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by

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# DEMONSTRATION OF A STEAM JET SCRUBBER OFF-GAS SYSTEM AND THE BURNER EFFICIENCY OF A MIXED WASTE INCINERATOR FACILITY

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## ABSTRACT

A full-scale incinerator system, the Consolidated Incineration Facility (CIF), is being designed to process solid and liquid low-level radioactive, mixed, and RCRA hazardous waste. This facility will consist of a rotary kiln, secondary combustion chamber (SCC), and a wet off-gas system. A prototype steam jet scrubber off-gas system has been tested to verify design assumptions for the CIF. The scrubber wastewater will be immobilized in a cement matrix after the blowdown has been concentrated to a maximum solids concentration in a cross-flow filtration system. A sintered metal inertial filter system has been successfully tested. Burner efficiency was tested in a high intensity vortex burner, which destroyed the hazardous waste streams tested.

## Process

Figure 1 is a process flowsheet of the CIF. Solids will be fed to the rotary kiln primary chamber using a ram feed system, and liquids will be introduced into the kiln through a burner nozzle. High Btu liquid wastes will be introduced in the SCC through a high intensity vortex burner.[1]

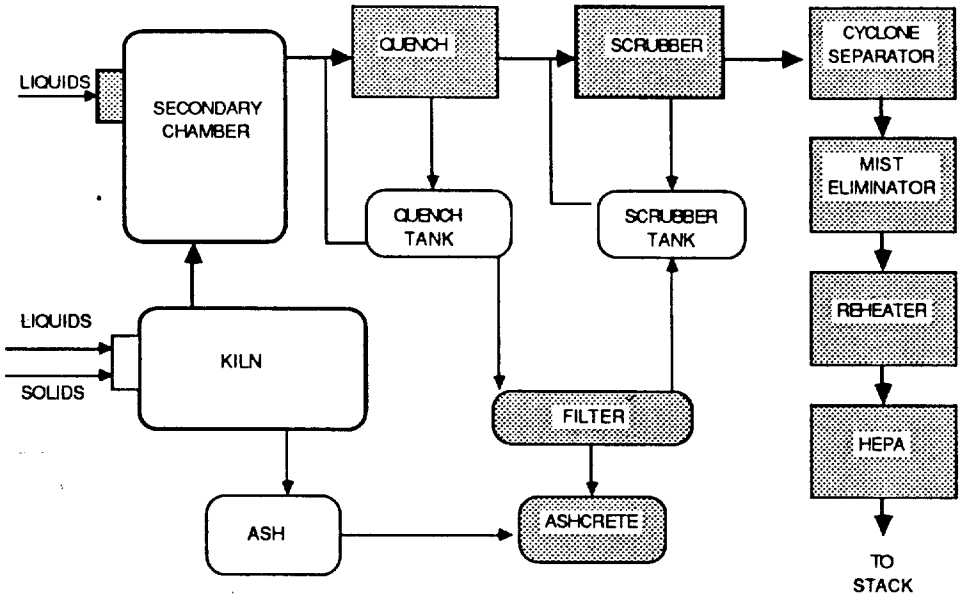


Figure 1. Consolidation Incineration Facility Flowsheet

Off-gas leaving the secondary combustion chamber enters the steam-jet scrubber off-gas system. The off-gas is cooled adiabatically to the saturation temperature in the quench vessel. Circulating scrubber solution supplemented with process makeup water is used as the quench liquid. The quenched gas enters a steam-atomized, free-jet scrubber that removes particulates and neutralizes acid gases with the injection of caustic solution. The scrubbed off-gas, after having liquid and ash particulates removed by centrifugal force in the cyclone separator, then flows through a high efficiency mist eliminator (HEME), which removes residual moisture. A reheater is provided ahead of the high efficiency particulate air filters (HEPA) to prevent condensation in the HEPA filters.

The scrubber wastewater passes through a cross-flow filtration system to concentrate the solids to 10 wt %. The filtrate will be recirculated to the quench/scrubber, and the concentrated scrubber blowdown will be solidified in a cement matrix.

## Testing

A prototype scrubber off-gas system that is approximately 1/50 scale of the specified processing equipment of the CIF has been tested using a full-scale rotary kiln as the off-gas generator. Efficiency curves for the scrubber and mist eliminator were derived from the collected data.

The cross-flow filtration system concentrated the scrubber liquor above 10 wt % solids. Two filtration tests were completed using sintered metal units at ratings of both 0.5 and 2.0 microns.

The high intensity vortex burner tested delivered a maximum heat output of 3 million Btu/hr. Five fuel and waste combinations were injected through a burner gun nozzle, while steam or air was injected through a concentric annulus around the central nozzle to atomize the waste. Combustion air was blown tangentially into the burner windbox to initiate the vortex action of the burner.

## Off-Gas System Tests

The collection removal efficiencies of the scrubber-cyclone and mist eliminator of the prototype off-gas unit were determined using a rotary kiln to generate the off-gas.[2] The efficiencies were based on particle concentration and chloride removal capacities. Off-gas testing was performed during the incineration of simulated contaminated soil, PVC, cellulose, and a design mixture.

1. Particle Size Distribution: Particle size distribution samples were collected while the kiln was burning the design mix consisting of 44% cellulose, 9% PVC, 26% polyethylene, and 21% latex. Five particle size distribution samples were collected: one sample at the scrubber inlet, and two samples at the outlet of the scrubber and the outlet of the HEME. A comparison of the average scrubber inlet, scrubber outlet, and HEME outlet particle size distributions is presented graphically in Figure 2.

As particles in the gas stream travel through the off-gas unit, the scrubber and HEME each remove a percentage of these particles. The net effect of removing these particles is that the concentration decreases even though the diameter increases as they pass through successive control devices. At the scrubber inlet, 60% of the particles have a diameter greater than 0.4 micron; at the scrubber outlet, 88% of the particles have a greater diameter; at the HEME outlet, 92% of the particles have a greater diameter than 0.4 micron. The increase in the percentage of larger particulates is atypical of what normally occurs in an off-gas process.

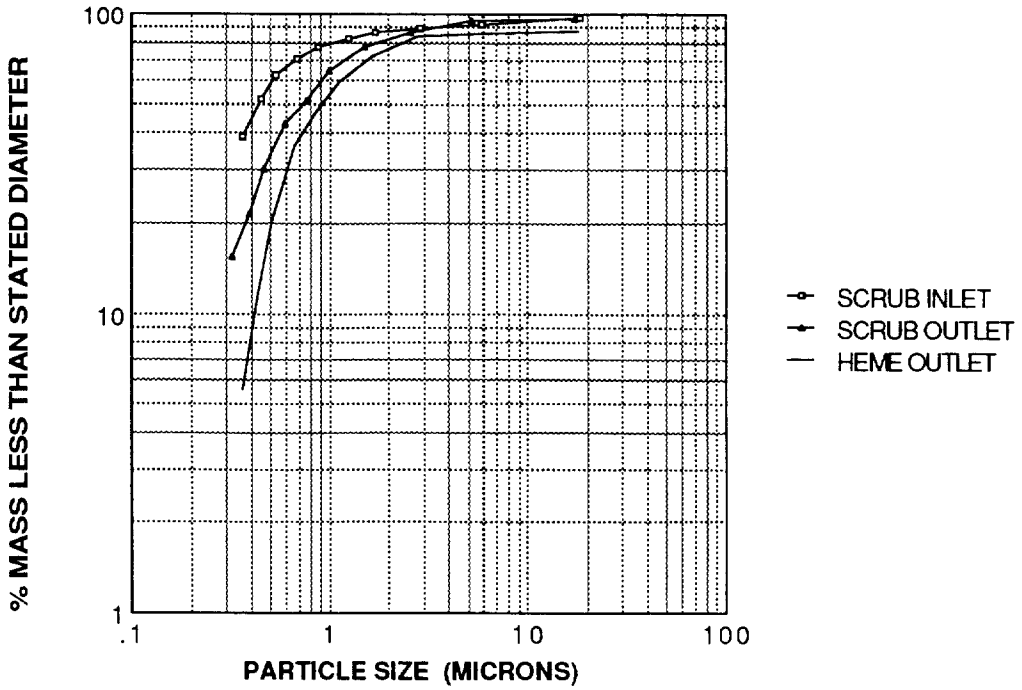


Figure 2. Comparison of Size Distributions

These phenomena are a result of a larger percentage of smaller particulates entering the control equipment (Figure 3) coupled with the higher collection efficiencies for smaller particulates for both the steam jet scrubber and HEME (Figure 4).

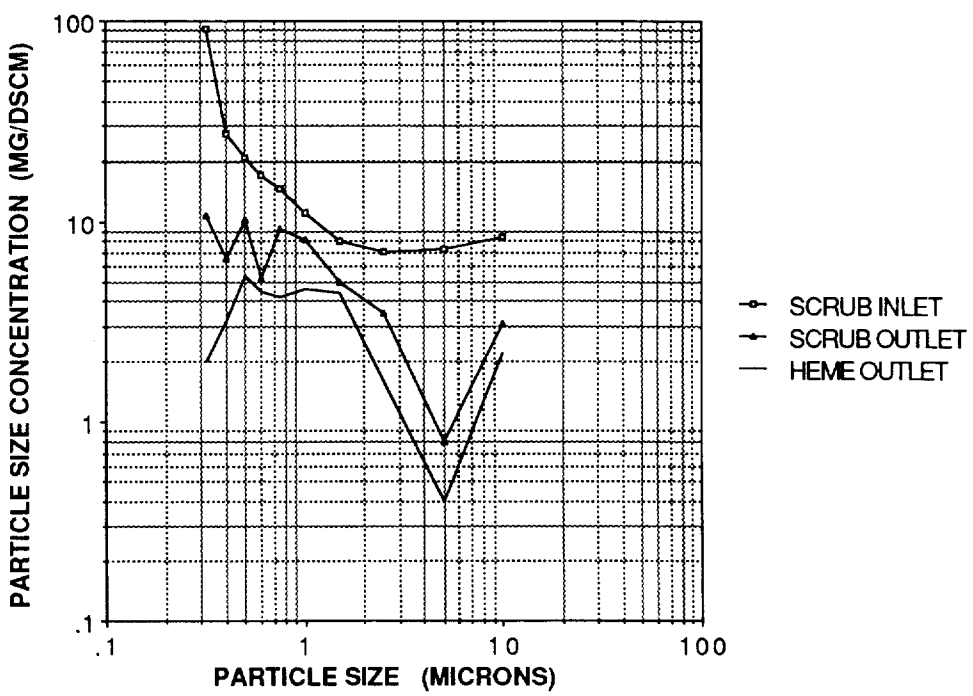


Figure 3. Comparison of Particle Concentrations

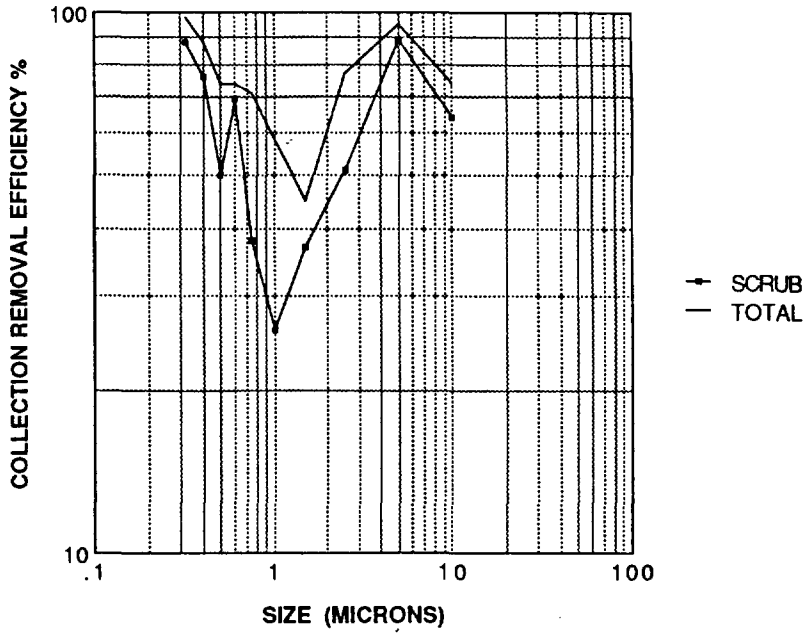


Figure 4. Scrubber and Mist Eliminator Efficiency

The collection removal efficiency curves in Figure 4 indicate the equipment is least efficient in removing particulates in the 0.5- to 1.5-micron range. The curves indicate that increasing removal efficiencies were obtained as the particle size decreased below 1.0 micron due to Brownian diffusion. The smaller the particulate, the more intense their Brownian motion and the easier their collection by diffusion forces.

In Figure 5 the Brownian displacement relative to the particle diameter is illustrated.[3] The larger particulates greater than 1.5 microns are collected principally by impaction and removal efficiency increases as the size does. The minimum in the efficiency curves occurs in the transition range between removal by Brownian motion and removal by impaction.

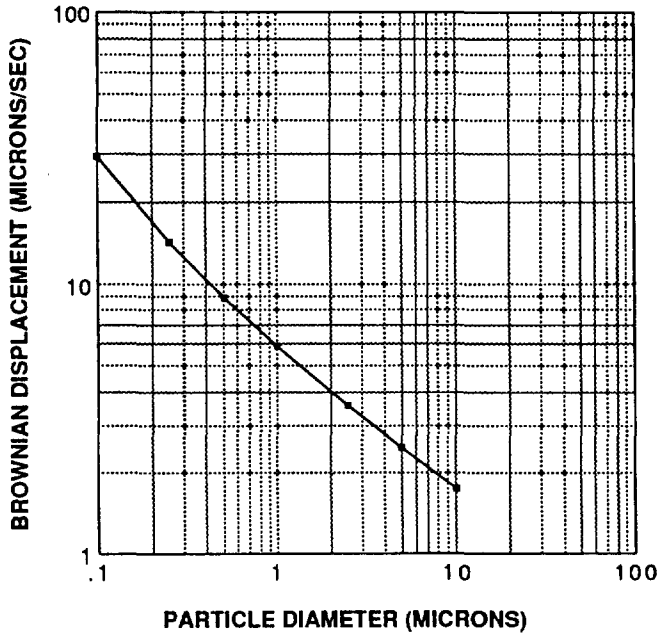


Figure 5. Brownian Movement of Particles

Overall, the scrubber-HEME collection efficiencies were low due to operation below the rated performance of the unit; literature data indicate that average efficiencies exceed 99%.[4] During the demonstration test, the steam jet scrubber was operated with a single steam/off-gas flow ratio of 0.2 resulting in an average emission at the scrubber outlet for all four waste types of 0.013 grain/dscf. As shown in Figure 6, further increase of energy input would have resulted in higher collection efficiencies.

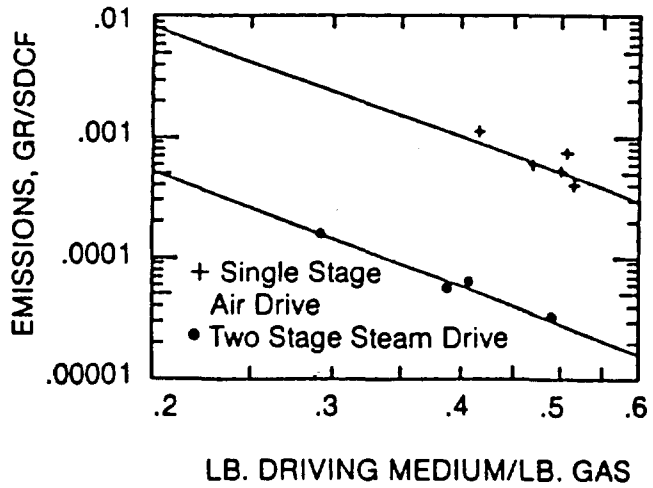


Figure 6. Steam/Air Ejector

2. Chloride Removal: The acid gas removal capability of the steam jet scrubber system was evaluated by measuring the chloride concentration at the inlet and outlet of the scrubber. Table 1 presents the results from the off-gas analyses.[2] The increase in the chloride concentration through the processing equipment in runs 5 and 7 was due to contamination from re-entrainment.

**Table 1. Chloride Off-Gas Test Results**

| Material | Run | Scrubber Inlet (mg/dscm) | Scrubber Outlet (mg/dscm) | HEME Outlet (mg/dscm) |
|---|---|---|---|---|
| Soil | 1 | 2.8 | 0.4 | |
| | 2 | 0.6 | 0.1 | |
| | 3 | 31.5 | <0.2 | |
| PVC | 4 | 46.8 | 0.9 | |
| | 5 | 0.6 | 0.9 | |
| Cellulose | 6 | <0.2 | <0.2 | |
| | 7 | <0.1 | 0.3 | 0.3 |
| Design Mix | 8 | 0.6 | <0.2 | 0.2 |

## Cross-Flow Filtration Tests

An inertial cross-flow filtration system will be used to concentrate the scrubber wastewater to 10 wt % total suspended solids (TSS) to minimize the volume of wastewater blowdown. A

filtration system was demonstrated using simulated wastewater made from nonradioactive flyash. The filter system tested consisted of two, 60-in.-long modules in series with an inner diameter of 1/2 in. Two separate tests were conducted on filters with ratings of 0.5 and 2.0 microns. The objectives of the tests were to demonstrate the ability of the filtration system to concentrate wastewater to a maximum solids concentration and to evaluate the effect that backwashing has on recovering the flux.

A 1% simulated solids slurry was concentrated in stages up to 12 and 18% using both 0.5- and a 2.0-micron stainless steel sintered metal filters, respectively. Table 2 compares the results from both of the filter media.

**Table 2. Filtration Test Results**

| | 0.5-Micron | 2.0-Micron |
|---|---|---|
| Filtrate Flow (gal/day) | 280 | 560 |
| Transmembrane Pressure (psig) | 45 | 8 |
| Maximum TSS | <10 | <18 |
| Filtrate Quality (ppm) | <1 | 1 - 10 |

The 2.0-micron media could maintain higher flux rates at lower differential transmembrane pressures than the 0.5-micron filter media. Turbidity was slightly higher in the 2.0-micron media as a result of the tradeoff in achieving the higher flux. However, the lower differential pressures resulted in the filter's ability to concentrate well above 10% TSS.

Testing indicated that flux rates increase linearly with transmembrane pressure to a maximum point, known as the optimum pressure, after which the flux rates begin to decline (Figure 7). The decreasing flow rates are indicative of the decreasing permeability of the dynamic solids layer as it builds up against the membrane during filtration.

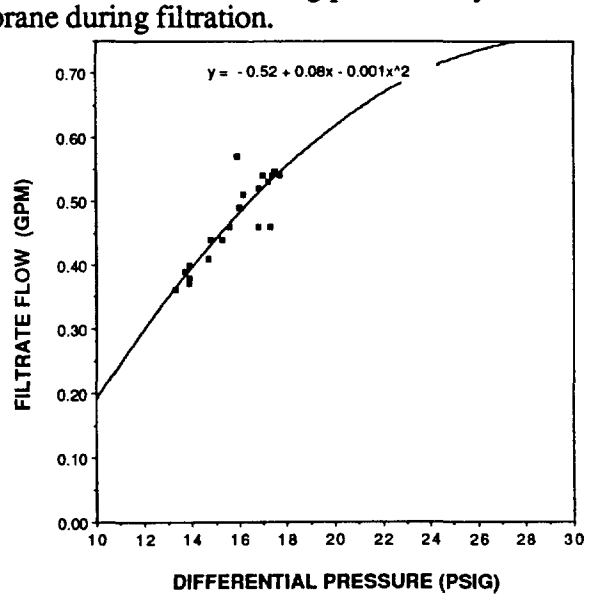


Figure 7. Filtrate Flows vs. Pressure

Backwashing (or backpulsing) is the means used in dislodging the buildup to recover the flux. Figure 8 illustrates that backpulsing is an effective means of recovering the flux since the flux was maintained for over a 3-hour time period without any decline. However, additional testing is scheduled to determine the length of time that backwashing is effective in recovering the flux.

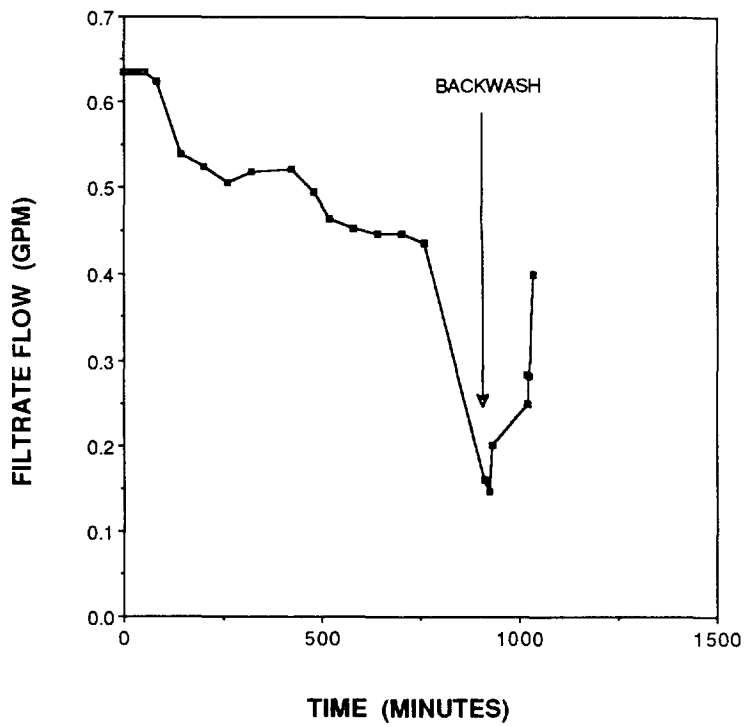


Figure 8. Filtrate Flow Over Time

## Vortex Burner Tests

In the CIF high Btu liquid wastes will be completely destroyed by two high intensity vortex burners in the CIF secondary combustion chamber. Testing on a pilot-scale vortex burner was conducted to determine the effect operating parameters have on combustion characteristics, to measure the destruction removal efficiency (DRE) of the burner, and to determine the turndown capability using nonradioactive waste simulants (benzene, carbon tetrachloride, waste oil, and an aqueous mixture).

1. Destruction Efficiency: The burners proved to be highly efficient requiring less than 2 seconds residence time in the burner chamber for complete destruction of the hazardous waste. Overall destruction efficiencies based on total unburned hydrocarbons found in the stack gas were in excess of 99.99%. The DRE for both benzene and carbon tetrachloride was tested at two sets of operating conditions, and in all cases, the burner destruction efficiency exceeded 99.99%. The volatile organic emission test results are presented in Table 3.[6]

**Table 3. Calculation of Destruction Removal Efficiency (DRE)**

| | Benzene Emissions (mg/hr) | | Carbon Tetrachloride Emissions (mg/hr) | |
|---|---|---|---|---|
| Burner Capacity: | 100% | 50% | 100% | 60% |
| | 62.0 | 46.6 | 73.4 | 0.1 |
| | 5.9 | 33.7 | 15.4 | 2.0 |
| | 273.4 | 16.7 | 8.3 | 0.6 |
| | 559.4 | 13.8 | 10.9 | 1.5 |
| | 0.4 | 3.9 | 0.3 | 0.8 |
| | 9.9 | 1,422.7 | 9.1 | 4.9 |
| | 3.7 | 87.5 | — | — |
| Average | 130.7 | 232.1 | 19.6 | 1.6 |
| Feed (g/hr) | 70,180 | 35,090 | 32,989 | 19,623 |
| DRE % | 99.9998 | 99.9993 | 99.9999 | 99.9993 |

2. Burner Turndown: The CIF waste streams will be reduced after approximately 3 years when most of the inventory waste has been processed. Therefore, to better assess the burner efficiency, the turndown rate was tested. Burner turndown, which is the capability of combustion waste feed rates to be reduced while still maintaining flame integrity, was higher using air atomization rather than steam atomization of the liquid waste. The steam tended to shroud or quench the flame, resulting in flame instability. The turndown rates that were achieved are indicated in Table 4. The two conditions were conducted at 100% of burner load capacity and approximately 50% load capacity.

**Table 4. Burner Turndown**

| Simulant | Air Atomization | Steam Atomization |
|---|---|---|
| Benzene | 9:1 | 3:1 |
| Carbon Tetrachloride | 6:1 | 1.33:1 |

It was determined that 3:1 burner turndown on firing rate of benzene was attainable while atomizing with steam. However, atomizing with air allowed the burner firing rate to be reduced to approximately 9:1. The turndown during the $CCl_4$ burn was less than that of benzene because of the lower heating value of $CCl_4$.

## Future Testing

Future off-gas testing will involve maximizing the efficiency of the steam jet scrubber to reduce the loading on the HEPA filters. Collected data will be used to generate scrubber efficiency curves at various steam/air ratios. The system will be modified for the addition of a cross-flow filtration system to observe long-term operation and to determine the maximum time that backwashing is effective in recovering the flux.

## Acknowledgment

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