OVERVIEW OF THE FLUME INTEGRAL EFFECTS AND SEPARATE EFFECTS TESTING AND ANALYSIS (FIESTA) FACILITY FOR INVESTIGATING CONTAINMENT DEBRIS TRANSPORT AND SUMP STRAINER HEAD LOSS

Cody Williams, Eli Willard, Amir Ali, Daniel LaBrier, Edward Blandford[*]
Department of Nuclear Engineering
University of New Mexico
259 Farris Engineering Center
Albuquerque, NM 87131 [*]edb@unm.edu

ABSTRACT

In support of an ongoing Generic Safety Issue 191 (GSI-191) experimental research initiative, the University of New Mexico (UNM) is constructing a flume testing facility capable of simulating the dominant phenomenology affecting debris transport and chemical effects at the Emergency Core Cooling System (ECCS) sump pump strainer under safety injection and recirculation phase conditions immediately following a loss of coolant accident (LOCA). The experimental facility, called the Flume Integral Effects and Separate effects Testing and Analysis facility (FIESTA), is designed to perform both integral effects and separate effects containment testing under post-LOCA conditions. The FIESTA facility is capable of investigating long-term debris transport phenomenology and chemical head loss in prototypical strainers under representative conditions that exist shortly after a pipe break. Initial tests performed at the FIESTA facility will utilize a full-scale strainer module provided by the South Texas Project (STP) at the sump side of the flume that is instrumented to measure time-dependent pressure drop data. This paper describes the capabilities of FIESTA including a description of the facility, current status, strategy for instrumentation and control, and future testing plan.

KEYWORDS
GSI-191, Integral Effects, Strainer Tests, Flume experiments, Debris Transport

1. INTRODUCTION

In the late 1990s, the United States Nuclear Regulatory Commission (NRC) identified a generic safety issue (GSI-191) to address the effects of containment sump strainer screen blockage on the performance of the ECCS in light water reactors (LWRs) [1]. A series of events showed the potential for debris within the plant, such as insulation material, failed coatings, corrosion products or latent debris, to be dislodged during a LOCA and transported through containment, eventually accumulating and forming a layer of fiber and debris on the containment sump strainer screens. The accumulation of particulates within the layers of fiber could subsequently restrict the recirculation of water necessary to properly cool the reactor core during a LOCA. Debris types include damaged thermal insulation, failed paint, and latent dust and dirt found throughout containment.

The Advisory Committee on Reactor Safeguards (ACRS) of the NRC raised the concern of chemically-induced corrosion products that could be generated throughout containment, transported, and ultimately being filtered by the accumulated fiber debris on the ECCS sump screen. Chemical products may include compounds which form from either the corrosion or leaching of materials that interact with the designed chemical environment. These chemicals have shown the potential to increase the head loss and compromise the net positive suction head (NPSH) safety margin required to assure successful operation of ECCS sump pumps [2].

UNM has a long history working on GSI-191 resolution including reduced-scale integral effects testing under the Integrated Chemical Effects Testing (ICET) and Corrosion Head Loss Experiment (CHLE) programs [3-5], flume testing [6], vertical column testing [7-10], and bench-top corrosion experiments [11-14]. UNM is constructing an experimental testing facility capable of simulating the dominant phenomenology affecting debris transport and chemical effects at the sump pump strainer under safety injection and recirculation phase conditions immediately following a LOCA. The FIESTA experimental facility is designed to simulate transport of fiber that is expected to accumulate on containment floor after a primary reactor coolant system (RCS) pipe break, continuing with fiber transport during the safety injection phase, and concluding with the fiber transport during the recirculation phase. The facility will also provide additional data for conventional and chemical head losses corresponding to the transported fiber and other debris materials that accumulate on the sump strainer screen under LOCA conditions.

1.1 Motivation

Large-scale sump horizontal strainer tests have been performed for several of the nuclear utility companies to investigate the accumulation of physical and chemical debris on prototypical sump strainer modules (Figure 1, left) [15-17]. These tests have focused dominantly on satisfying the regulatory concerns regarding the functionality of the sump strainer pump system during a considered LOCA scenario. Fiber transport tests will be performed initially at the FIESTA facility and strive to address some fundamental questions surrounding fiber transport. This includes the quantity and class distribution of fiber that is transported (a) from the break location to the floor of containment, (b) departure from the bioshield region assuming a break is in this location, and (c) ultimately to the strainer module. Initial testing will focus on limited case fiber transport studies (such as investigating the transportability of a single class of fibers) and full fiber class transport studies based on previously determined estimates of available quantities of fiber in post-LOCA environments.

In addition, concerns have been raised regarding the estimation of chemically induced head loss (contrasted with conventional head loss which refers to the head loss attributed to debris loading alone). Current methodologies used to determine the contribution of chemically induced head loss include semi-empirical correlations developed using data collected from limited plant-specific horizontal strainer tests. A semi-empirical correlation has been developed using a superficial chemical loading parameter, L* (mass of precipitates/screen surface area) with available sparse data [18]. This chemical head loss data and others was obtained using the widely-accepted contributors to head loss (i.e. aluminum oxyhydroxide and sodium aluminum silicate) and were used to provide highly conservative estimates for the amounts of chemical precipitates that existed in a post-LOCA environment [19-21]. Emphasis in previous tests was placed on accelerating the addition of chemical surrogates in order to quantify the safety margin of NPSH on the strainer module. Follow-on tests performed at the FIESTA facility will generate data in prototypical performance ranges for the STP ECCS strainer to better inform semi-analytic approximations of head loss induced by chemical and non-chemical debris, particularly the effects of metered chemical loading during the early stages of strainer head loss tests. These tests are intended to replicate the procedures and configuration used for deterministic strainer performance testing [15].

One additional motivation for scaled testing of post-LOCA phenomenology is to investigate accepted distortions between vertical column [7-10] and horizontal strainer [15-17] head loss test results. There are several significant differences between these two testing approaches: gravitational effects, free surface effects, and strainer topology (horizontal versus vertical plate orientation). Previous tests have performed extensive investigation into the phenomenology of horizontal transport of simulated post-LOCA fiber and debris using a reduced-scale testing facility [22-24]. The FIESTA facility is capable of performing tests to bridge the gap between vertical column head loss tests and horizontal strainer tests where several of the variables involved (such as fiber and chemical surrogate preparation) are identical.

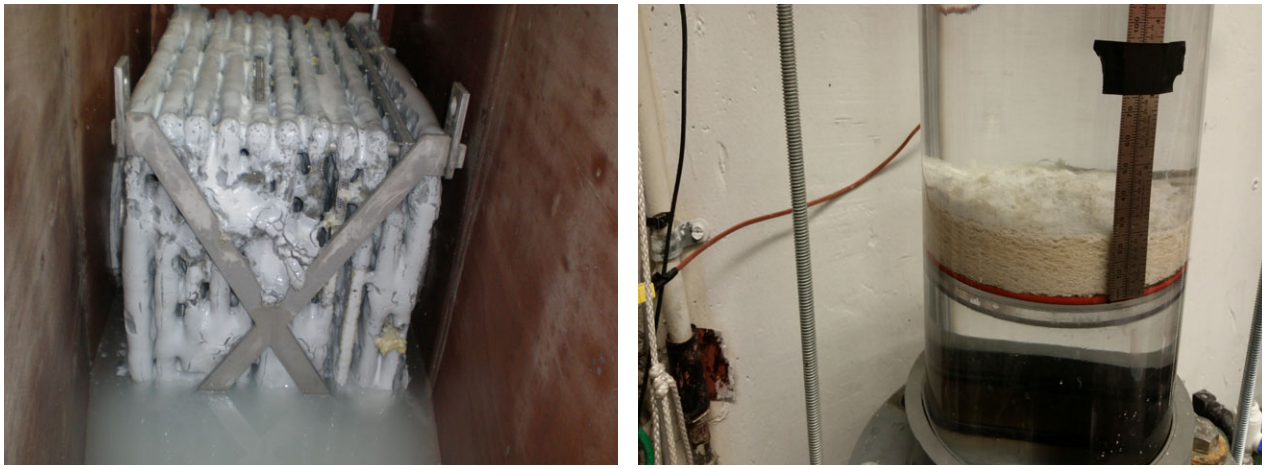

Figure 1. Debris accumulation on sump strainer module for previous tests [15] (left) and UNM vertical head loss column tests [7-10]

In summary, the primary mission of FIESTA is to achieve the following testing objectives:

1. Provide both confirmatory quantitative data and qualitative evidence for the evolutionary transport of fiber from a hypothetical break location to the sump screen in LOCA post-blowdown sequences including washdown, pool fill-up, and recirculation modes.
2. Validate the applicability of industry-accepted chemical surrogate loading used in horizontal strainer testing. In particular, investigate the time-dependency of surrogate introduction on head loss by expanding the range of chemical loading to validate current data collected for, and provide additional data to, the development of L*.

The secondary mission of FIESTA is to perform the following future tests:

1. Validate the applicability of conventional head loss correlations and filtration models developed for vertical column tests to horizontal strainer applications.
2. UNM has developed an extensive experience on vertical column strainer tests with chemical surrogates and this effort has not been cross validated with horizontal strainer tests.
3. Provide defendable evidence for conservative assumptions about debris transport throughout containment made in licensee submittals. Examples of separate effects tests will look at the both the fraction of fibers that are washed through first level of gratings and washed through additional levels of grating in containment and a determination of the class of fibers that ultimately make it to containment floor.
4. Perform separate effects (such as zinc phosphate ($Zn_3(PO_4)_2$)) transport experiments under a range of flow chemical introduction conditions. There is significant uncertainty about the stability and transportability of zinc phosphate scale layers that will form in containment under LOCA conditions.

2. FIESTA EXPERIMENTAL DESCRIPTION

2.1 Facility Overview

The FIESTA facility (Figure 2, left) is a closed loop insulated flume that has the capability of reproducing post-LOCA sump temperatures. Similar to the large flume test previously performed at UNM [6], coolant flow in the FIESTA facility enters the tank at the east side of the room and will proceed through a scaled bioshield section before entering the strainer section where appropriate flow rates are reproduced based on particular containment needs. Installation of a weir in the flume channel also makes it possible to perform a variety of fiber transportation studies. The designed weir, similar to what is used in a power plant (Figure 2, right), is used to regulate the flow of coolant and debris within the downstream portion of the channel. The channel region upstream of the weir can be used to represent the bioshield section within a power plant where pool fill up and washdown can be studied. The bioshield section of the flume is outfitted with strut channel along the top. A scaled removable TSP basket can be installed within the channel for separate and integral effects tests in the future. A horizontal strainer is mounted at a prototypical location downstream of the weir and the flow exit region simulating where debris deposits and simulates head loss during LOCA conditions.

The walls of the facility are composed of clear polycarbonate, allowing for in-situ visualization of fiber and debris transport, as well as settling effects and possible flow acceleration or eddies. Small-scale submersible cameras are used to monitor the addition of fiber at the upstream end and the bed formation at the downstream end; cameras can be relocated to various positions (submerged or above water) within the test facility as needed to record phenomena of interest (weir spill over, fiber settling, etc.). The floor plates of the test facility were designed with bolt holes that allow for the addition of a tapered interior channel (Figure 2, bottom), which provides the ability to control the average approach velocity of testing solution to the strainer. The interior channel is made of polycarbonate to allow visualization of fiber and debris transport. With the interior channel in place, tests can be conducted in the low debris range to help validate previous tests that were performed at Alden Research Laboratory [15].

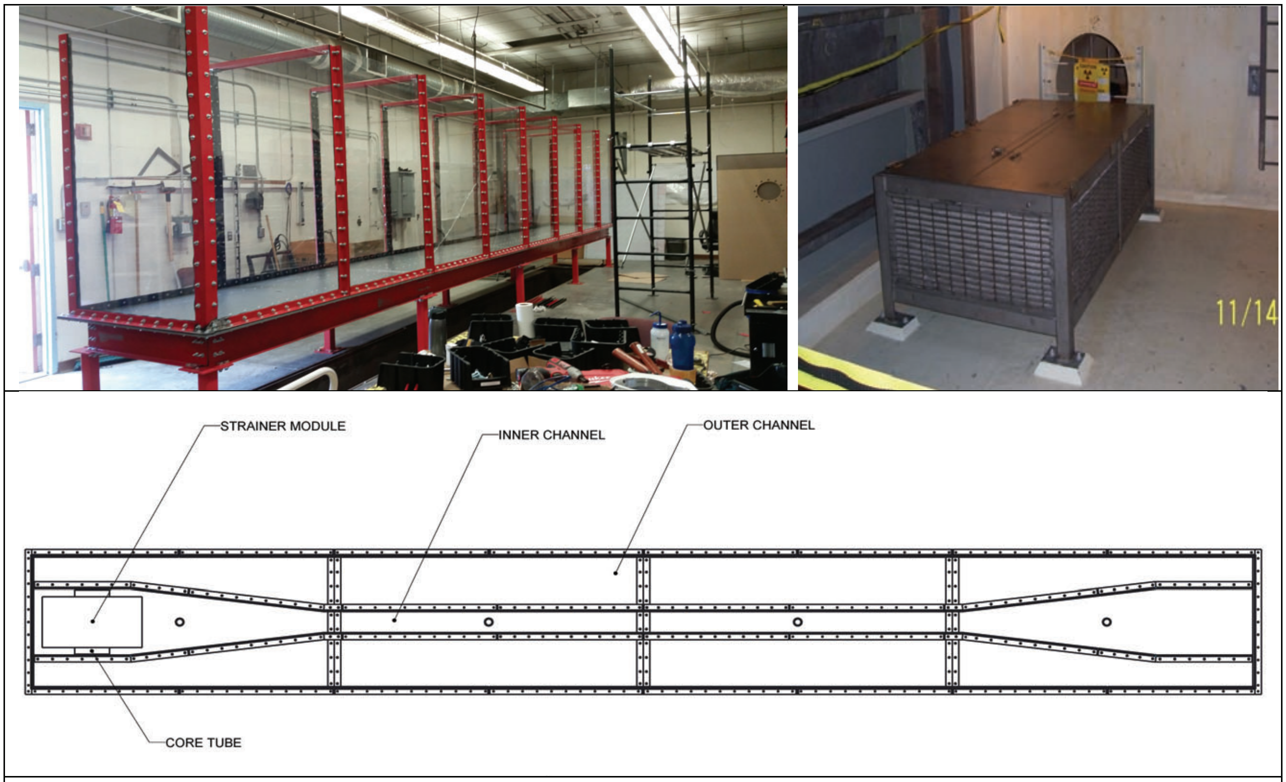

Figure 2. Current status of UNM FIESTA Facility (top left), picture showing STP weir and TSP basket located in NE region of containment and closest to Train C Sump (top right), and Schematic of FIESTA interior channel for sump strainer tests (bottom)

2.2 Scaling Analysis

Properly scaled experiments maintain geometric, kinematic, and dynamic similarity between the model and the prototype. Demonstration of physically similar phenomena is essential to modeling success. The FIESTA testing facility is actually a full-scale facility in some respects while reduced-scale in other aspects. The FIESTA facility is scaled to match a radial slice of STP containment however has been built as a rectangular flume facility due to simplification in construction. In practice, a flume built in a radial slice configuration would have distortion in the bioshield region due to wall effects and a reduced volume. This was done knowing there will be a quantifiable and manageable geometrical scale distortion between STP's containment and FIESTA. The FIESTA facility is full scale in terms of length and consistent with the lengths of other horizontal strainer testing facilities. This section provides a brief overview of the required scaling analysis in order to perform FIESTA testing. As described later, there are 3 different modes of testing where the scaling requirements differ based on the dominant governing phenomenology of interest.

In order to preserve physical similitude in an open channel flume, this requires matching the ratio of appropriate pairs of forces in both scaled model and prototype that play significant roles in the physical processes being examined. Often of interest is the ratio of inertial forces to viscous forces (the Reynolds Number) as well as the ratio of inertial forces to gravity forces (the Froude Number) in both model and prototype. The stream Reynolds Number (Re) for wide, shallow channels is the product of fluid velocity (U) and flow depth (y) divided by the fluid's kinematic viscosity (ν). The Froude Number (Fr) is the fluid velocity (U) divided by the square root of the product of the gravitational constant (g) and the flow depth (y).

$$N_{Re} = \frac{Uy}{\nu} \quad , \quad N_{Fr} = \frac{U}{\sqrt{gy}} \quad (1)$$

For practical applications, matching both dimensionless numbers would require a change in the working fluid in order to take advantage of different thermophysical properties. For horizontal strainer testing, heated water has historically used. Since turbulent flow conditions exist for some of the fiber transport tests where simulated cascading water collects inside the bioshield, it is very important that turbulent kinetic energy (TKE) distribution in this region is well characterized and matches industry simulations for STP. In addition, the STP strainer module has a surface area of 91.44 ft^2 when fully submerged as it will be during FIESTA testing. UNM will utilize a debris scaling factor of 2.514% which is consistent with prior testing. With respect to volume scaling, it is very important that the fiber transport tests have a well-matched volume ratio compared to the prototype. Ensuring a matched volume ratio and appropriate boundary conditions for water cascading into the bioshield is strongly dependent on break location relative to weir location. A detailed scaling analysis and geometry determination must be performed prior to this part of the testing program commences.

2.3 FIESTA Technical Specifications

The FIESTA facility incorporates a modular design that allows for performing tests focused on debris transportation under conditions similar to those expected in a post-LOCA environment. The flume floor is coated with epoxy in order to represent the surface roughness of the reactor containment floor and investigate debris transport at representative shallow water depths. The facility takes advantage of extensive existing infrastructure from the original Open-Channel Hydraulics Laboratory [6]. The facility is located adjacent to an open-channel return duct in order to take advantage of existing plumbing infrastructure from a previous open-channel flume facility. The duct drains to an epoxy-coated concrete pit (10000 gallon capacity) located inside of the laboratory, and can be used to store working fluid for later sampling or reuse, as well as serve as a reservoir in the case of the need for emergency evacuation of the flume. A summary of the structural parameters and operating capabilities of the FIESTA facility is provided in Table I.

Table I. Structural parameters and operating capabilities of the FIESTA facility

Structural Parameters:	Operating Capabilities:
• Flume Dimensions: 32 ft x 4 ft x 6 ft • Base: Four 8 ft x 4 ft steel plates, epoxy coated • Walls: 4 ft x 6 ft polycarbonate sheets; modular design allows for sectional isolation • Drains: centrally located in each base plate	• Total water volume: 768 ft^3 (possible); 250-500 (nominal) • Flow rates: 500 gallons per minute • Temperature: 185°F • Strainer differential pressures (DPs) up to 9 ft H_2O

Elevated temperatures are achieved through the use of utility steam supply on the UNM campus. An industrial shell-and-tube heat exchanger unit is used to rapidly heat the facilities working fluid. The temperature is controlled based on the amount of condensate that is pumped from the heat exchanger outlet back to utilities. The main recirculation pump is used to return water from the strainer (downstream) end of the flume to the entry (upstream) end of the flume. The pump is controlled using a variable frequency drive (VFD) and a gate valve. The VFD is used to adjust the operating frequency of the pump; the gate valve is used to fine tune the flow rate.

Fibrous debris will be prepared in large external tanks using a modified NEI preparation technique developed at UNM for vertical column head loss tests [25]. The fiber will be prepared just prior to test initiation and kept agitated using drum mixers; post-preparation fiber agitation is necessary to prevent fiber settling which can lead to agglomeration and non-prototypic clumping. The fiber will be added to the flume using a fluidized box that is located above the most upstream section of the flume. This box has fittings on the top where working fluid is pumped in, and a valve on the bottom that controls the rate at which fiber is released. The box will also use a mixer to agitate fiber in order to avoid agglomeration and clumping. The box is positioned above the surface and will be adjustable so that during pool fill up tests, the distance between the fiber and the surface of the water is minimized to reduce disruptions to the characteristics of the filling process.

Several features are also being developed at UNM for future FIESTA tests.

- Metering and booster pumps will be used to control various hydraulics that take place during a test, such as an integrated spray system to investigate jet impingement and washdown scenarios. This system can be used to simulate the initial release of fiber after a break, and the pool fill up portion of the LOCA. The jets simulate high velocity water that is leaking from the break, while maintaining the TKE of the scenario being simulated. The size of the jets, and the flows through them can be adjusted based on how large or small of a break is being simulated. A booster pump is used to feed the spray system, and a separate booster pump is used to control the jets inside the bioshield section (can be regulate or turned off, based on test requirements).
- Metering pumps will be used to control the inflow of precipitates and debris (non-fibrous). The metering pumps allow for greater accuracy for chemical addition rates.
- Lateral struts spanning over the flume allow for grating and other prototypical objects to be suspended above the free surface of the water. Suspended gratings allow for the study of fiber class distribution produced by insulation being entrained on galvanized steel gratings in upper containment during the blowdown phase.

2.4 FIESTA Instrumentation and Control Strategy

The FIESTA facility will be fitted with all necessary instrumentation and control equipment to ensure accurate matching of the testing conditions. This adaptive and portable instrumentation include devices to measure temperature, velocity, differential pressure, flow rate, pH, and turbidity. All FIESTA experimental data will be recorded using LabView software. The measured parameters and instrumentation used in the FIESTA facility are discussed in more details in this section.

2.4.1 Temperature

Temperature measurements are necessary to confirm that the targeted temperature profile has been achieved. If the temperature profile does not develop as predicted and as designed, several other parameters may be affected. Without proper temperature sensing probes, a head loss impact may develop due to changes in viscosity and density, and the impact may be misattributed to other parameters. Temperature may also affect the chemical composition and solution pH. The kinetics of formation of chemical precipitates is strongly dependent on the free energy of the solvent, which is a function of temperature. Type T thermocouples are selected as the temperature sensor for this project. Thermocouples will be placed every four feet along the length of the flume to accurately observe the temperature profile.

2.4.2 Velocity

Velocity measurements are necessary to determine the mass flow rate and the velocity profile along the length and width of the flume. A mass flow rate measurement is necessary to confirm that the proper amount of material and coolant is being passed through the strainer in accordance to testing design and established flow regimes (see Section 3.2 for predicted flow profiles for strainer module tests). The location of the bulk velocity measurement will be on the return pipe to minimize interference with the normal operations within the main channel of the flume. Magnetic flow meters are more compatible with the proposed testing, as they work best with conductive mediums with a thin flow stream, and are capable of being connected to a data acquisition system for continuous measurement.

Velocity profile measurements will be taken along the width of the flume channel to observe boundary layer development and bulk flow profiles. These are critical measurements for hydrodynamic modeling and predictive capabilities. An adjustable array of pitot tubes, which are commonly used for fluid flow measurements, will be used to measure the velocity of the flume fluid. Rapid measurements of the liquid velocity can be achieved, which allows for several measurements to be made in many locations. The pitot tube array is designed to mechanically maneuver to various designated locations throughout the flume, where it can be dipped into the solution and provide velocity data at that point. These data points can be collected and plotted as functions of position along the length and width of the flume, providing velocity profile information.

2.4.3 Pressure Changes

There are two distinct pressure change measurements that will be performed during flume tests: main stream flow pressure changes, and the differential pressure (dP) across the experimental strainer module. Main stream flow pressure drop naturally occurs as a result of flow in a channel. This is a useful reference to compare against—and to validate—the hydrodynamic modeling for the flume. Main stream pressure drops may be directly measured, or it may be inferred or calculated from other measurements already discussed, such as temperature and velocity measurements. To measure a pressure drop across a debris bed, a relative pressure must be established. This is a challenge with a strainer module because the inlet and outlet locations are isolated from each other. The inlet for coolant flow is three dimensional, so coolant is able to enter the strainer module from above, below, and any side. The outlet flow exits through a cylindrical port on one side of the module, and is isolated via piping from the inlet flow. The instrumentation implemented for the pressure drop across the debris bed is a dP transducer probe. The water-tight housing requirement is not prohibitively invasive, and the capability to perform continuous measurements and multiple types of measurements is attractive. Removable dP probes will be affixed to each face of the strainer module, with additional dP probes located both upstream and downstream of the strainer module. UNM is also investigating further methods for measuring head loss across the module that will not damage the strainer while providing more accurate pressure distribution measurements within the strainer.

2.4.4 Solution Analyses

Four key physical and chemical parameters of the testing solution will be measured during normal flume operations: pH, turbidity, chemical concentrations, and accumulation of debris and chemical products on the debris bed. Many of these parameters are highly coupled; having a firm understanding of each measurement at all times is essential to avoid misattribution of phenomena. As the chemical and particulate environment of the integral flume system changes, the filtration of products and latent debris responds. A highly porous debris bed will allow most materials to pass through and recirculate. A thick or impermeable debris bed will trap free materials, and will as a result become increasingly impermeable. This loss of porosity leads directly to a suction head loss on the sump strainer, which is the primary data required from the flume assembly.

The pH of a solution indicates the acidity or basicity of a solution, and is related to the chemical causticity. The pH of a solution is not expected to change dramatically during steady-state operations; therefore, it is not necessary to have in-line pH measurements of the flowing medium. At times when new chemicals are added, especially buffering materials, or when the temperature is adjusted, additional samples may be necessary to track the response of pH and relative corrosiveness. Bench-top pH meters will be utilized to document the solution acidity at regularly scheduled intervals as required by test plans.

Turbidity is a measurement of water clarity and purity, and is highly coupled to pH and chemical concentrations, and to a smaller extent, velocity and temperature. Chemical products tend to dissolve more thoroughly in low pH solutions, thereby lowering the turbidity. A high chemical concentration of certain constituents will promote the formation and flocculation or precipitates, thereby increasing the water turbidity. High channel velocities may entrain settled materials, and will increase turbidity. Temperature changes will affect the kinetics of product formation and dissolution; these effects can vary based on the chemicals present. Turbidity measurements will be made for samples extracted from the testing solution using a bench-top turbidimeter.

Keeping an accurate record of chemical concentrations is critical to determine possible precipitates which may collect at the strainer. These concentrations may also affect other parameters, such as pH and turbidity. The chemical precipitate surrogates and baseline chemicals introduced to the integral flume system are well-defined, so having knowledge of chemical concentration over time is a convenient method to inform what chemical products are being removed from solution due to precipitation and filtration at the strainer. Sampling will occur during regularly scheduled intervals, as well as times at which chemicals are added to the system. Chemical concentration measurements (using inductively-coupled plasma optical emission spectroscopy (ICP-OES)) will be performed by a third-party chemical analysis laboratory.

2.4.5 Post-Test Analyses

Identifying the materials and chemicals that transport or are filtered by the strainer is critical to establish the significant participants in head loss. Fibrous debris can be analyzed and characterized using several methods in post-test analyses, such as fiber length distribution using a light table. Chemical and particulate accumulation may be characterized using zeta potential, which informs colloidal formations and flocculation during testing, and measured through micrographic or microscopic techniques, such as a scanning electron microscope (SEM) for qualitative imaging, and energy-dispersive x-ray spectroscopy (EDX) for chemical composition and identification.

3. FIESTA EXPERIMENTAL TESTING AND OPERATIONS

3.1 Fiber Transport Tests

The first series of tests for FIESTA will focus on debris transport along the epoxy-coated concrete floor inside STP. The FIESTA floor is coated with epoxy in order to approximate the surface roughness of the reactor containment floor and investigate debris transport at representative shallow water depths. These tests will be performed at ambient conditions (room temperature and pressure) using local tap water for the flume fluid. Scaled amounts of fiber will be prepared and stored prior to the start of the test. Fiber types for these tests are designated in three categories: (1) fines and shards (predominantly Class I and II fibers); (2) bulk and clumped fiber (predominantly Class IV-VI fibers); (3) a mixture of fibers prepared using a modified-NEI preparation method developed for UNM vertical head-loss column tests (predominantly Class II and III fibers) [25].

Table II. General conditions for initial FIESTA fiber transportation tests

Series	Weir in Place	Fiber (1)	Fiber (2)	Fiber (3)	Temperature	Water Source	Added Chemicals
Fiber Transport 1	Yes	X	X	X	Ambient (20-25 °C)	Local Tap	None
Fiber Transport 2	No	X	X	X			

The first transport test will be conducted with the sectioning weir in place eight feet downstream of the water source of the flume (Figure 3). The weir consists of a stainless steel plate with an 18” diameter hole, centered along the long axis of the plate, and positioned 18” off of the floor of the flume. With the weir in place, the first section of the facility is designated as a scaled version of the bioshield section inside containment.

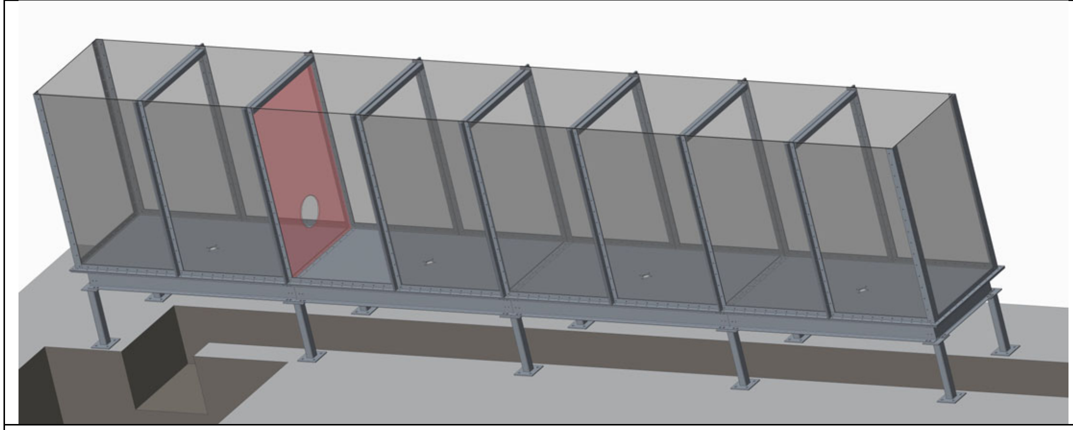

Figure 3. Render of the FIESTA facility equipped for fiber transport tests

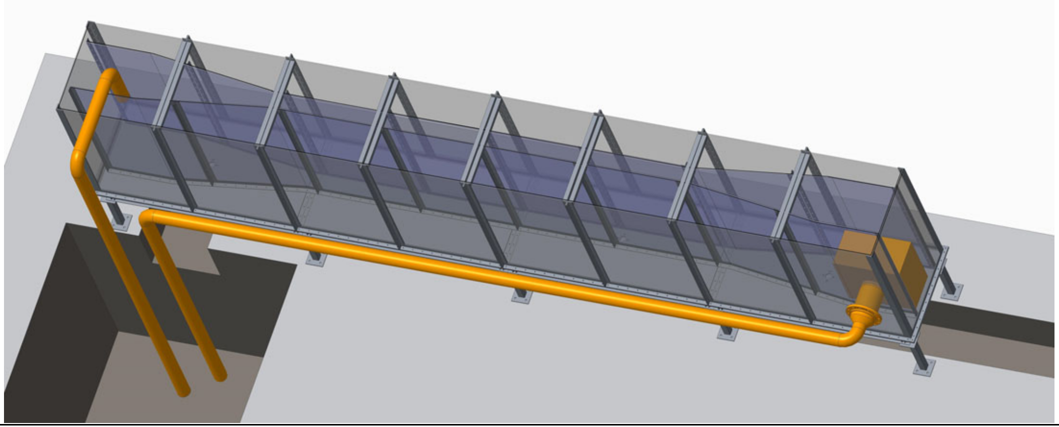

Figure 4. Render of the FIESTA facility for strainer module tests

The test will start with a completely empty flume; water and fiber will be added into the bioshield section initially. Once the water level in the bioshield section of the flume reaches the weir height, water and fiber will begin to pour over the weir. It is expected that the water inlet will agitate the fiber in certain portions of the bioshield section. This agitation may cause some fiber to recirculate, and thus be left behind once water starts to pour over the weir. Identifying the quantity and class of fiber that transports beyond the weir will be the primary objective of this initial test. While the strainer will be in place to ensure that flow conditions are prototypical, quantifying the fiber loading of the strainer is not an objective of this first test.

The second transport test to be conducted in this facility will study the settling of fiber along the containment floor downstream of the weir. For this second test, the entire facility will be treated as a post-bioshield containment floor. The test will start with the flume at near four foot water level and the strainer in place at the downstream end of the facility. Water will be circulating at a flow to match the average approach velocity to the strainer. To begin the test, fiber will be metered in through the overhead fiber deliver box, simulating fiber transportation from the bioshield section over the weir. The primary objectives of this test are to quantify the fiber fraction that makes it to the strainer, and qualify the class of fibers that settle out along the floor of the facility.

Once fiber transport tests are completed, the velocity inside the flume will gradually be decreased. Once the velocity has reached zero, sectioning plates will be put into place every eight feet. These plates will break the flume up into four eight foot sections. After the plates are in place, the sections can be drained individually. This allows for individual water and fiber samples from each section to be taken in isolation. Once taken, the fiber samples will be placed on a light table, and a light table test will be performed. The data collected from each light table test will qualify which classes of fiber are found in which section of the flume. This data will be used to better characterize which classes of fiber make it to the strainer, and which classes settle along the containment floor.

3.2 Strainer Module Tests

A limited number of tests will focus on replicating flume tests for STP [15] with an emphasis on generating data in prototypical performance ranges for the STP ECCS strainer to better inform semi-analytic approximations of head loss induced by chemical and non-chemical debris, particularly the effects of metered chemical loading during the early stages of strainer head loss tests. The FIESTA facility was designed to incorporate a narrow channel within the main flume channel in order to develop flow conditions similar to those produced in previous industry tests (Figure 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. Initial tests will stress separate effects characterization of the strainer unit prior to fiber addition tests, followed by fiber-loaded strainer tests with progressive additions of conventional debris and chemical surrogates.

Table III. Roster of strainer module tests

Test Objective	**Chemical Conditions**
Clean Strainer Tests (no fiber)	Pure water, baseline chemicals, WCAP surrogate [26]
Thin Bed Tests	WCAP surrogate with initial loading rates informed by UNM corrosion data.
Thick Bed Tests	WCAP surrogate with initial loading rates informed by UNM corrosion data.

The chemical batch loading schedule will emphasize low concentrations needed for chemical loading correlation (L*) calibration and intermediate loads corresponding to potentially lower total inventories. 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. Procedures for preparing and loading chemical surrogates for the FIESTA tests will be followed in accordance with WCAP-16530 [26] guidelines.

Debris combinations selected for the FIESTA flume tests emphasize most likely expected (risk-dominant) behavior, and will be introduced in a series of small batches. All material quantities are scaled from STP plant conditions to the test module surface area. Objectives of introducing small mixed batches include: (1) allowing the bed to form as uniformly as possible with no gaps or cavities, (2) collecting head-loss performance data at intermediate loadings up to the maximum specified for each test, (3) facilitating interpretation of surface-averaged Reynolds number for the full-scale strainer module. Conventional debris consists of Nukon™ fiberglass and particulates, including latent dirt and failed coatings. Fiberglass debris will be prepared using a modified NEI procedure developed by UNM to ensure a dominant proportion of Class II debris sizes [25]. Particulate debris will consist of latent debris surrogate, and degraded epoxy and acrylic coatings to use as failed coating surrogate.

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 NPSH is low. In general, flow velocities and the fluid temperature will be maintained within 20% of the target values during bed formation. Velocity and temperature sweeps will be performed prior to the first addition of chemical products in order to represent the minimum and maximum Reynolds conditions that the bed will experience.

Computational fluid dynamic (CFD) simulations using Star CCM+ were performed to visualize the velocity distribution of the FIESTA facility with the interior channel installed. A standard K-ε model was used to simulate the turbulence in the flow field. A uniform flow was assumed at the entrance of the channel, and the turbulence model was applied to capture all flow details near the FIESTA floor. The simulation results provide useful input to the experimental design by estimating the required inlet flow rate corresponding to the desired approach velocity near the strainer located in the portion of the interior channel, while also helping to determine the TKE within the channel and identifying potential stagnation zones that could contribute to debris settling.

Conditions of this baseline simulation include water at ambient temperature, constant fluid density, and steady state flows; the input mass flow rate was set at 4 kg/s (~65 gpm). More than 1.5 x10^6 tetrahedral elements were used for running this simulation. For simplicity, the strainer was introduced as a flow restriction (a non-porous block) located in the downstream section of the interior channel. A full sectional vertical view and two parallel sectional views extracted at 6 and 25 inches from the FIESTA floor level are shown (Figure 5). These flow field images indicate a possible stagnation zone could be present near the strainer on the FIESTA floor. Other cross sectional flow field images (Figure 6) indicate that the approach velocity range of interest (0.008 ft/s – 0.03 ft/s) can be achieved based on the input mass flow rate. This range of approach velocities is representative of flow velocities at several nuclear power plants which allow FIESTA to be utilized for different testing conditions.

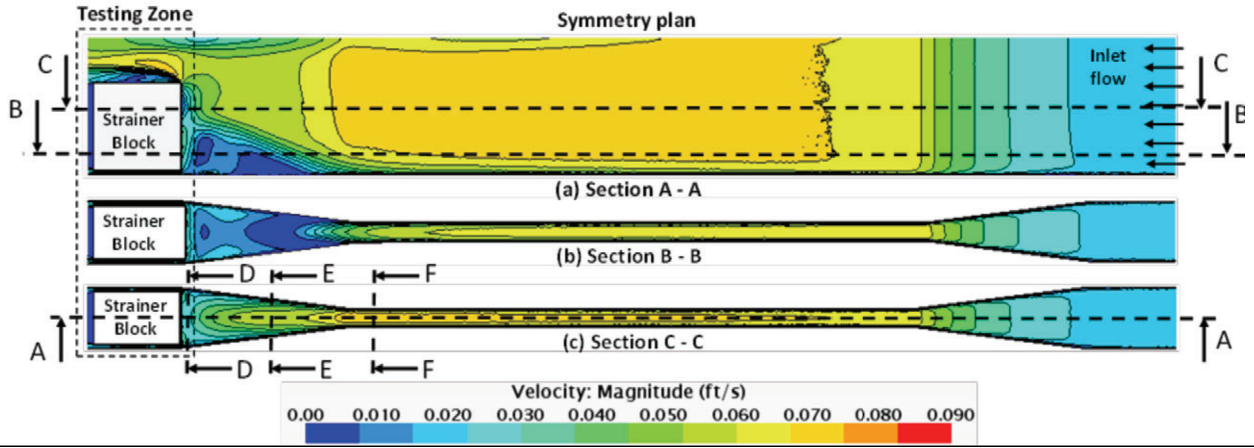

Figure 5. Flow field along the flow direction in FIESTA (a) vertical center (b) 6 inches and (c) 25 inches from the floor

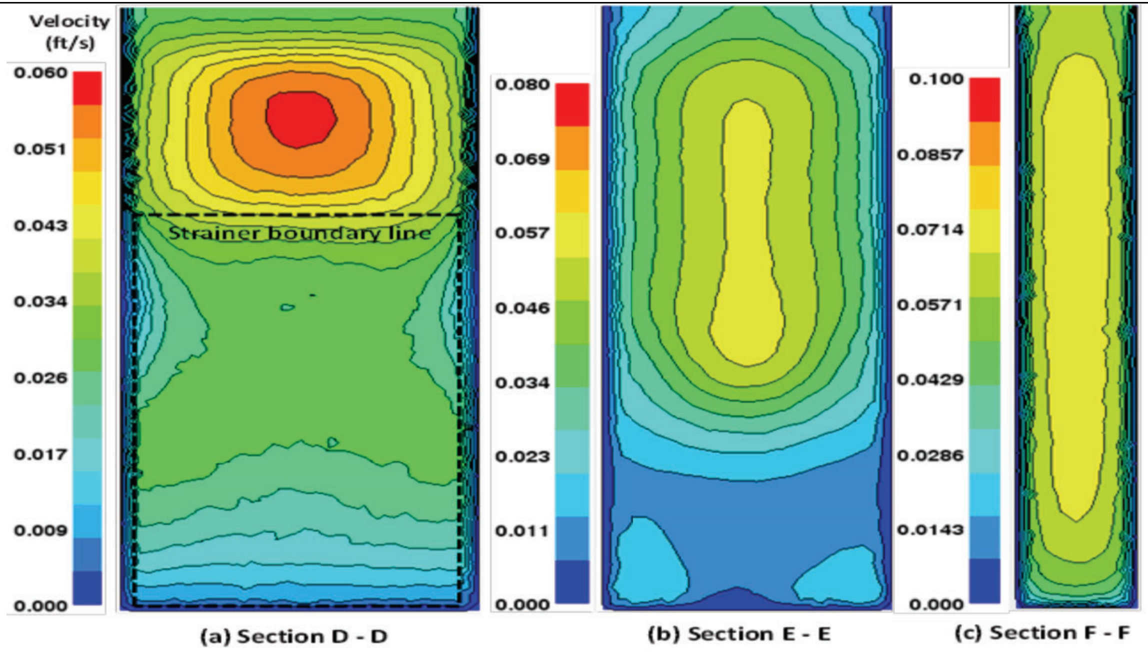

Figure 6. Flow field across the flow direction in FIESTA at different cross sectional areas

4. CONCLUSIONS

UNM has built an experimental flume facility geared towards performing scaled hydrodynamic simulations of various pipe break scenarios and related experimental validation studies for the resolution of GSI-191. The FIESTA facility is designed to be flexible to meet the needs of both the industrial and academic communities, by executing plant-specific validation tests while supporting the missions of performing investigative studies that contribute to the scientific resolution of separate and integral effects related to sump strainer head loss. Initial experiments are designed to investigate realistic transportation of fiber, and chemical and physical debris effects on strainer head loss under specific conditions with an emphasis on low-range chemical loading. Long-term goals of the FIESTA facility include further development of facility systems capable of simulating the early stages of a post-LOCA environment, which are critical in the development of correlations and models focused on providing insight on integrated fiber, debris and chemical systems. Extensive tests that emphasize the development of debris bed filtration mechanisms for industrial scale systems will also be developed to further incorporate data collected in both horizontal and vertical head loss tests.

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