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# Air Pollution Control System Testing at the DOE Offgas Components Test Facility

by

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# Air Pollution Control System Testing at the DOE Offgas Components Test Facility

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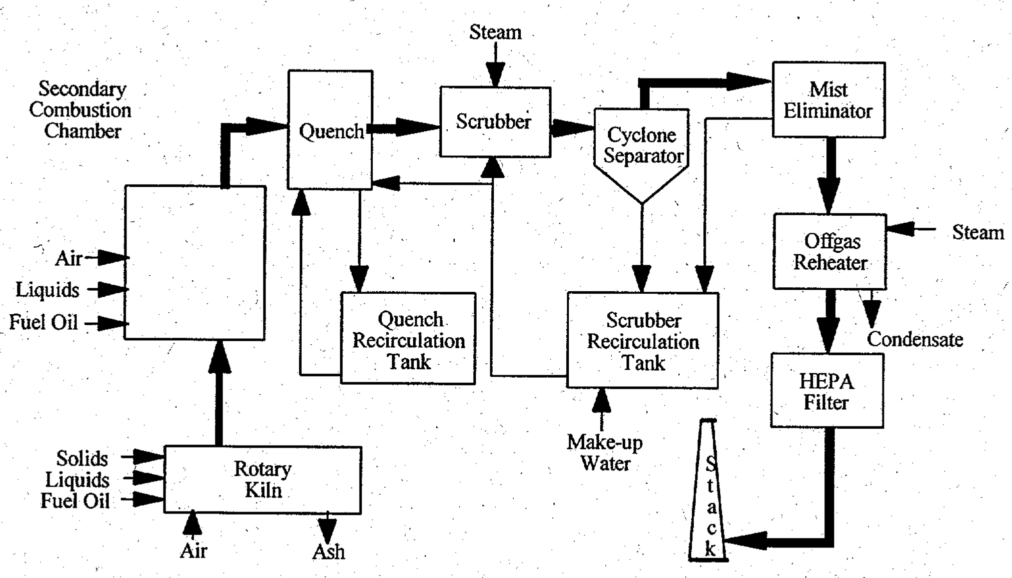
## ABSTRACT

In 1997, the Department of Energy (DOE) Savannah River Site (SRS) plans to begin operation of the Consolidated Incineration Facility (CIF) to treat solid and liquid RCRA hazardous and mixed wastes. The Savannah River Technology Center (SRTC) leads an extensive technical support program designed to obtain incinerator and air pollution control equipment performance data to support facility start-up and operation. A key component of this technical support program includes the Offgas Components Test Facility (OCTF), a pilot-scale offgas system test bed. The primary goal for this test facility is to demonstrate and evaluate the performance of the planned CIF Air Pollution Control System (APCS). To accomplish this task, the OCTF has been equipped with a 1/10 scale CIF offgas system equipment components and instrumentation. In addition, the OCTF design maximizes the flexibility of APCS operation and facility instrumentation and sampling capabilities permit accurate characterization of all process streams throughout the facility. This allows APCS equipment performance to be evaluated in an integrated system under a wide range of possible operating conditions. This paper summarizes the use of this DOE test facility to successfully demonstrate APCS operability and maintainability, evaluate and optimize equipment and instrument performance, and provide direct CIF start-up support. These types of facilities are needed to permit resolution of technical issues associated with design and operation of systems that treat and dispose combustible hazardous, mixed, and low-level radioactive waste throughout the DOE complex.

## INTRODUCTION

The Consolidated Incineration Facility (CIF), located at the Savannah River Site, is currently undergoing preoperational testing to treat solid and liquid RCRA hazardous and mixed wastes generated by site operations and clean-up activities. In this facility, waste thermal treatment is performed in a 13 million Btu rotary kiln incinerator and 5 million Btu secondary combustion chamber. The facility air pollution control system (APCS) consists of a recirculating liquid quench and steam-atomized scrubber for offgas cooling and cleaning, a cyclone separator and mist eliminator for liquid/gas separation, and final HEPA filtration prior to atmospheric discharge through the facility stack. A process flow diagram for the CIF is shown in Figure 1.

**FIGURE 1**
CIF Process Flow Diagram

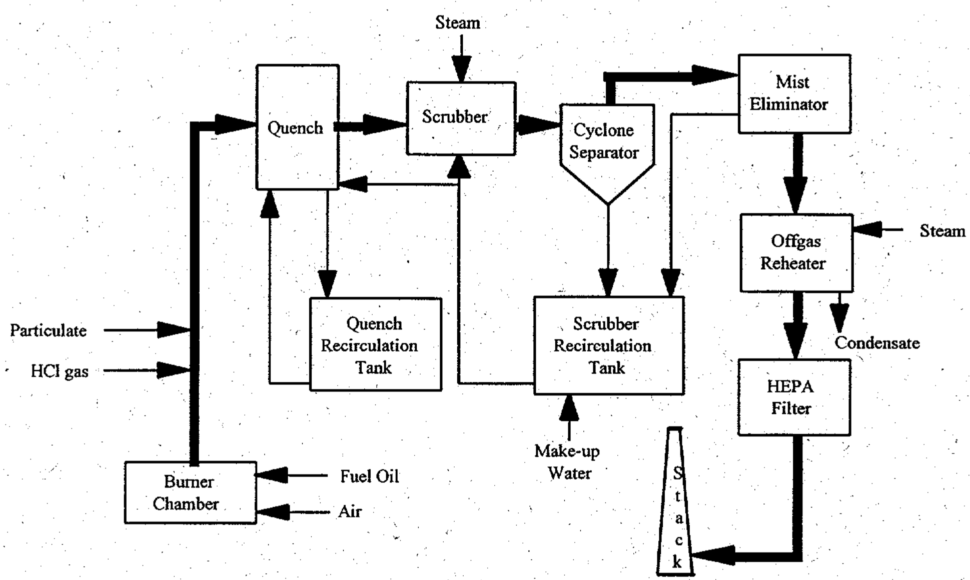



The technologies selected for use in the CIF were based on reviews of existing commercial and DOE incinerators, on-site air pollution control experience, and recommendations from contracted consultants. This approach resulted in a unique facility design utilizing experience gained from other operating hazardous/radioactive incinerators. The Savannah River Technology Center (SRTC) designed, installed, and operated a 1/10 scale pilot facility, known as the Offgas Components Test Facility (OCTF), to demonstrate the design integrity of the CIF APCS and optimize the equipment/instrument performance in the full scale waste treatment facility. Operation of this on-site pilot facility has provided long-term performance data of integrated systems and critical facility components. This effort has reduced facility start-up problems and helped to insure compliance with all facility performance requirements.

## OCTF DESIGN AND CAPABILITIES

The OCTF is a pilot-scale air pollution control system, currently configured to test the design of the CIF APCS. A schematic of the OCTF is shown in Figure 2. Hot offgas is produced in a three million Btu burner chamber. Particulate and HCl gas are metered into the gas stream to simulate particulate carry-over and acid gas produced during incineration of typical hazardous wastes. The offgas is cooled in a co-current recirculating water quench before entering a high efficiency steam-atomized scrubber. The scrubber removes particulates and neutralizes acid gases. The scrubbed offgas enters a cyclone separator where liquid and solid particulates are removed from the gas stream. After exiting the cyclone, the offgas enters a mist eliminator to remove any residual liquid droplets. A reheater upstream of the HEPA filters prevents condensation in the filter housing. The filtered offgas is discharged to the atmosphere through the facility stack.

**FIGURE 2**
OCTF Process Flow Diagram




The OCTF is designed to evaluate operational parameters of air pollution control system designs. The OCTF utilizes a modular design which allows replacement/addition of existing unit operations with other technologies that could be tested in the future. The current configuration of the OCTF is a 1/10 scale mock-up of the CIF APCS. This configuration permitted completion of a comprehensive CIF test program. Individual OCTF equipment components and instruments currently installed were designed and fabricated by the same vendors selected for the CIF. The performance of all CIF APCS components were evaluated as a function of system operating parameters at the OCTF. In addition to obtaining valuable performance data, the OCTF proved to be a useful tool for training operators and maintenance personnel.

## OCTF TEST PROGRAM

The OCTF test program was originally designed to evaluate operational parameters of the CIF offgas system design. Equipment performance was studied to optimize operation in order to reduce emissions and minimize secondary waste generation. The primary technical issues identified for investigation on the OCTF are discussed below.

- Validate basic operability of offgas system design. Insure proper operation of all unit operations as arranged in the designed CIF offgas system.

- Measure particulate removal efficiency in the air pollution control system as a function of equipment operating parameters, including solids and salt concentrations in the recirculating liquids, steam/offgas ratio, and offgas flowrate.

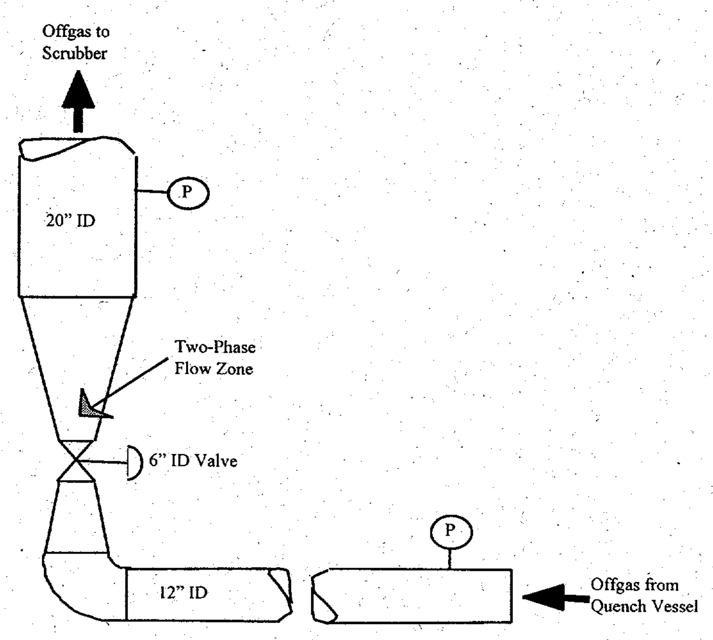
- The offgas system must be operated to provide acceptable HEPA filter life. Parameters affecting filter life that were studied include salt concentrations in the quench and scrubber solutions, flue gas particulate loading and flow rate, water droplet carryover, and water condensation.
- Prototypic pH, conductivity, density, and flow instrumentation are included in the OCTF design. The instrumentation and proposed control schemes (particularly pressure control) will be evaluated for reliability and stability.

## OCTF TEST PROGRAM RESULTS

During early OCTF testing, three design issues were immediately identified and resolved. Resolution of these issues prior to startup of the full-scale facility resulted in significant cost savings and minimal impact to the facility startup schedule.

The first design issue was discovery of unexpectedly high pressure drops across the scrubber inlet damper. Figure 3 shows a schematic drawing of the duct between the quench and the scrubber. A damper (butterfly valve) was included in the design to control offgas flow into the steam-atomized scrubber. The valve was sized to permit optimum control characteristics over the range of expected offgas flowrates. However, measured pressure drops across the valve and associated piping were considerably higher than predicted by design calculations. Tests were conducted utilizing a video camera installed in the process duct to determine the cause of the high pressure drop.

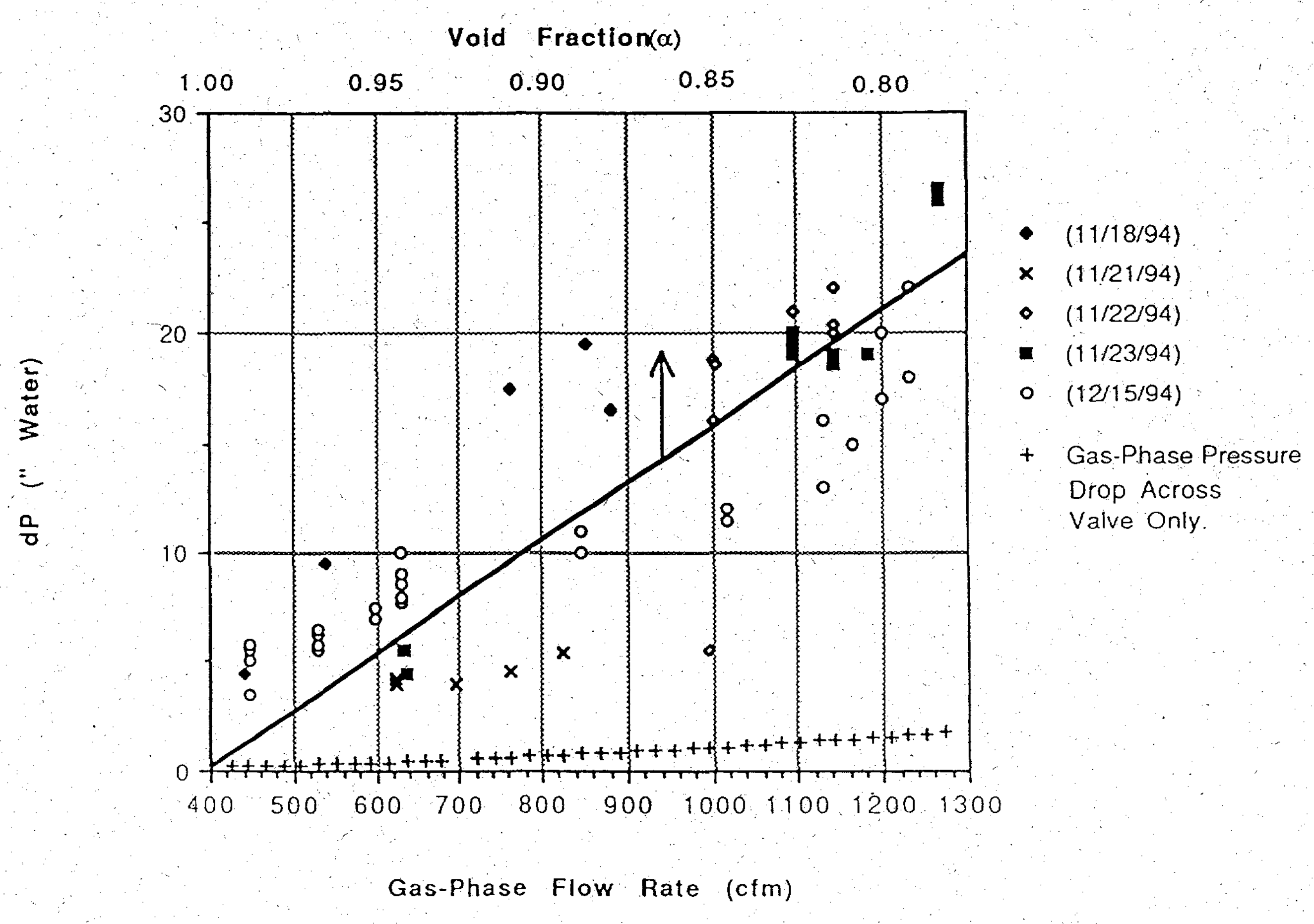
**FIGURE 3**
Scrubber Inlet Damper Duct



Test results concluded that the high pressure drop was due to two-phase flow through the damper. The design calculations assumed the offgas flowing through the valve was a single gas-phase stream only. However, test results revealed a significant fraction of liquid existed above the vertically-oriented damper, creating a section of duct with two-phase flow. Condensed water could not drain past the valve since the offgas velocity through the valve was sufficient to cause water flow reversal, preventing counter-current gravity draining through the valve. These test results are plotted in Figure 4. Scrubber inlet damper differential pressure data is plotted from several days (11/18/94-12/15/94) of testing at various offgas flowrates. Also on this graph is the theoretical pressure drop for a single, gas-phase, offgas passing through the control valve (+). The solid line plots the pressure drop with a linear decrease in the offgas void fraction over the range of flows in the data set. This line is not attempting to define the functional relationship between pressure drop, flow rate, and void fraction, but to illustrate that the observed pressure drop across the valve can be explained by a decreasing void fraction in the region with two-phase flow.

**FIGURE 4**

Scrubber Inlet Damper Pressure Drop Results



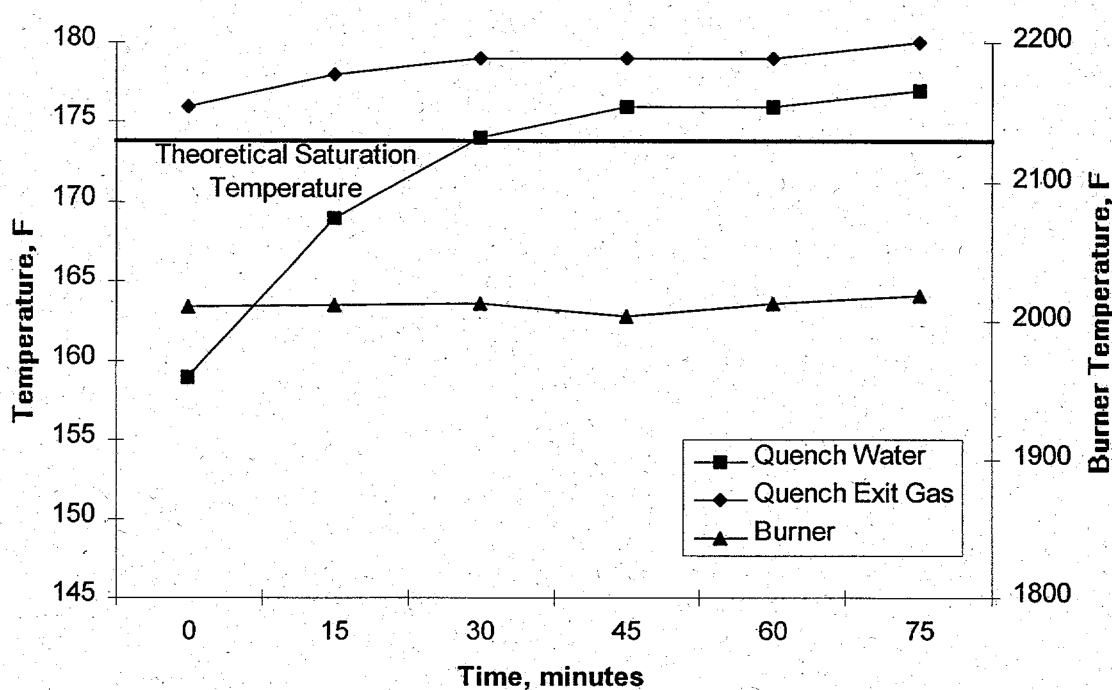
The results of these tests were used as a basis for a major facility design change, both at the OCTF and the CIF. The scrubber inlet damper was re-sized to reduce the offgas velocity through the valve, permit water to gravity drain through the valve, and prevent the formation of a two-phase flow region in the duct. After these changes were implemented, the problem of high pressure drops was resolved.

The second design issue identified during initial OCTF testing concerned the adequacy of the quench design. During operation, we experienced repeated severe quench nozzle plugging that reduced the water flow to the quench nozzles by 2/3. Also, the temperature of the offgas exiting the quench vessel frequently exceeded the design operating temperature of 180°F (temperatures in excess of 210°F were observed) when burner temperatures exceeded 1500°F at offgas flows less than 10% of design, even at design quench water flows. To maintain an acceptable quench offgas temperature, the quench tank contents were periodically (every 2-3 hours) drained (approximately 50%) and replaced with cold (ambient) process water. Failure to periodically drain the quench tank resulted in unacceptably high quench water and quench exit offgas temperatures. To resolve this issue, a test was conducted to evaluate the adequacy of the quench to cool hot burner chamber offgas at design flows and temperatures to an acceptable temperature (< 180°F) and verify the quench recirculation tank water temperature was acceptable (< 180°F) without any external cooling.

The test consisted of three runs at low (1600°F), medium (1800°F), and high (2012°F) burner offgas exit temperatures at design offgas flow rates. The quench was operated at full design water flow for each run. The test procedure for these runs required holding the burner offgas temperature at the desired setpoint ($\Delta T < 20$°F/hr) while monitoring the temperature of both the offgas exiting the quench and the quench recirculating liquid. No make-up/cooling water was allowed to enter the quench recirculation tank during a run. The run continued until the quench recirculation water temperature reached a steady-state equilibrium temperature, defined as quench water $\Delta T < 5$°F/hr. Also, prior to this test, a basket strainer was installed in the quench water recirculation line. This strainer was designed to prevent solids from plugging the quench water nozzles.

Figure 5 contains the equilibrium temperature results from the high temperature run. Both quench recirculating water temperatures and quench flue gas exit temperatures are plotted with respect to the left x-axis. Burner flue gas temperature is plotted with respect to the right x-axis. All data is plotted as a function of time. It can be seen that quench water temperature quickly equilibrates with the quench exit gas temperature. Observed equilibrium adiabatic saturation temperatures were typically 4-6 °F higher than theoretical. This is likely due to water vapor in ambient air not accounted for in calculating the theoretical adiabatic saturation temperature, which assumes all water in the burner flue gas is the result of fuel oil combustion.

**Figure 5**
Quench Test Results - High Temperature Run




The quench performed as designed at all test conditions. The hot burner offgas was cooled to an acceptable temperature (< °180 F) and the recirculating quench liquid temperature equilibrated at an acceptable temperature which was slightly below the gas temperature. The strainer also prevented any measurable loss of quench water flow during these tests. As a result of these tests, a strainer was added to the CIF quench tank to minimize the possibility of quench nozzle plugging.

The third design issue studied at the OCTF was HEPA filter life. Initial OCTF runs indicated that HEPA life could be as short as 2-3 days. However, the system must be operated in such a manner to provide acceptable HEPA filter and prefilter life (> 30 days). Short filter life significantly increases facility operating costs associated with procuring, replacing (or cleaning), and disposing system filters. The filter housings used both at the CIF and the OCTF contain standard disposable glass fiber HEPA filters. Upstream of the HEPA filters are disposable glass fiber prefilters. The primary objective of these tests was to determine the APCS operating parameters that are required to meet the goal of 30-day HEPA filter and prefilter life.

The operating parameters that were investigated included:

- Type of HEPA prefilter
- Mass ratio of scrubber steam to offgas ($\alpha$)
- Mass ratio of scrubber water to offgas ($\beta$)

Two types of HEPA prefilters were tested. The first was a Flanders paper prefilter (model # T-00K-C-04-00-NL-12-00-E0281, 60-65% @ 1000 cfm). The second prefilter was an Otto York 304 stainless steel prefilter sized to remove 99% of all particles greater than 5 μm in diameter. The Flanders prefilter is a disposable filter, while the Otto York prefilter was cleaned with water after each test and reused.

The results of the test runs are summarized in Table 1. New (or cleaned) prefilters and HEPA filters were installed in the test facility prior to beginning each run. The scrubber operating conditions were maintained at the settings given in the Table 1. Each run ended after sufficient filter pressure drop vs. time data was collected. The actual prefilter and HEPA filter pressure drop observations at the conclusion of each run is also listed in Table 1.

**TABLE 1**
HEPA Test Results

| | Run # | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 6 | 7 | 8 |
| Steam Alpha | 0.22 | 0.22 | 0.43 | 0.26 | 0.26 | 0.26 |
| Water Beta | 0.5## | 0.5 | 1.0 | 1.0 | 1.0 | 0.5 |
| Prefilter Type | Paper | Paper | 304 SS | 304 SS | Paper | 304 SS |
| | | | | | | |
| Observed Prefilter dP | 3.50" after 40 hrs | 2.20" after 110 hrs | 1.20" after 415 hrs | 1.15" after 375 hrs | 3.25" after 215 hrs | 0.85" after 475 hrs |
| Observed HEPA dP | 0.40" after 40 hrs | 0.35" after 110 hrs | 0.85" after 415 hrs | 3.00" after 375 hrs | 0.40" after 215 hrs | 2.80" after 475 hrs |
| | | | | | | |
| Projected Prefilter Life* | 2 days | 10 days | 42 days | 30 days | 10 days | 68 days |
| Projected HEPA Life** | # | # | 37 days | 18 days | # | 27 days |

* Projected Prefilter Life estimates are derived by extrapolating a third order polynomial function fit to observed data. For paper prefilters, the maximum dP permitted is 4". For cleanable metal prefilters, the maximum dP is 10"

** Projected HEPA life estimates are derived by extrapolating a third order polynomial function fit to observed data. The maximum dP for HEPA filters is 4".

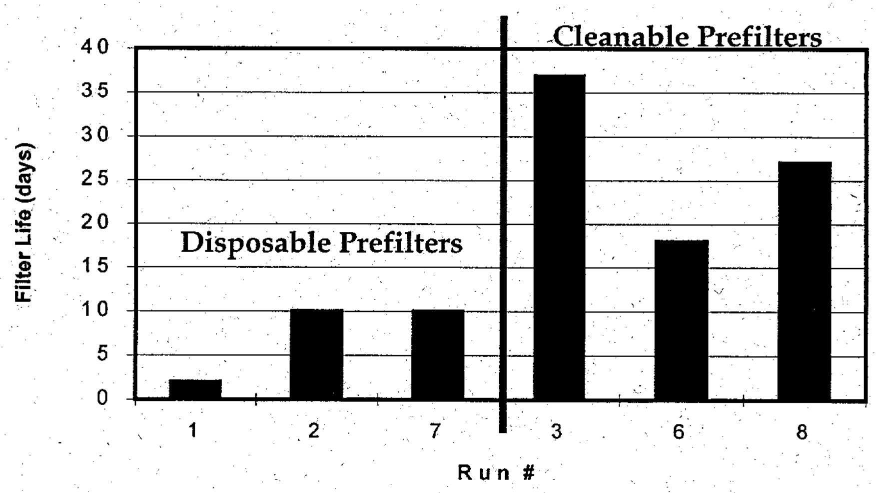
\# Insufficient data to fit a valid a third order polynomial model.

\## Partial plugging of scrubber water nozzles during this run is expected to have contributed to poor scrubber performance.

A mathematical model was fitted to the prefilter and HEPA filter pressure drop (dP) vs. time data. The model that consistently showed the best data fit (in particular for the data sets showing a filter at the maximum useful dP) was a third order polynomial relating the dependent variable (dP) to the independent variable (time). Using this model, filter life expectancies were extrapolated for runs ending prior to reaching the maximum allowable dP. For the disposable Flanders prefilters and HEPA filters, this value was assumed to be 4" water. If filter dP was allowed to exceed this value, filter breakthrough was often observed. For the cleanable metal prefilters, the maximum dP was assumed to be 10" water. These filter life predictions are included in the last two lines of Table 1.

Acceptable filter performance was obtained only when using the cleanable metal prefilters. The maximum observed disposable prefilter life was 10 days under all conditions tested. Under similar conditions, prefilter life was extended approximately 3X when using the metal prefilters. It should be noted that use of the disposable paper prefilters always resulted in plugging and changing of the prefilter before any significant dP increase occurred on the HEPA filter. This explains the inability to predict HEPA life for these runs (1, 2, 7). Insufficient data was available for the HEPA dP profile because the prefilter would plug too rapidly. Yet, use of the metal cleanable prefilter often resulted in plugging of the HEPA filter before the dP limit for the prefilter was obtained. Thus, the data tends to indicate the cleanable prefilter allows a greater fraction of particulate through to the HEPA filter. Yet, this more even distribution of particulate between the prefilter and HEPA filter permits a significantly longer time interval between filter (either prefilter or HEPA filter) changeout or cleaning. The time between filter changeout (or cleaning) is graphically depicted in Figure 6.

**Figure 6**
Predicted Filter Life




The runs which utilized cleanable HEPA filters were #3, 6, and 8. During these runs, the steam/offgas flow ratio was varied between 0.43 and 0.26. Also, the scrubber water/offgas flow ratio was varied between 1.0 and 0.5. The theoretical best conditions are at higher steam and water flowrates (Run 3). The second best performance was observed in Run 8, when the steam and water flows were both low. This is due to the fact that proper scrubber performance requires the ratio between the scrubber water flow to scrubber steam flow equal two (# water / # steam = 2). If the ratio is too high, the majority of the steam is used to atomize the water and there is insufficient steam for turbulence and pulling offgas through the scrubber. While a low ratio results in insufficient water to properly scrub the offgas. This explains the relatively poor performance in Run 6 (water / steam ratio = 3.8).

This test demonstrated that satisfactory prefilter and HEPA filter life is obtainable with the existing CIF APCS. Test results indicate that the life of HEPA prefilters/filters can exceed the operational goal of thirty days under the following conditions: steam ratio, $\alpha = 0.43$, scrubber water ratio, $\beta = 1$, and using 304 SS cleanable prefilters.

## CONCLUSIONS

The Consolidated Incineration Facility (CIF) at the US Department of Energy (DOE) Savannah River Site has a unique facility APCS design utilizing experience gained from other operating hazardous/radioactive incinerators. In order to study the CIF APCS prior to operation, a 1/10 scale pilot facility, known as the Off-gas Components Test Facility (OCTF) was constructed and operated by the Savannah River Technology Center. The primary purpose of this test facility was to demonstrate the design integrity of the CIF APCS. OCTF testing did prove the adequacy of the basic system design; however, initial OCTF operation did reveal the need for several facility design changes. The required changes were verified in the test facility prior to implementation on the full scale production facility, minimizing the impact to the CIF start-up schedule. Pilot-scale testing has proven useful for resolving technical issues associated with design and operation of advanced waste treatment systems for combustible hazardous, mixed, and radioactive waste.