Experimental Challenges and Successes in Measuring Aerosol Concentrations at Prototypic Spray Conditions Encountered at the Hanford Waste Treatment and Immobilization Plant - 13327

JR Bontha, PA Gauglitz, DE Kurath, HE Adkins, CW Enderlin, J Blanchard, RC Daniel, C Song, PP Schonewill, LA Mahoney, WC Buchmiller, G Boeringa, J Jenks

Pacific Northwest National Laboratory, PO Box 999, Richland, Washington 99352, j.r.bontha@pnnl.gov

ABSTRACT

To date, majority of the work done on measuring aerosol releases from failure of process piping was done using simple Newtonian fluids and small engineered-nozzles that do not accurately represent the fluids and breaches postulated during accident analysis at the Hanford Waste Treatment and Immobilization Plant (WTP). In addition, the majority of the work conducted in this area relies on in-spray measurements that neglect the effect of splatter and do not yield any information regarding aerosol generation rates from this additional mechanism. In order to estimate aerosol generation rates as well as reduce the uncertainties in estimating the aerosol release fractions over a broad range of breaches, fluid properties and operating conditions encountered at the WTP, the Pacific Northwest National Laboratory (PNNL) has designed, commissioned, and tested two experimental test stands. The first test stand, referred to as the large-scale test stand, was designed specifically to measure aerosol concentrations and release fractions under prototypic conditions of flow and pressure for a range of breaches postulated in the hazard analysis for 0.076 m (3-inch) process pipes. However, the size of the large-scale test stand, anticipated fluid loss during a breach, experimental risks, and costs associated with hazardous chemical simulant testing limited the large-scale test stand utility to water and a few non-hazardous physical simulants that did not fully span the particle size and rheological properties of the fluids encountered at the WTP. Overcoming these limitations and extending the range of simulants used, required designing and building a smaller test stand, which was installed and operated in a fume hood. This paper presents some of the features of both test stands, the experimental challenges encountered, and successes in measuring aerosol concentration in both test stands over a range of test conditions.

INTRODUCTION

The Hanford Tank Waste Treatment and Immobilization Plant (WTP) being designed and built for the U.S. Department of Energy - Office of River Protection will treat and vitrify highly radioactive components of wastes contained in the 177 underground storage tanks at Richland, Washington. One of the events postulated in the hazard analysis at the WTP is a breach in process piping that produces an aerosol-laden spray with droplet sizes in the respirable range. The postulated breach could result from a number of causes (e.g., jumper connection misalignment, pipe erosion/corrosion, mechanical impact, seal/gasket failures, etc.) and expected to be rough and irregular.

At Hanford, the practice for estimating generation rate and size distribution of aerosol droplets produced in a spray leak has been to use correlations published in the literature. These correlations are based on results obtained from small-engineered spray nozzles using solids-free liquids. However, the fluids processed at WTP include slurries and high-viscosity liquids with properties very different from the properties of the liquids used to develop the correlations currently used to evaluate spray leaks. In addition, the range of geometries postulated for random breaches differs from the geometry of the engineered spray nozzles used to develop the correlation in terms of both aspect ratio and area. Therefore, the correlations used to model spray leaks from process piping may not accurately represent spray leak conditions at the WTP (or elsewhere on the Hanford Site).

The amount of aerosol produced is a function of the dimensions of the opening, which affects both the total amount of flow and the fraction that becomes respirable aerosol. In some predictive correlations for aerosol generation, the respirable fraction is not sensitive to breach dimensions [1]. In other correlations, the respirable fraction increases significantly as the dimensions of the breach decrease [2]. The maximum postulated breach size for WTP spray modeling depends on the pipe size. For pipe diameters up to 3 inches, the maximum opening has a length equal to the pipe diameter and a width equal to one-half of the pipe wall thickness [3]. Some models in use on the Hanford site set a minimum breach dimension based on the gas Weber number (We_g) or on plugging considerations. Arguments have been made, for example, that openings with We_g <60 do not support significant jet breakup and, therefore, do not result in significant aerosol production [4] or that openings with minimum dimension <0.6 mm would be plugged by slurries that contained relatively large particles, as observed with K-Basin slurries [5]. In practice, the plugging assumption may determine a minimum breach size, which can limit the estimated amount of aerosol produced if the correlation used to model aerosol predicts greatly increased respirable droplet production as the breach size decreases.

These consideration discussed above indicate the need for experimental data in two technical areas to improve the WTP methodology [3]. The first technical need was to determine aerosol droplet-size distribution and total droplet-volume from prototypic breaches and fluids, including sprays from large breaches and sprays of slurries where data from the literature are scarce. The second technical need is to quantify the role of slurry particles in small breaches where the slurry particles may plug the hole and prevent high-pressure sprays. PNNL designed, built, and tested two test stands to address these needs. The first test stand, referred to as the large-scale test stand, was designed specifically to measure aerosol concentrations and release fractions under prototypic conditions of flow and pressure for a range of breaches postulated in the hazard analysis for 3 inch process pipes. The size of the large-scale test stand, anticipated fluid loss during a breach, experimental risks, and costs associated with hazardous chemical simulant testing limit its utility to water and a few non-hazardous physical simulants that did not fully span the particle size and rheological properties of the fluids encountered at the WTP. Overcoming these limitations and extend the range of simulants used, required designing and building a smaller test stand that was installed and operated in a fume hood.

This paper presents some of the unique features of both test stands, the experimental challenges encountered, and successes in measuring aerosol concentration in both test stands over a range of test conditions.

LARGE SCALE TEST STAND

There were several challenges faced during the design of the large-scale test stand. These stemmed from the requirement for measuring aerosol concentrations and release fractions under prototypic conditions of flow and pressure for a range of breaches postulated in the hazard analysis for 3-inch process pipes [6]. The process conditions included line pressures varying from 0.7 – 2.6 MPa (100 – 380 psi), line velocities greater than 1.8 m/s (6 ft/s), and breach dimensions varying from holes as small as 0.001 m (1 mm) to slots as large as 0.00274 x 0.076 m (2.74 x 76 mm). The ~4-fold variability in pressure and ~270-fold variability in orifice area present significant challenges in measuring aerosol concentrations as well as measuring the quantities of fluid lost during a breach; both of which were required for estimating the aerosol release fractions. An additional complication was the spatial as well as the temporal variations of the aerosol concentrations resulting from time/distance dependent jet break-up and non-uniform mixing inside the chamber. The system design required considerable flexibility to accommodate the broad range of planned experimental conditions.

Figure 1 shows schematic of the large-scale test system designed and built in Laboratory 184 of PNNL’s Applied Process and Engineering Laboratory (APEL). The system consists of the following major components: 1) flow loop, 2) test chamber, 3) aerosol instrumentation, 4) general instrumentation, and 5) data acquisition systems (DAS). This section presents a detailed description of the flow loop and test chamber. The instrumentation and DAS are presented in the next section.

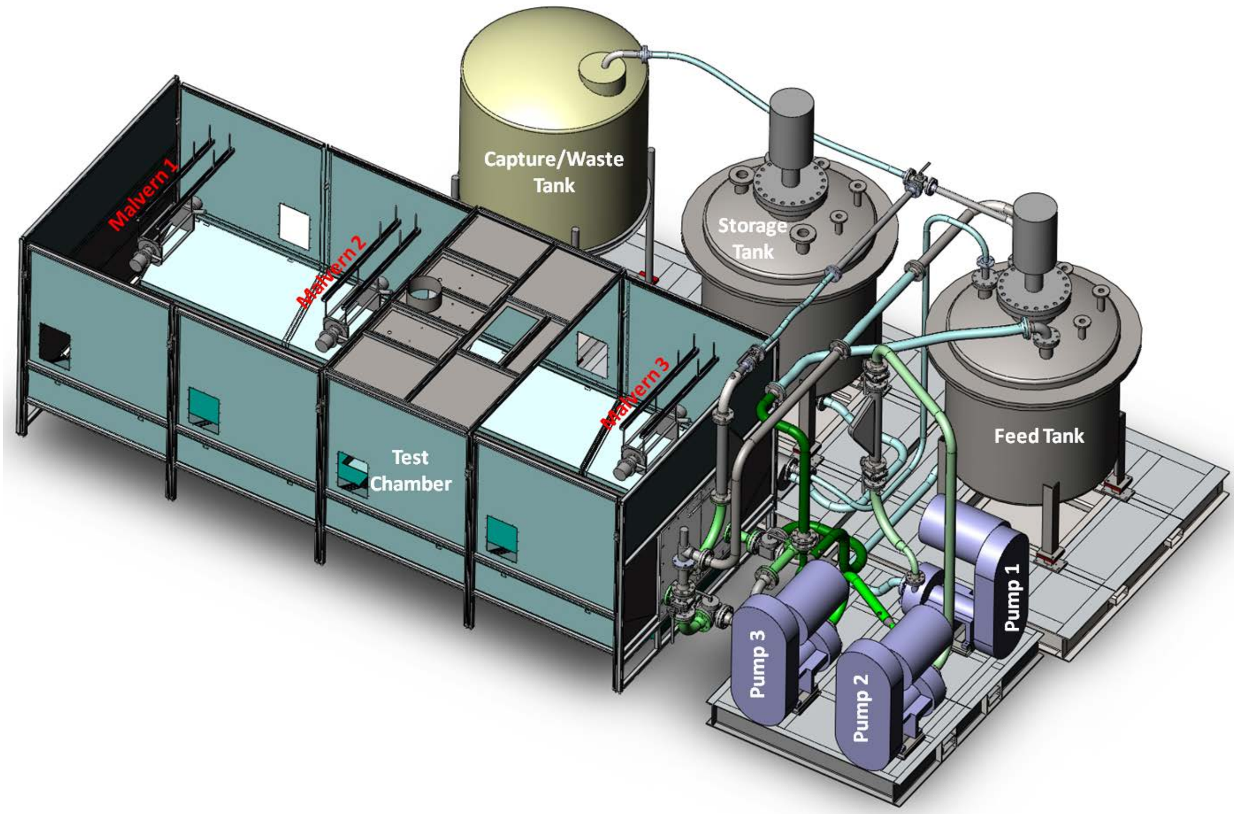

Fig 1. Schematic of the Large-Scale Test Stand

Flow Loop

The flow loop was composed of the primary loop section, which includes the breached pipe, pumps, and ancillary equipment such as simulant feed/storage tanks, transfer pumps, and agitators. The flow loop was designed and built on the four skid-mounted units identified below:

1. Pump skid assembly
2. Feed tank skid assembly
3. Storage skid assembly
4. Capture/waste tank skid assembly.

The loop was designed to produce sprays from prefabricated spool pieces, called "test sections," with prototypic breach sizes varying from the smallest to the largest postulated breach in a 0.076 m (3-inch), schedule-40 pipe. Except for the largest orifice, the loop can maintain fluid velocities at or above 2 m/s (6.5 ft/s) with pressures from 0.7 to 2.7 MPa (100 to 380 psig) during sprays.

All skids were plumbed together with the test section protruding from the pump skid into the test chamber. All sections of the loop, except for the return line, vessel-to-vessel lines, and feed vessel-to-pump transfer lines, were constructed primarily of 0.076 m (3-inch), schedule-40, stainless-steel pipe; this is the same piping used throughout the majority of WTP. The feed tank was plumbed directly to the loop, and a second tank, labeled “Storage Tank” (see Figure 1 for vessel labeling), connected to the feed tank through a transfer pump. The transfer pump provided extra capacity for handling large sprays (~0.01 m^3/sec or 160 GPM loss through the breached section) for up to 5 or 6 min. The transfer pump, which is a Carver centrifugal pump controlled by a Honeywell variable frequency drive (VFD) and an ultrasonic level sensor located in the feed vessel enabled the test operators to maintain the fluid vessel in the feed tank if desired. Fluid exited the bottom of the feed tank via a 0.076 m (3-inch) flexible hose connected to the inlet of the upstream pump on the pump skid.

The flow path continued through the first pump, the upstream Coriolis flow meter, the next two pumps in series, and into either the test section or the bypass leg as controlled by manual 3-way T-port valves. The flow exits the test section and enters the downstream Coriolis flow meter. There are two pressure relief devices included in the loop—the 3.1 MPa (450-psi) rupture disk at the exit of the third pump and the 1.9 MPa (275-psi) pressure relief valve before the downstream flow meter. The rupture disk was installed primarily to prevent over-pressurization of the loop, whereas the PRV was installed to prevent over-pressurization of the downstream Coriolis meter.

After exiting downstream flow meter, the fluid can be diverted either to a waste/capture tank or back to the feed tank (as is the case during testing). This type of flow-loop configuration allows the system to be an open loop to the capture tank or a closed loop flowing back to the feed tank.

In addition to the primary flow system, extension piping was added to the loop for selected test cases to move the test section from one end of the test chamber to either the center or to ~1.1 m (43 inches) from the back wall (or splash wall) of the spray chamber. These extension pieces allowed the test section to protrude 2.0 m (77 inches) and 4.7 m (184 inches) further into the test chamber. This flexibility was used to evaluate the effect of spray distance and distance from the splash wall on the aerosol concentration and PSD.

The desired area-averaged velocity in the loop of >2 m/s (6.5 ft/s) and pressures of up to 2.6 MPa (380 psi) at the test section were achieved using three Krebs millMAX centrifugal pumps connected in series. Each pump consisted of a 50-hp motor, 760 LPM (200-GPM) slurry pumps capable of producing 0.9 MPa (133 psig) with water and handling non-Newtonian fluids with a Bingham rheology (consistency: 6-cP/yield stress:6-Pa) with 50 µm, 2.5 specific gravity particles at a solids loading of 20 wt%. The flow rate through the pumps was controlled using Honeywell VFDs. The VFDs were connected in a master/slave configuration with the downstream pumps frequencies slaved to match the frequency of the upstream or master pump. Pressure in the loop was regulated using two globe valves that are located downstream of the test/bypass sections.

The flow rate through the loop was measured both upstream and downstream of the breach using two Coriolis mass flow meters. The locations where the Coriolis meters were installed provides for sufficient pressure to minimize interference with the meter readings from entrained air/gas. The downstream Coriolis meter is located between two pressure regulating globe valves and downstream of a PRV used to protect the meter from pressures >1.9 MPa (270 psig). The location of the flow meters allowed the spray leak flow rate to be determined from the differences in the flow rates during the tests. In addition to the mass flow rates, the loop also has instrumentation at several locations to measure temperature (via remote temperature detectors) and pressure (via absolute pressure transducers).

The pump skid was plumbed to three supporting tanks, all of which are mounted on load cells, and each tank is contained on a separate skid. The load cells were provided to determine the mass of simulant sprayed during each test and, thereby, determine the spray leak flow rate.

The feed tank was plumbed directly upstream of the pumps and receives the discharge from the recirculation flow from the test loop. As previously described, the feed tank contains a level switch system used to control any makeup flow from the storage tank. The working capacity of the tank is approximately 2300 L (600 gal) and 2-hp mixer connected to a VFD provides agitation to the tank.

The storage tank was plumbed upstream of the feed vessel and supplies makeup fluid to the feed vessel via the transfer pump. The primary purpose of the storage vessel is to keep the net positive suction head of the pumps constant by keeping the hydrostatic head in the feed vessel constant within a few inches. The working capacity of the vessel is approximately 2300 L (600 gal), and a 2-hp mixer connected to a VFD provides agitation to the tank.

The main function of the capture/waste vessel (see Figure 1) is to support slurry capture and loop flush operations. The working capacity of the vessel is approximately 3785 L (1000 gal). Also, this vessel can receive the loop discharge when testing with an open flow-loop configuration (if required). Although the open-loop configuration was never used during actual test runs, it was always used during flush operations when cleaning the loop. When the loop is in the recirculation configuration, non-discharged fluid is recycled back to the feed tank. The initial and final load cell readings from the storage and feed tank are used to calculate the total flow discharged during each test.

The load cells on which the feed, storage, and capture/waste tanks were mounted enable proper accounting of the mass of fluid lost through the orifice during each test. Mechanical agitators and baffles in the feed and storage tanks provide uniform solids concentration in the tanks before and during each test. Also, both the feed and storage tanks were jacketed and connected to a chiller to remove mechanical heat generated during loop operation and maintain a constant temperature during the test. Finally, diffusers were used to decrease the flow velocity of the fluid entering the feed tank. The diffuser consists of flow expansion sections from the top tank inlet to the bottom of the tank.

These expansion sections increase the pipe diameter from 0.05 m to 0.15 m (2 to 6 in). A flat plate was mounted at the end of the diffuser helps to spread the fluid horizontally and minimize vortexing caused by the returning fluid. The diffuser was submerged in the tank to minimize splashing and air entrainment.

Spray Chamber

The test/spray chamber, shown schematically in Figure 1, is the chamber in which aerosols from the test section were contained and characterized to determine the size distribution of aerosol droplets and the total droplet volume concentration as a fraction of the total spray volume.

The spray chamber was designed to meet the following requirements:

- It is adjustable from a minimum size of ~1.2 m (4 ft) wide × 2.4 m (8 ft) high × 1.5 m (5 ft) long (~4.4 m^3 or 160 ft^3 volume) to a maximum size of approximately 2.4 m (8 ft) wide × 2.4m (8 ft) high × 6.1 m (20 ft) long (35 m^3 or 1280 ft^3 volume). The test chamber volume is incrementally adjustable in increments of 1.5 m (5 ft) in length and 0.6 m (2 ft) in width. The dimensions presented above are approximate, as the chamber is not a rectangle. The bottom third of the chamber walls, for instance, are sloped inward towards a collection pan that is 4 ft wide. A vast majority of tests were performed in the ~2.4 m (8 ft) wide × 2.4m (8 ft) high × 6.1 m (20 ft) long chamber, the volume of which was 27.48 m^3 (970.3 ft^3) after accounting for the slope in chamber walls, smaller collection pan, and the internals. Although the tests were generally conducted with the largest available chamber size, the ability to reconfigure the size was provided to accommodate low aerosol concentrations.
- It is made of materials (primarily stainless-steel sheets) that have minimal affinity for attracting or interacting with aerosols (e.g., developing high static charges) generated during the testing.
- Non-aerosolized liquid is directed to a collection vessel.
- It is accessible for mounting aerosol characterization instruments.
- It has viewing ports for visually observing and video/still camera recording of the discharging spray.
- The enclosed volume is easily calculated.
- It is easily cleaned of simulant materials when not in use.
- It has an exhaust system for clearing/evacuating aerosols between tests.

Throughout testing, the fluid volume that collected at the bottom of the chamber was minimized via sump pump transfer from the chamber to a tank vessel or drain. The windows were covered during testing to preclude any potential light interference with the aerosol measuring instruments. In the absence of sprays, the back panel (wall) was removed to allow operators to enter the chamber if maintenance or configuration activities were being performed.

The test section is a spool piece that has breaches (i.e., circular holes and slots) through which the fluid is discharged to create the spray leak for characterization (i.e., release fraction and PSD). For the testing discussed in this section, a broad range of circular holes (ranging from 1 to ~4.5 mm) and slots (ranging from 0.5 mm × 5 mm to 2.74 mm × 76.2 mm) were tested to establish the release fraction and PSD for the largest anticipated breach in a 0.076 m (3-inch) pipe at the WTP.

To facilitate spray initiation and cessation for each test, individual orifices were sealed with a specially designed release assembly that allowed the orifice to be opened when the desired conditions in the loop were met. The release assembly consisted of an over-center lever positioned at each orifice. Each lever was opened using a manual pull-rod from outside the test chamber.

At the start of testing, there was significant concern regarding the uniformity of the aerosol concentration throughout the chamber, particularly when the full 6.1 m (20-ft) length of the chamber was used. To create a more homogenous aerosol concentration within the chamber, multiple fan configurations were considered. These included 1) two open fans at approximately the center of the first 3 m (10-ft) section and ~0.3 m (1-ft) below the spray header and 2) four "shrouded" Detmar fans located at approximately the center of the 20-ft chamber and just above the collection pan of the chamber. A series of tests were conducted using a 2-mm hole to identify the fans and fan settings that gave the best mixing and repeatable measurements of the aerosol concentrations within the chamber. The results indicated that only the center two shrouded Detmar fans shown in the "Fan Array" were required to achieve adequate mixing. These 4-inch fans were installed with flexible ducting that moved the inlet closer to the bottom of the chamber and spray header to preclude any influence on the jet.

SMALL-SCALE TEST STAND

The size of the large-scale test stand, anticipated fluid loss during a breach, experimental risks, and costs associated with hazardous chemical simulant testing limit its utility to water and a few non-hazardous physical simulants that did not fully span the particle size and rheological properties of the fluids encountered at the WTP. Overcoming these limitations and extend the range of simulants used, required designing and building the small-scale test stand that was installed and operated in a fume hood [7]. To facilitate comparison of the experimental data between large and small-scale test stands key hydrodynamic parameters of pressure and flow need to be similar between the two test stands. The size limitations of the small-scale system, driven by the need to fit the system in a walk-in hood, limited the diameter of the piping to 0.025 m (1-inch). Therefore, hydrodynamic similarity, particularly with respect to the fluid flow, was maintained by keeping the wall shear similar to the prototypic conditions maintained in the large-scale test stand. In addition, the smaller diameter tubing limits the flow rates to < 37.85 LPM (10 GPM) in the flow loop. This coupled with the size of the feed vessel, limited the size of the breaches that tested in the small-scale test stand to orifices of area $\leq$0.5E-4 m^2.

Flow Loop

The small-scale flow loop was located in the walk-in hood in Applied Process Engineering Laboratory (APEL) at PNNL, and is shown in Figure 2.

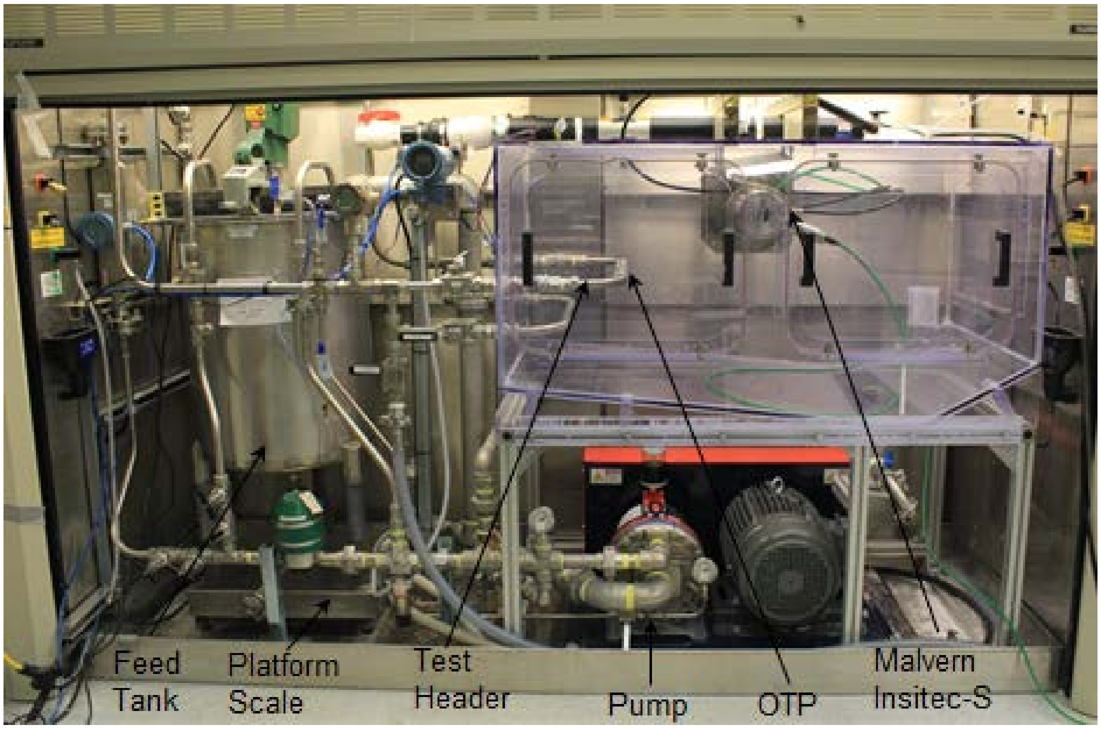

Fig 2. Small-Scale Test Loop

Each simulant and liquid solution used in the test was prepared in a secondary tank and transferred into the system feed tank using a portable diaphragm pump. Simulant was circulated from the feed tank through the pump, into the horizontal test header, and then back to the feed tank. Flow rate was measured upstream of the test header with a MicroMotion Coriolis flow meter. The target flow rate of 38 LPM (10 GPM), and pressures of up to 2.6 MPa (380 psi) were achieved using a Hydra-Cell D/G-35-X diaphragm feed pump controlled by a Honeywell variable frequency drive (VFD). The feed tank was mixed at all times, using a Lightnin Model X5P25 0.25-HP clamp mount mixer for most of the tests. For simulants with high yield strengths and/or viscosities, a Lightnin Model X5P100 1-HP mixer with two impellers was used.

Swappable orifice test pieces (OTP) were positioned in an interchangeable portion of the test header within the aerosol test enclosure. The wall thickness of each OTP was equivalent to that in a 3-inch, schedule-40, stainless steel pipe, thus providing a leak-path length equal to the large-scale breaches and much of the piping used in the WTP. The inner surface of each OTP was flush with the inner wall of the 300-Series, stainless-steel tubing.

The small-scale test system included a bypass header and a pump purge line, both equipped with isolation valves. For all but the largest orifice slot sizes, the bypass header allowed the simulant to be recirculated while the system was adjusted to the target flow rate and pressure. The largest orifices required pressure and flow to be set while spraying. The purge line, located below the pump suction line (and connected to the pump housing), provided an additional recirculation flow path back to the feed tank, and could be used to either bypass the test loop altogether or to allow the majority of fluid to recirculate after the target test flow rate and pressure had been set. In many of the aerosol tests, the flow rate and pressure were set, and the purge line isolation valve then was opened while other pre-spray tasks were completed. The resulting unrestricted flow and lower line pressure (~0.3 MPa or 50 psi versus a target test pressure of 2.6 MPa or 380 psi) became critical during simulant testing to minimize overheating of the simulant.

Upon initiating a spray, the bypass header and pump purge valves were closed. Manually controlled flow control valves were used to maintain the designated target pressure in the test header. A mixing fan installed under the bypass header was employed to improve mixing and provide a more homogeneous aerosol concentration in the aerosol test enclosure. The fan setting that provided adequate aerosol mixing within the enclosure was determined to be 6 V.

The test header was constructed using Swagelok tubing with a nominal outer diameter of 1.0 in. and a nominal wall thickness of 1.6E-03 m (0.065 in). The fluid velocity at the target flow rate of 38LPM (10 GPM) was 1.6 m/s (5.4 ft/s). The velocity was calculated using the nominal outer diameter of 1-inch tubing with a wall thickness of 1.6E-3 m (0.065 in). A flow rate of approximately 38 LPM (10 GPM) through the test header was calculated to provide the same wall shear stress (within about 10 percent) as would exist in 0.076 m (3-inch) schedule-40 pipes with a flow velocity of 2 m/s (6.5 ft/s). This flow velocity and pipe size are typical of the smaller lines in the WTP equipment, and were used in the test header for the large-scale tests; therefore, the approximate matching of wall shear stress provided consistent conditions for the orifice entry point between the two test stands. The simulants for which the matched-shear-stress criterion was approximately met were Newtonian simulants and non-Newtonian simulants with Bingham yield stresses of $\leq$6 Pa and Bingham consistencies of $\leq$6 mPa·s.

For the majority of the aerosol tests, a feed volume of 150 L (40 gal) or less was adequate and recycling simulant from the aerosol test enclosure back into the feed tank was not necessary. However, in some cases it was necessary to transfer simulant, while spraying, back into the feed vessel using a diaphragm transfer pump.

INSTRUMENTATION AND DATA ACQUISITION

Several instruments were used to collect process data as well as the aerosol concentration/size distribution data in the large- and small-scale test stands. These are discussed below.

Aerosol Instrumentation

The large- and small-scale spray leak test stands employed two instruments for measuring aerosol concentration and size distribution: a Malvern Insitec-S open-frame process aerosol analyzer (Malvern Instruments, Ltd.) and a Process Metrix PPC (Process Metrix).[1] Both instruments operate on the principle of laser diffraction, and both systems have proprietary DASs that convert the measured signals into aerosol concentration and size. The rationale for using multiple aerosol concentration and PSD measuring sensors was based on the uncertainties associated with 1) the anticipated aerosol concentrations for the range of orifices that would be used in the test chamber and 2) use of the full size of the test chamber to assess aerosol generated through jet breakup and/or splash mechanisms. Shakedown testing indicated that the Insitec-S was best suited to be the primary aerosol-measuring instrument. However, PPC data was collected throughout the entire large-scale testing to provide validation of the Insitec-S data with small breaches as well as a redundant measurement technique for aerosols that were <70 µm in size. It should also be noted that because of the larger size of the large-scale test stand, three Insitec-S units were used in the large-scale test stand whereas only one was used in the small-scale test stand.

General Instrumentation

Tables 1 and 2 list the broad suite of general instruments used to collect process data in the large- and small-scale test stand.

TABLE 1. Instrumentation used for Process Parameter Measurements in Large-Scale Test Stand

Measurement	Relative Test Location	Manufacturer	Range
Weight	Storage Tank (TK-1)	Hardy Instruments	0 ~ 7000 kg
	Feed Tank (TK-2		0 ~ 7000 kg
	Capture/Waste Tank (TK-3)		0 ~

[1] In the small-scale system, PPC data was collected only during initial system shakedown and validation runs. PPC data was collected during a majority of the large-scale tests.

Measurement	Relative Test Location	Manufacturer	Range
			3500 kg
Pressure	Bypass Leg (Absolute) (PS6) Test Section (Absolute) (PS4) Test Section (Backup) (PS5) Feed Pump 1 (PS-1) Feed Pump 2 (PS-2) Feed Pump 3 (PS-3) Flow Meter 2 (PS-6 and PS-7) Globe Valve 2 (PS-8)	Omega	0 ~ 35 atm
Humidity	Test Chamber (RH-1) Test Chamber (RH-2) Ambient (RH-3)	Omega	0 – 100% RH
Temperature	Test Chamber (TS-5) Ambient (TS-6) Storage Tank (TS-1) Feed Tank (TS-2) Capture/Waste Tank (TS-4) Test Section (TS-3)	Omega	0 – 100℃
Flow Rate	Down Steam of Pump 1 (FE-1) Down Stream of Primary Pres. Reg. Valve (FE-2)	MicroMotion	0 – 1150 LPM
Density	Down Steam of Pump 1 (FE-1) Down Stream of Primary Pres. Reg. Valve (FE-2)	MicroMotion	1 – 1300 kg/m^3

TABLE 1. Instrumentation used for Process Parameter Measurements in Small-Scale Test Stand

Instrument Name	Measurement	Range
Micro Motion Coriolis mass flow sensor	Flow rate in test header	1 – 0.14 LPM
Honeywell pressure transmitter	Pressure in test header upstream of the OTP	0 ~ 35 atm
Honeywell pressure transmitter	Pressure in test header downstream of the OTP	0 ~ 35 atm
Thermocouple (Type T)	Temperature upstream of test header	0 ~ 50°C
Thermocouple (Type T)	Feed tank temperature	0 ~ 50°C
Feed tank platform scale	Mass in the feed tank	0 ~ 240 kg

Data Acquisition Systems (DAS)

In the large-scale test stand, data from the general instruments was collected using a Programmable Logic Controller (PLC) based DAS that captured the raw data from the various devices that measure pressure, temperature, humidity, mass, and density, and logged the measurements into a file in 0.1-s (10-Hz) intervals. On the other hand, the small-scale test stand utilized a calibrated Omega Data Logger, connected to a PC, to collect temperature data and raw voltages that were converted, using the instrument calibration data, into the appropriate units for the measured data. The Malvern Insitec-S and the PPC aerosol concentration and PSD measuring devices come with their own commercial off-the-shelf software/DAS.

TEST CONDITIONS

The small and large-scale test stands discussed above were used to determine the aerosol concentration and size distribution for a broad set of breaches under a range of operating pressures using simulants representing different WTP process fluids. Tables 3 and 4 represent the range of aerosol test parameters and simulants tested, respectively.

TABLE 3. Target Ranges of Aerosol Test Parameters

Parameter	Parameter Range	Comments
Pressure	0.7, 1.4, 2.6 MPa (or 100, 200, 380 psig)	1.4 (200 psig) and 2.6 MPa (380 psig) are the highest pressures postulated during important accident scenarios at the WTP. The acceptable range was ±10% of the target set point.
Circular breach diameter	Small-Scale: 0.3 - 2.0 mm Large-Scale: 1 – 4.46 mm	A breach size of 0.3 mm was the smallest orifice size that

		never plugged during the plugging tests [7]
Rectangular breach size range (length range × width range)	Small-Scale: 5 × 0.3–1; 5–20 × 0. 5 (mm x mm) Large-Scale: 0.5 x 1 – 2.74 x 76 (mm x mm)	Rectangular breaches independently varied by width and length.

TABLE 4. Target Simulants and the WTP Process Stream Categories

Simulant Class	Material	Target Property Range	WTP Process Stream Categories
Baseline	Water	Viscosity of ~1 mPa·s (~1 cP) density 1000 kg/m^3 surface tension ~73 mN/m	Ultrafilter Permeate/ Treated Low Activity Waste (LAW)
Range of Newtonian Viscosity	Solutions of water and non-hazardous salts (sodium nitrate and sodium thiosulfate)[(a)]	Viscosities of ~1.5, ~2.5 mPa·s (1.5, 2.5 cP)	Cs Ion Exchange Eluate Recycle Streams
Range of Slurries (non-hazardous)	Gibbsite and Boehmite particulates in water [(b,c)]	The PSDs of the slurries were selected to match Hanford waste PSDs (average waste feed and representatively small PSDs, because smaller PSDs are least likely to plug breaches). 8 and 20 wt% solids	Newtonian Slurries Non-Newtonian Slurries
Washed and Leached Chemical Slurry Simulant	A washed and leached version of the simulant used in Pretreatment Engineering Platform (PEP) testing [8][(d)]	Solids loading was adjusted to meet target Bingham yield stresses of 6 and 30 Pa	Non-Newtonian Slurries

Simulant Class	Material	Target Property Range	WTP Process Stream Categories

(a). Large scale testing was done with only sodium thiosulfate solutions in water
(b). Large scale testing was done with only the 8 & 20 wt% Gibbsite/Boehmite slurries representing small-treated Hanford waste streams [7]
(c). Small scale testing was done with only the 8 & 20 wt% Gibbsite/Boehmite slurries representing small as-received, regular as-received, large as-received, and small-treated Hanford waste streams [8]
(d). Tested in the small-scale test stand [8]

RESULTS

An example demonstrating the operability of the test stands is shown in Figure 3 for a 2 mm orifice at a target pressure of 2.6 MPa (380 psi). Here pressure and temperature vs. time are plotted. It can be seen from the data in Figure 3 that during the entire duration of the test, the pressure variation was ± 0.02 MPa (3 psi) and the temperature increase was about 4 °C. The noise in the pressure data is typical; some tests had decreases in pressure that were slightly larger than in the case that is shown.

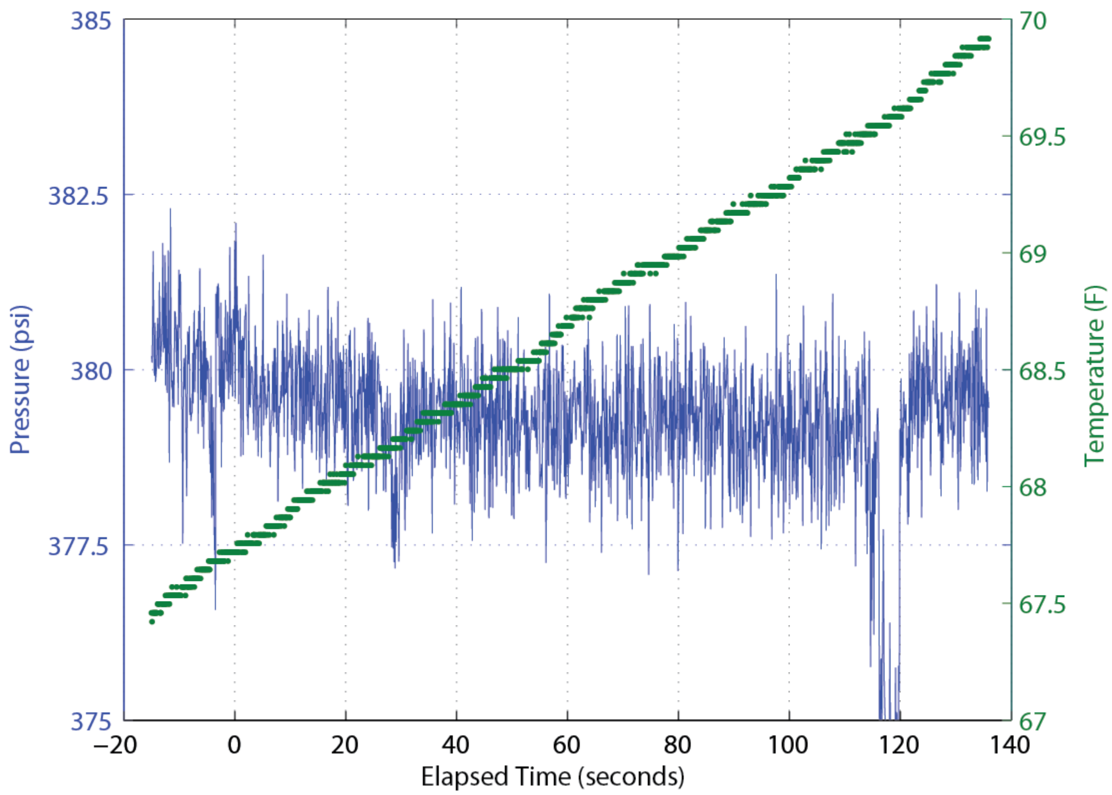

Fig 3. Pressure and Temperature Data for a 2-mm orifice at 2.6 MPa (or 380 psi) in water. An elapsed time of zero is approximately when the spray was initiated.

Figure 4 shows a comparison of the transient cumulative droplet concentration in the small and large test chambers for 2.6 MPa (380-psi) water sprays from a 1-mm circular orifice. As expected, the concentrations are higher in the small-scale chamber. For the small-scale chamber, the rate of concentration increase, or the slope of the droplet concentration with time, also is much higher. This is a thirtyfold slower rate of concentration increase in the large-scale chamber, which is approximately equal to the fortyfold difference in the large- and small-scale chamber volumes [7].

CONCLUSION

This paper presents the details and results of two test stands designed and built at PNNL for measuring aerosol concentrations from an accidental spray leak. The test stands represent a one-of-the-kind capability that was used to measure aerosol generation from breaches as small as 300 µm to as large as 2.7 mm x 76 mm using a variety of Newtonian and non-Newtonian fluids ranging in viscosities from 1 cP to 2.5 cP, yield stresses of up to 30 Pa, and fluid pressures up to 2.6 MPa (380 PSI).

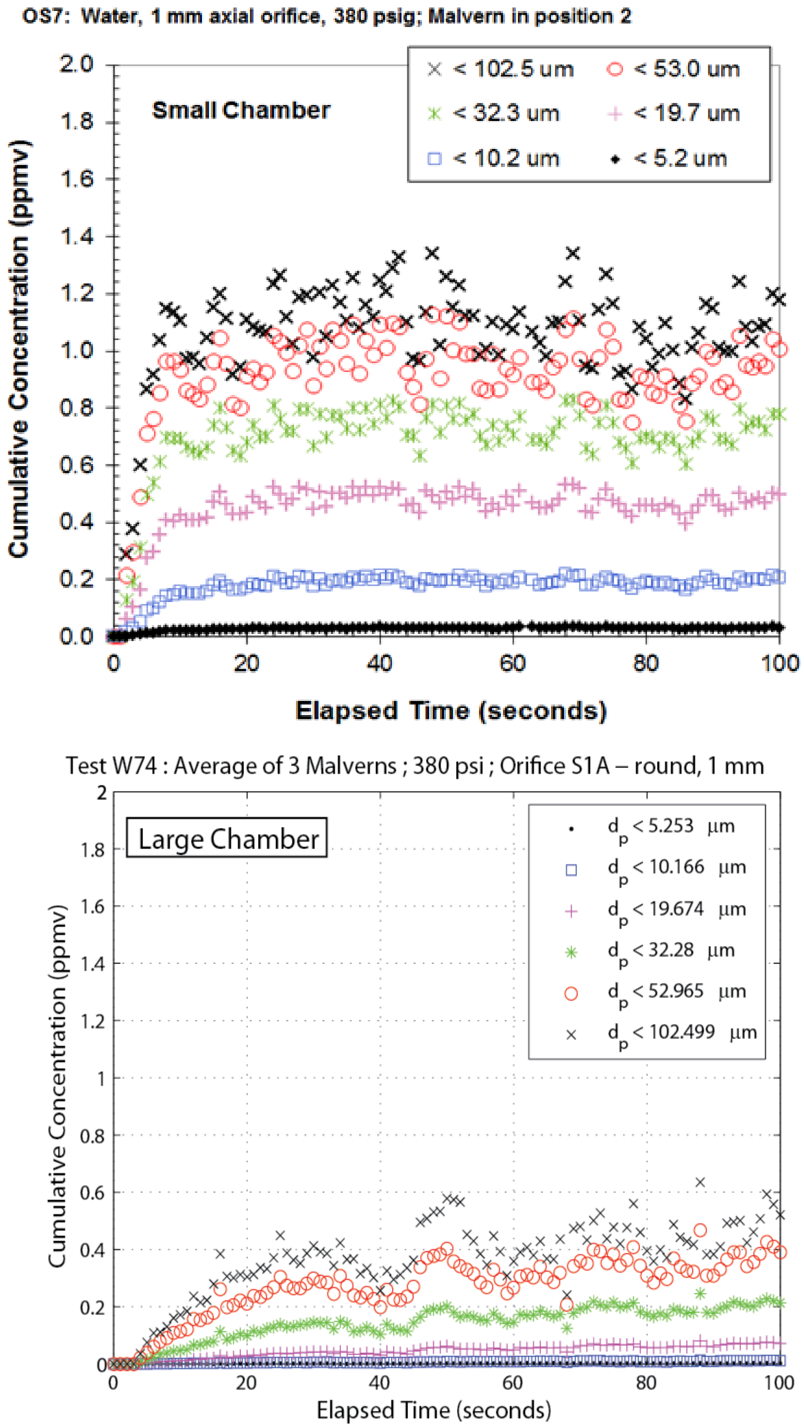

Fig 4. Comparison of the Transient Cumulative Droplet Concentrations in the Small and Large Chambers for 2.6 MPa (380-psi) Water Sprays from 1-mm Circular Orifices

REFERENCES

1. Epstein M and MG Plys. 2006. *Measured Drop Size Distributions with Cold Sprays Emanating from Small Leak Openings.* FAI/06-55, Fauske & Associates, LLC., Burr Ridge, Illinois.

2. Hey BE and DS Leach. 1994. *A Model for Predicting Respirable Releases from Pressurized Leaks*. WHC-SD-GN-SWD-20007, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

3. Larson AR and BT Allen. 2010. *WTP Methodology for Spray Leak Scenarios*. 24590-WTP-RPT-ENS-10-001, Rev. 1, River Protection Project, Waste Treatment Plant, Richland, Washington.

4. Zimmerman BD. 2003. *Waste Transfer Leaks Technical Basis Document.* RPP-13750, Rev. 0, CH2MHILL Hanford Group, Inc., Richland, Washington.

5. Crowe RD. 2010. *Sludge Treatment Project (STP) Methodology for Spray Leak Scenarios.* PRC-STP-00292, Rev 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

6. Schonewill PP, PA Gauglitz, JR Bontha, RD Daniel, JJ Jenks, DE Kurath, JM Billing, HE Adkins, Jr, CW Enderlin, CA Burns, C Fischer, CD Lukins, JL Shutthanandam, and DM Smith. 2012. *Large-Scale Spray Releases: Aerosol Test Results*. WTP-RPT-217 Rev 0 (to be published), Pacific Northwest National Laboratory, Richland, Washington.

7. Mahoney LA, PA Gauglitz, ML Kimura, GN Brown, DE Kurath, J Blanchard, C Song, RC Daniel, BE Wells, and D Tran. 2012b. *Small-Scale Spray Releases: Aerosol Test Results*. WTP-RPP-216,

8. Kurath DE, BD Hanson, MJ Minette, DL Baldwin, BM Rapko, LA Mahoney, PP Schonewill, RC Daniel, PW Eslinger, JL Huckaby, JM Billing, PS Sundar, GB Josephson, JJ Toth, ST Yokuda, EBK Baer, SM Barnes, EC Golovich, SD Rassat, CF Brown, JGH Geeting, GJ Sevigny, AJ Casella, JR Bontha, RL Aaberg, PM Aker, CE Guzman-Leong, ML Kimura, SK Sundaram, RP Pires, BE Wells, and OP Bredt. 2009. *Pretreatment Engineering Platform Phase I Final Test Report*. PNNL-18894, WTP-RPT-197, Pacific Northwest National Laboratory, Richland, Washington.