lab Arroyo testing (below grade cavities shown in Figure 5). The facility will be located adjacent to the open-channel return duct in order to take advantage of existing plumbing infrastructure from the original large flume. Drains will be installed at multiple locations along the downstream portion of the channel in order to study debris transport and settling throughout the length of the flume at the conclusion of testing. For these tests, the drains will be used during shakedown preparation to recover post-test conventional debris and calibrate procedures developed to encourage transport. Total solid debris inventory can then be increased to account for measured retention losses.

Elevated solution temperatures can be achieved by use of a heat exchanger system to avoid extreme temperature gradients. Additional small-scale heat exchangers will be installed to allow the facility to vary the temperature of the solution during a test (e.g. a temperature sweep). Incorporation of a STP strainer module (Figure 6) allows for characterization of prototypical head loss under a variety of specified debris loads and velocity/temperature test conditions. Plant operating velocities will be established by controlling total volumetric flow across the strainer face area.


**Figure 6. Series of strainer modules (left) and single strainer module (right) for STP**

Fiber and chemical surrogates can be introduced just upstream of the narrow transport channel. Generous facility length for this application enables many options for conditioning the return flow and introducing debris to encourage vertical uniformity and minimize debris retention losses. Vertical uniformity in this test facility is critical for performing a variety of tests examining debris transport and bed evolution where fiber inventory in solution can be controlled and varied.

## 4.2 Flume Test Diagnostics

A suite of bench-scale and online measurements will be used to support data acquisition for these tests. Table 2 lists the basic tools that are needed to conduct the flume tests and describes their purpose and sampling frequency.

**Table 2. Supporting Diagnostics and Data Collection**

| Diagnostic | Purpose | Flume Sampling Frequency | Mode |
|---|---|---|---|
| Volumetric flow rate | Face velocity on the test module | 0.1 to 0.02 Hz (every 10 to 50s) | Online |
| Differential Pressure Array | Hydraulic loss through the debris bed. Clean strainer response along the module. | matched with flow samples | Online |
| Static pool pressure | Fluid density in combination with level | matched with flow samples | Online |
| Liquid Temperature | Fluid properties, pH correction | matched with flow samples | Online |
| Room Temperature | Differential pressure correction | matched with flow samples | Online |
| Atmospheric Pressure | Pump NPSH | Once per 4 hours or as specified in test plan | Spot Read |
| Liquid Level | Fluid density, chemical conc, water make up. | 4 times per hour or as specified in test plan | Online or Spot Read |
| Total pipe volume | Chemical conc. | NA | Once |
| pH | Chemical debris preparation and flume test conditions | Once per 4 hours after first chemical add or as specified in test plan | Bench Reading |
| Viscosity (option) | Fluid properties | Once per 4 hours after first chemical add, or as specified in test plan | Bench Reading |
| ICP | Flume concentration for mass balance | Once per 4 hours after first chemical add, or as specified in test plan | Grab Sample |
| Turbidimeter (option) | Possible mass balance verification | Once per hour, or as specified in test plan | Bench Reading |
| Zeta Potential (option) | Characterize chemical environment | Once per hour, or as specified in test plan | Bench Reading |
| High Intensity Flash (option) | Shadowgraph imaging of debris-bed loading | Up to 4 times during nonchem add.<br>Up to 4 times during chemical add. | Manual Video or Image |

| Diagnostic | Purpose | Flume Sampling Frequency | Mode |
|---|---|---|---|
| Pulse x-ray (option) | Shadowgraph imaging of debris-bed loading | Up to 4 times during nonchem add.<br>Up to 4 times during chemical add. | Individual images |
| Mass balance | Milligram to kg accuracy for surrogate chemical preparation | NA | As needed |
| Particle sizing | Characterize surrogate chemical product | NA | As needed |
| Light table | Verify debris preparation | NA | Each debris batch |

## 5 Test Descriptions

Several generic steps are relevant to all debris-laden tests. Prior to each test, the FIESTA facility must be cleaned, filled and prepared with stock chemical fluid, and heated to specified temperature. When specified baseline chemical conditions have been met, clean-strainer data will be collected while the flume is heating and the pump will be cycled periodically within a range of ±50% of the desired maximum test velocity. Clean-strainer data taken across all tests will form an aggregate basis for correlating clean-strainer head-loss as a function of temperature and velocity when only stock chemical solutions are present. The documented WCAP preparation, storage, and settling acceptance procedures will be followed in tests where the WCAP chemical surrogate is used [5].

Procedures will be developed for (a) cleaning the flume system, (b) preparing the stock chemical environment, (c) preparing/introducing nonchemical debris, and (d) preparing/introducing WCAP chemical product.

Appendix A describes additional details and notional sequences expected for each of the FIESTA flume tests listed in Table 1. For each test is provided a statement of Purpose, Operational Objectives, and Notes on procedure as they are currently formulated. As these details evolve, formal test procedures and schedules will be developed to guide each exercise. Although final conditions for test FTA-400 will be selected during the course of testing, it is described in the appendix as a DBA test with full debris loads. Several options are open for FTA-400 because the July 2008 ARL tests may serve as a sufficient description of DBA under worst conditions.

## 6 Application of Test Data

In the present STP LAR, conventional debris head loss is estimated for a very large number of debris combinations and fluid flow conditions using a modified application of the familiar head-loss correlation published in NUREG/CR-6224. The modifications include (a) automatic compression of the bed to minimize uncertainties in the actual bed compression, and (b) a factor of 5 uncertainty applied to all predictions to account for variations observed between test facilities and between head-loss responses from ostensibly similar debris loads. During the RAI process, STP has been challenged on (1) the use of a correlation that has long-standing recognized defects. At the same time, STP has been challenged to (2) understand and quantify the degree of uncertainty between semitheoretical predictions used in the risk evaluation and actual debris bed behavior on a strainer. The third challenge to head-loss analysis is (3) accounting for additional head loss induced by chemicals if they form during an accident sequence.

The FIESTA tests described here are designed to address all three challenges using a time-efficient and technically defensible approach. While the test conditions are defined to span the range of known strainer performance challenges from thin-bed to DBA debris loads, the data will be correlated and interpreted using the VISTA approach for Reynolds flow scaling. Reynolds flow scaling offers technical bases for:

1) Correlating head-loss across a wide range of flow conditions and supports rigorous uncertainty analysis by relegating all variations to an unknown average bed porosity;
2) Collapsing flow conditions (defined by velocity, fluid properties, and bed configuration) into a familiar engineering context to better judge the similarity and disparity between available test data,
3) Judging the sufficiency of the final test matrix by comparison to calculated bed configurations across the full spectrum of accident scenarios.

Without an explanatory model to relate discrete tests to conditions experienced in the plant, there can be no finite bound on an exploratory test matrix. The present GSI-191 closure schedule cannot be satisfied unless a strategic test matrix is supported by physical insights. Note that application of the VISTA approach to high-temperature vertical loop data identified bed compression as the largest uncertainty affecting accurate head-loss prediction. The FIESTA tests are likely to confirm this observation and provide a basis for quantifying the degree of uncertainty to place on average bed porosity. Ultimate application of a VISTA correlation derived from flume test data may also require a choice of low porosity and/or a multiplicative uncertainty factor to envelope observed test data in much the same way that the L* approach bounds chemical effects

Chemical effects will be addressed by deriving the L*, monotonically increasing, additive head-loss envelope for all chemical loaded tests. Particular attention is being given to low chemical concentration ranges where prior information is sparse, but the entire range of chemical loading will be quantified for all tests that include chemicals. Careful quantification is needed to capture any variation of the additive chemical effect between different debris configurations and to quantify uncertainties that exist between previous and current tests.

# 7 References

1) NRC Trip Report, August 2013.

2) South Texas Project Test Report for ECCS Strainer Testing, AREVA NP Document #66-9088089-000. August 2008.

3) Leavitt, J.J. and Kee, E., "Quantification of Chemical Head Loss Epistemic Uncertainty: Basis for Incremental Chemical Head Loss Correlation," ALION-REP-STP-8998-08 Rev. 1. July 2014.

4) Letellier, B.C., Macali, M.E., Kee, E.J., "Viscous Inertial Shear-Transition-Adaptive (VISTA) Porous Media Head-Loss Formulation for Assessment of South Texas Project Licensing Amendment Request," ALION-REPSTP-8998-11, Rev. 0. July 2014.

5) WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191." March 2008.

# Appendix 1: Detailed Test Descriptions

## FTA-000 (Shakedown)

Purpose:

Demonstrate facility readiness and staff competency in basic skills needed to perform an extended debris/chemical test that may last for several days.

Operational Objectives:

- Instrument operation/calibration and data acquisition
- Perfect and train debris preparation/storage
- Perfect and train WCAP preparation/storage
- Perfect and train debris/chemical introduction premeasured batches
- Demonstrate near 100% debris transport
    - Mild agitation
    - No bed disturbance
- Post-test fiber recovery to calibrate residual retention
- Perfect and train cleaning procedures including
    - Chemical recovery and/or disposal requirements
- Calibrate heating and cooling times for planning flow cycles
- Develop QA checklists related to all steps of a full debris/chemical test series
- Build a debris bed and observe effects of planned flow cycles
- Determine time scale need for debris introduction, temperature sweeps and stability holds so firm schedules can be defined for each test
- Determine staffing needs for extended test series

Notes:

A series of shakedown tests will be performed that combine various objectives and culminate in a compressed, but complete, test that exercises all elements of the procedures. This "dry run" will help anticipate all data logging and auxiliary equipment needs.

## FTA-100 (Clean Strainer)

### FTA-110 Pure Water

Purpose:

Collect data that will be used to develop a clean-strainer head-loss correlation for pure water that can be compared to a clean-strainer head-loss correlation for chemically loaded water. Comparison of these models will provide a global indication of whether viscosity and density effects are important.

Operational Objectives:

- Further practice in facility operation and data acquisition
- First application of temperature and flow cycles for production data

Notes:

This test can be planned to run sequentially with other clean strainer tests, or sequentially with the first debris test to conserve pure-water inventory and heating costs.

After shake down tests ensure that all diagnostics are functional, the facility will be cleaned according to procedure and filled with pure water. No stock chemicals will be added. The fluid will be heated gradually to 85C and then allowed to cool back to the target test temperature of 55C while data are recorded continuously. During the heating and cooling phase, the pump will be cycled periodically within a range of ±50% of the desired maximum test velocity.

### FTA-120 Baseline Chemicals

Purpose:

Develop a clean-strainer head-loss correlation for baseline chemical fluid can be compared to a clean-strainer head-loss correlation for pure water. Comparison of these models will provide a global indication of whether viscosity and density effects are important, and if so, provide a basis for measuring chemical fluid viscosity.

Operational Objectives:

- Further practice in facility operation and data acquisition
- First application of baseline chemical procedures for data production
- Additional exercise of temperature and flow cycles for production data

Notes:

This test can be planned to run sequentially with other clean strainer tests, or sequentially with the first debris test to conserve pure-water inventory and heating costs.

After shake down tests ensure that all diagnostics are functional, the facility will be cleaned according to procedure and filled with pure water and stock chemicals. The fluid will be heated gradually to 85C and then allowed to cool back to the target test temperature of 55C while data are recorded continuously. During the heating and cooling phase, the pump will be cycled periodically within a range of ±50% of the desired maximum test velocity.

FTA-130 Baseline Chemicals Plus WCAP Surrogate

Purpose:

Develop a clean-strainer head-loss correlation for baseline chemical fluid loaded with WCAP surrogate that can be compared to a clean-strainer head-loss correlation for pure water. Comparison of these results will provide a global indication of whether viscosity and density effects are important, and if so, provide a basis for measuring chemical fluid viscosity when surrogate precipitates are present.

Operational Objectives:

- First application of WCAP preparation and loading for data production
- Practice and perfect batch preparation and loading for more critical debris combination tests

Notes:

This test can be planned to run sequentially with other clean strainer tests, but it cannot be planned in combination with other debris loading tests because the strainer must be clean while chemical products are added.

After shake down tests ensure that all diagnostics are functional, the facility will be cleaned according to procedure and filled with pure water and stock chemicals.

- Chemical product equal to a reduced 30-day inventory will then be added to the flume. The fluid will be heated gradually to 85C and then allowed to cool back to the target test temperature of 55C while data are recorded continuously. During the heating and cooling phase, the pump will be cycled periodically within a range of ±50% of the desired maximum test velocity.

- Additional chemical product up to the WCAP 30-day inventory will then be added to the flume. The fluid will be heated gradually to 85C and then allowed to cool back to the target test temperature of 55C while data are recorded continuously. During the heating and cooling phase, the pump will be cycled periodically within a range of ±50% of the desired maximum test velocity.

FTA-140 Debris Added to Full Chemical Load (Optional)

Purpose:

To extract additional information from the clean strainer series, solid debris can be added at the end of test FTA-130 after a full chemical loading is established. This test is optional because the physical order of bed formation followed by chemical product formation is reversed. This optional exercise may also be useful to practice debris preparation and introduction procedures, even though the head-loss response is considered nonprototypic.

Operational Objectives:

- Practice all debris preparation, introduction and transport procedures
- Observe the effects of flow cycles on a debris bed

Notes:

At the end of test FTA-130, prepared batches of particulate and fiber will be added following the same procedure specified for tests FTA-200 through FTA-400. Similar variations in temperature and velocity will also be induced to generate a parallel data record that isolates the effect of reversing the addition of solid debris and chemical products.

## FTA-200 (1/4th-inch contiguous bed)

Purpose:

Obtain test data in the performance range of intermediate fiber loading to better quantify strainer response for risk dominant conditions. This test will also inform the lower limit adopted for test FTA-300.

Operational Objectives:

- First introduction of debris for data production
- "High-resolution" addition of many small batches of premixed debris and particulates
- Batch addition of prepared chemical surrogate
- Full transport and flow sweeps with no bed disturbance

Notes:

Particulate consistent with failed and damaged coatings in a MBLOCA will be premixed with a 1/4$^{th}$-in. equivalent thickness of fiber. Latent debris will be included in the loading.

Several small batches of constant mass ratio will be added to monitor head-loss for the onset of effective filtration. This threshold will be used to inform the test conditions for FTA-300. Batch addition will continue until the total target loading is reached.

A flow sweep over temperature and velocity will be performed prior to chemical product introduction. The flow sweep will be designed to prevent bed disturbance and to increase compaction, if there is any effect at all. If post-sweep head loss is less than the pre-sweep head loss, additional debris will be added to reestablish the prior condition.

Chemical addition will follow a prescribed batch schedule designed to obtain additional data in the low concentration regime and proceed to full 30-day chemical projections.

FTA-300 (1/16th-inch contiguous bed)

Purpose:

Obtain test data in the performance range of very low fiber loading to better quantify strainer response for risk dominant conditions. This test will use a target fiber inventory established by examination of test FTA-200. It is expected that the onset of filtration may occur near a $1/16^{th}$-in. equivalent, but the exact amount will be decided based on FTA-200 results.

Operational Objectives:

- "High-resolution" addition of many small batches of premixed debris and particulates
- Batch addition of prepared chemical surrogate
- Full transport and flow sweeps with no bed disturbance

Notes:

Particulate consistent with failed and damaged coatings in a SBLOCA will be premixed with a $1/16^{th}$-in. equivalent thickness of fiber. Latent debris will be included in the loading.

Several small batches of constant mass ratio will be added to monitor head-loss for the onset of effective filtration. These intermediate results can be compared with similar batch additions in FTA-200, which will differ by the particle-to-fiber mass ratio. Batch addition will continue until the total target loading is reached.

A flow sweep over temperature and velocity will be performed prior to chemical product introduction. The flow sweep will be designed to prevent bed disturbance and to increase compaction, if there is any effect at all. If post-sweep head loss is less than the pre-sweep head loss, additional debris will be added to reestablish the prior condition.

Chemical addition will follow a prescribed batch schedule designed to obtain additional data in the low concentration regime and proceed to full 30-day chemical projections.

## FTA-400 (DBA debris load)

Purpose:

Compare results to previous ARL test under similar conditions and assess the degree of uncertainty in L* for extreme debris conditions. This test will also inform VISTA correlation in the regime of contiguous bed loadings, and quantify the degree of uncertainty in porosity caused by bed compaction.

(Note that higher priority options for this test may supersede the description provided here)

Operational Objectives:

- "High-resolution" addition of many small batches of premixed debris and particulates
- Batch addition of prepared chemical surrogate
- Full transport and flow sweeps with no bed disturbance

Notes:

Particulate consistent with failed and damaged coatings in a LBLOCA will be premixed with a maximum loading of fiber. Latent debris will be included in the loading.

Several small batches of constant mass ratio will be added to monitor head-loss for the onset of effective filtration. These intermediate results can be compared with similar batch additions in FTA-200 and FTA-300, which will differ only by the particle-to-fiber mass ratio. Batch addition will continue until the total target loading is reached.

A flow sweep over temperature and velocity will be performed prior to chemical product introduction. The flow sweep will be designed to prevent bed disturbance and to increase compaction, if there is any effect at all. If post-sweep head loss is less than the pre-sweep head loss, additional debris will be added to reestablish the prior condition.

Chemical addition will follow a prescribed batch schedule designed to obtain additional data in the low concentration regime and proceed to full 30-day chemical projections.

# Attachment 3
# Definitions and Acronyms

## Definitions and Acronyms

| | |
|---|---|
| ARL | Alden Research Laboratory |
| BA | Boric Acid |
| BAP | Boric Acid Precipitation |
| BC | Branch Connection |
| BEP | Best Efficiency Point |
| B-F | Bimetallic Welds |
| B-J | Single Metal Welds |
| BWR | Boiling Water Reactor |
| CAD | Computer Aided Design |
| CASA | Containment Accident Stochastic Analysis |
| CCDF | Complementary Cumulative Distribution Function or Conditional Core Damage Frequency |
| CCW | Component Cooling Water |
| CDF | Core Damage Frequency |
| CET | Core Exit Thermocouple(s) |
| CHLE | Corrosion/Head Loss Experiments |
| CHRS | Containment Heat Removal System |
| CLB | Cold Leg Break or Current Licensing Basis |
| CRMP | Configuration Risk Management Program |
| CS | Containment Spray |
| CSHL | Clean Strainer Head Loss |
| CSS | Containment Spray System (same as CS) |
| CVCS | Chemical Volume Control System |
| DBA | Design Basis Accident |
| DBD | Design Basis Document |
| D&C | Design and Construction Defects |
| DEGB | Double Ended Guillotine Break |
| DID | Defense in Depth |
| DM | Degradation Mechanism |
| ECC | Emergency Core Cooling (same as ECCS) |
| ECCS | Emergency Core Cooling System |
| ECWS | Essential Cooling Water System (also ECW) |
| EOF | Emergency Operations Facility |
| EOP | Emergency Operating Procedure(s) |
| EPRI | Electric Power Research Institute |
| ESF | Engineered Safety Feature |
| FA | Fuel Assembly(s) |
| FHB | Fuel Handling Building |
| GDC | General Design Criterion(ia) |
| GL | Generic Letter |
| GSI | Generic Safety Issue |
| HHSI | High Head Safety Injection (ECCS Subsystem) |
| HLB | Hot Leg Break |
| HTVL | High Temperature Vertical Loop |
| HLSO | Hot Leg Switchover |
| ID | Inside Diameter |
| IGSCC | Intergranular Stress Corrosion Cracking |
| ISI | In-Service Inspection |
| LAR | License Amendment Request |
| LBB | Leak Before Break |
| LBLOCA | Large Break Loss of Coolant Accident |
| LDFG | Low Density Fiberglass |
| LERF | Large Early Release Frequency |
| LHS | Latin Hypercube Sampling |
| LHSI | Low Head Safety Injection (ECCS Subsystem) |
| LOCA | Loss of Coolant Accident |
| LOOP/LOSP | Loss of Off Site Power |
| MAAP | Modular Accident Analysis Program |
| MAB/MEAB | Mechanical Auxiliary Building or Mechanical Electrical Auxiliary Building |
| MBLOCA | Medium Break Loss of Coolant Accident |
| NIST | National Institute of Standards and Technology |
| NLHS | Non-uniform Latin Hypercube Sampling |
| NPSH | Net Positive Suction Head, (NPSHA – available, NPSHR – required) |
| NRC | Nuclear Regulatory Commission |

**Definitions and Acronyms**

| | |
|---|---|
| NSSS | Nuclear Steam Supply System |
| OBE | Operating Basis Earthquake |
| OD | Outer Diameter |
| PCI | Performance Contracting, Inc. |
| PCT | Peak Clad Temperature |
| PDF | Probability Density Function |
| PRA | Probabilistic Risk Assessment |
| PWR | Pressurized Water Reactor |
| PWROG | Pressurized Water Reactor Owner's Group |
| PWSCC | Primary Water Stress Corrosion Cracking |
| QDPS | Qualified Display Processing System |
| RAI | Request for Additional Information |
| RCB | Reactor Containment Building |
| RCFC | Reactor Containment Fan Cooler |
| RCS | Reactor Coolant System |
| RG | Regulatory Guide |
| RHR | Residual Heat Removal |
| RI-ISI | Risk-Informed In-Service Inspection |
| RMI | Reflective Metal Insulation |
| RMTS | Risk Managed Technical Specifications |
| RVWL | Reactor Vessel Water Level |
| RWST | Refueling Water Storage Tank |
| SBLOCA | Small Break Loss of Coolant Accident |
| SC | Stress Corrosion |
| SI/SIS | Safety Injection, Safety Injection System (same as ECCS) |
| SIR | Safety Injection and Recirculation |
| SRM | Staff Requirements Memorandum |
| SSE | Safe Shutdown Earthquake |
| STP | South Texas Project |
| STPEGS | South Texas Project Electric Generating Station |
| STPNOC | STP Nuclear Operating Company |
| TAMU | Texas A&M University |
| TF | Thermal Fatigue |
| TGSCC | Transgranular Stress Corrosion Cracking |
| TS | Technical Specification(s) |
| TSB | Technical Specification Bases |
| TSC | Technical Support Center |
| TSP | Trisodium Phosphate |
| UFSAR | Updated Final Safety Analysis Report |
| UNM | University of New Mexico |
| USI | Unresolved Safety Issue |
| UT | University of Texas (Austin) |
| V&V | Verification and Validation |
| VF | Vibration Fatigue |
| WCAP | Westinghouse Commercial Atomic Power |
| ZOI | Zone of Influence |