

WERF MACT FEASIBILITY STUDY

K. Kooda, LMITCO (USA)

ABSTRACT

This study was undertaken to determine the technical feasibility of upgrading the Waste Experimental Reduction Facility (WERF) to meet the offgas emission limits proposed in the Maximum Achievable Control Technologies rule. Four practicable offgas treatment processes were identified, which, if installed, would enable the WERF to meet the anticipated MACT emission limits for dioxins and furans (D/F), hydrochloric acid (HCl), and mercury (Hg). Due to the three-year time restraint for MACT compliance, any technology chosen for the upgrade must be performed within the general plant project funding limit of \$5 M. The option selected consists of a partial-quench evaporative cooler with dry sorbent injection for HCl removal followed by a sulfur-impregnated activated carbon bed for Hg control. The planning cost estimate for implementing the option is \$4.17 M (with 24% contingency). The total estimated cost includes capital costs, design and construction costs, and project management costs. Capital costs include the purchase of a new offgas evaporative cooler, a dry sorbent injection system with reagent storage, a new fabric filter baghouse, a fixed carbon bed adsorber, and two offgas induced draft exhaust fans. It is estimated that 21 months will be required to complete the recommended modification to the WERF. The partial-quench cooler is designed to rapidly cool the offgas exiting the secondary combustion chamber to minimize D/F formation. Dry sorbent injection of an alkali reagent into the offgas is recommended. The alkali reacts with the HCl to form a salt, which is captured with the fly ash in the baghouse. A design HCl removal efficiency of 97.2% allows for the feeding 20 lbs/hr of chlorine to the WERF incinerator. The sorbent feed rate can be adjusted to achieve the desired HCl removal efficiency. A fixed bed of sulfur-impregnated carbon was conservatively sized for a total Hg removal capacity when feeding 10 g/hr Hg to the WERF incinerator. An added benefit for using carbon adsorption is that the activated carbon will also capture a large fraction of any residual D/F present in the offgas.

INTRODUCTION

The Waste Experimental Reduction Facility (WERF) at the Idaho National Environmental and Engineering Laboratory (INEEL) currently incinerates low-level waste (LLW) and mixed low-level waste (MLLW). New emission standards reflecting the performance of maximum achievable control technologies (MACT) have been proposed to afford increased protection to human health and the environment over existing Resource Conservation and Recovery Act (RCRA) standards. These standards include more strict emission limits for a variety of pollutants, as well as the use of continuous emissions monitoring systems to confirm compliance. The following sections provide a general overview of the incineration process at the WERF, explain the proposed MACT emission limits, and identify areas where the WERF would fail to comply with the proposed limits, unless changes were made in its air pollution control system (APCS).

Problem Statement

This technical feasibility study was undertaken to determine answers to the following questions:

- What technologies are available and necessary to upgrade the WERF Incinerator APCS to meet the intent of the proposed MACT rule?
- Due to the anticipated MACT implementation schedule, can this upgrade be accomplished within the restraints of the General Plant Project funding limit (\$5 M)?
- What can be done to expand waste acceptance criteria at WERF?

WERF Background

The WERF was constructed in the converted Special Power Excursion Reactor No. 3 building and commenced operations in 1982. Initially, the purpose of the project was to demonstrate that commercially available technologies could be used for managing the LLW generated by the nuclear facilities located at the INEEL. The pilot-scale facility data obtained from this experiment was to be used in developing future production-scale waste processing facilities.

In the late 1980s, additional experiments were performed to evaluate the ability of WERF to treat MLLW. Treatment involved reducing the waste toxicity and volume via incineration. Due to the success of these experiments, WERF has developed into a facility capable of treating complex-wide MLLW. This includes waste currently being generated and legacy waste from prior U.S. Department of Energy (DOE) operations. From October 1984 to February 1991, the WERF incinerator completed nearly 10,000 hours of operation without significant incidences or failures. During that time, more than 325,000 ft³ (greater than 1.4 million lbs) of waste was incinerated with an average volume reduction ratio of 200:1. Most of the waste incinerated was LLW. In February 1991, the WERF underwent a planned shutdown to perform major modifications to upgrade facility operating documentation and re-baseline the facility configuration and administrative management programs. Since the resumption of WERF operation in July 1995, the incinerator has treated 572,000 lbs of LLW; 44,000 lbs of characteristic MLLW; and 295,000 lbs of listed MLLW.

The WERF incinerator is a dual-chambered (primary and secondary chamber), controlled air incinerator, manufactured by Environmental Control Products of Charlotte, North Carolina, with a thermal capacity of 6.5 MBtu/hr. Solid waste is gravity fed to the primary chamber where it is oxidized in an oxygen-deficient environment. This sub-stoichiometric environment is maintained by controlling the air introduced into the primary chamber so that volatile materials can be driven off in a controlled manner, and particulate emissions are minimized.

The WERF APCS currently uses a three-step process for cooling the combustion gas exiting the secondary chamber prior to entering downstream air pollution control (APC) components. In the first step, outside air is mixed with the offgas just downstream of the secondary chamber to reduce the offgas temperature. The offgas then passes through the air-to-

air heat exchanger for additional cooling, and after exiting the heat exchanger, more ambient air is added before it enters the baghouse system. The WERF baghouse system consists of two pulse-jet type baghouses. They are installed in parallel with a common outlet plenum. The offgas exits the baghouse and flows into a high efficiency particulate air (HEPA) filter designed to remove submicron particles that the baghouse filters cannot capture. Figure 1 is a block flow diagram for the existing incinerator APCS.

The offgas flows from the HEPA filters through a duct system equipped with continuous emission monitors (CEMs). The CEMs are used to measure the offgas oxygen (O₂), carbon monoxide (CO), and hydrochloric acid (HCl) concentrations. The CEMs are used for automatic waste feed shut-offs if offgas emission concentrations are greater than permitted values. The offgas then flows into two induced draft fans. The fans maintain a negative pressure within the incinerator and APCS and transports the offgas from the incinerator through the APCS and into the north stack, which is the emission point for the system.

The incinerator is normally operated once per month in a 10 to 20 day campaign. While processing, characteristic MLLW and LLW can be burned. However, listed MLLW must be treated exclusively in dedicated campaigns. Since the cost of disposing of listed waste, including incinerator ash, is very expensive, exclusive campaigns avoid generating more listed ash than necessary. Presently, the WERF is incinerating both INEEL-generated MLLW and other DOE facility-generated MLLW. Off-site MLLW is subject to the State of Idaho Governor's Agreement that "Primary Treatment" (incineration) will be accomplished within 6 months of receiving the waste, and the waste residues are required to leave the State of Idaho no later than 6 months after completion of the primary treatment.

Current WERF Waste Acceptance Criteria

The WERF Waste Acceptance Criteria (WAC) is used to identify waste that is acceptable or unacceptable for treatment. The WAC specifies acceptable limits for mass, radionuclides, liquid viscosity, water content, heating value, and specific chemical content. The WERF WAC is based upon applicable regulations, DOE orders, and the receiving facility specific requirements. The WERF accepts LLW and MLLW for treatment by incineration. Most limits for specific chemical compounds or elements pertain to MLLW. Because of the current lack of chlorine-removal technology in the WERF APCS, the administrative limit for chlorine is generally one-half the WERF WAC for chlorine. The current WAC limits that administratively control the amount of chlorine or mercury in the waste are listed in Table 1.

The proposed limits and WERF emissions data for comparison are summarized in Table 2. In order to meet the proposed MACT ruling the data clearly indicates that the emission of hazardous air pollutants of concern for the WERF include HCl/Cl₂, Hg, dioxin/furan (D/F), and possibly, total hydrocarbons (THC). Much of the MLLW within the DOE complex contains polyvinyl chloride or chlorinated chemical compounds. Polyvinyl chloride is a common plastic used in personal protective equipment, such as shoe covers, gloves, anti-contamination clothing, and bubble hoods. In addition, there are chlorinated chemical compounds that were commonly used as solvents and degreasers in the DOE complex.

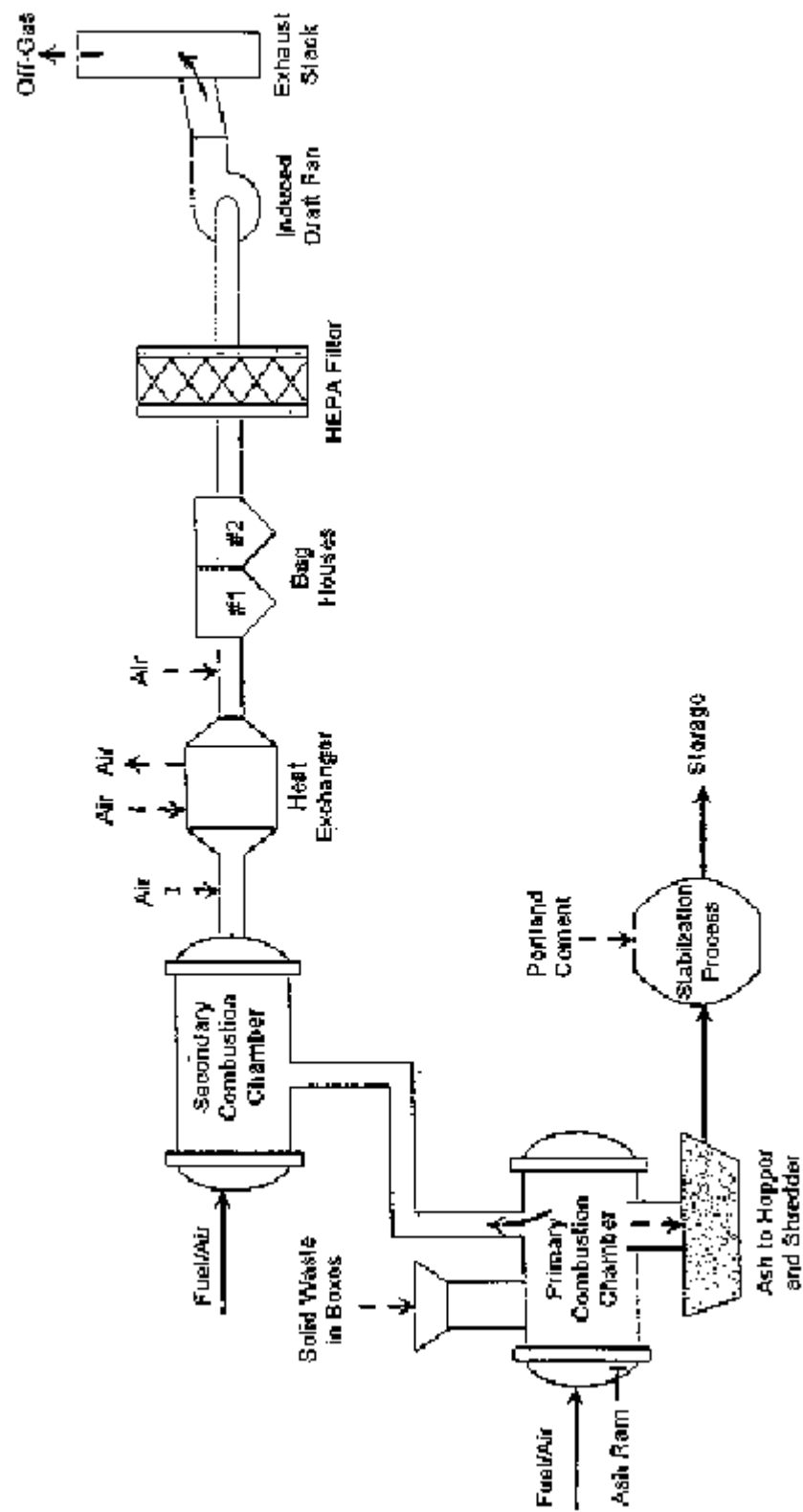


Figure 1. Block flow diagram of the WERF incinerator process

Characteristic	Liquid Aqueous Waste	Liquid Organic Waste	Solid Waste	Administrative Limit	Criterion Basis for Current WAC Idaho Administrative Procedures Act 16.01.01011,04	Future Limit with no APCS Upgrade	Future Limit with APCS Upgrade
PCBs ≤50 ppm blended to ≤5 ppm	≤5 ppm	≤5 ppm	≤5 ppm				
Total Cl ^a	≤10,000 ppm ^b	≤10,000 ppm ^b	≤10,000 ppm ^b	≤5,000 ppm	40 CFR 265	≤1,400 ppm	≤50,000 ppm
Total F ^a	≤3,500 ppm	≤3,500 ppm	≤3,500 ppm		Best management practice		
Total halogens ^a	≤10,000 ppm ^b , must be identified	≤10,000 ppm ^b , must be identified	≤10,000 ppm ^b , must be identified		WERF Trial Burn Plan, 40 CFR 265		
Total Hg	≤1,760 ppm ^d	≤5,000 ppm ^d	≤1,100 ppm ^d	≤260 ppm	40 CFR 265	≤0.5 ppm	≤55 ppm
Total Ag, Ba, Cd, Hg, Sb, Tl					WERF Safety Analysis Report		
a. Halogenated waste is accepted on a case-by-case basis only after evaluation by the generator interface (GI). b. The acceptability of specific total (including free and chemically combined) concentrations will be determined on a case-by-case basis after evaluation by the GI. The acceptable concentrations may be larger in some cases. c. May be limited, must be identified d. The analysis must be for the total quantity of each of these metals.							

Table 1. Current and possible future waste acceptance criteria for MLLW to be incinerated at the WERF.(1)

Table 2. Comparison of WERF emissions data to MACT limits.

Hazardous Air Pollutants or Surrogates	MACT ^{a, b}	WERF ^a
Dioxin/Furan, ng toxic equivalent/dscm	0.20 or 0.40 and $\leq 400^{\circ}\text{F}$	5.88 ^c 4.7 ^d 42.7 ^e
Mercury, $\mu\text{g/dscm}$	40	11,834 ^f
Particular matter (gr/dscf)	0.015	0.007 ^d 0.003 ^e
Hydrochloric acid/chlorine, ppmv	75 ^e	804 ^d 522 ^e
Carbon monoxide, ppmv	100	0.6–3.6
Total hydrocarbons, ppmv	10	6 ^g
Semi-volatile metals (Cd and Pb), $\mu\text{g/dscm}$	100	<3.5 ^e
Low-volatility metals (As, Be, and Cr), $\mu\text{g/dscm}$	55	10.8 ^e

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| a. | All values are corrected to 7% O ₂ . |
| b. | The limit for existing incinerators may be higher in the final rule. |
| c. | February 1998 mini-burn (numerical average of 1.9, 5.2, 4.5, 1.8, 16). |
| d. | Low Temperature Trial Burn May 1997. |
| e. | High Temperature Trial Burn July 1997. |
| f. | Proposed RCRA Part B Permit Application. |
| g. | Estimated from WERF trial burn data.(3) |

Using the proposed MACT limit of 75 ppmv in the offgas, without HCl/Cl₂ emission control, the WERF chlorine feed limit concentration is 1,400 ppmw in the feed when treating 400 lbs/hr of waste. This represents 0.6 lbs/hr of chlorine to the incinerator. The current chlorine waste feed limit is administratively controlled at 4 lbs/hr to ensure that HCl release is maintained at or below 4 lbs/hr. Even at this chlorine feedrate, much effort is required to segregate the chlorine-containing waste in the MLLW to avoid violating the permitted value. Since chlorinated compounds represent a significant portion of the DOE MLLW inventory, waste segregation for chlorine feed control is not considered practical. Therefore, this study evaluated HCl control technologies that could be retrofitted into the WERF incinerator/offgas treatment system. At incinerator conditions, the formation of HCl is thermodynamically favored over that of chlorine gas.(2) Chlorine gas formation is thermodynamically favored at lower temperatures, but kinetic limitations prevent a significant shift in concentrations generated in the incinerator. As a result, almost all chlorine in the APCS is in the form of HCl. For this reason, HCl control in the APCS is considered equivalent to total chlorine control in this report.

The current Hg emission limit at WERF, as proposed in the RCRA permit application and listed above, is approximately 160 times the MACT proposed emission level. This limit is based upon air dispersion modeling and health risk assessments. Assuming all the Hg in the waste feed volatilizes, without Hg emission control, the MACT proposed limit translates to a waste feed Hg concentration of 0.5 ppmw when feeding 400 lbs/hr of waste to the WERF incinerator. Blending mercury-contaminated waste to this concentration or reducing the waste

feed-rate to meet the proposed MACT emission limit is not considered to be a reasonable solution. Therefore, technologies to remove Hg from the WERF offgas were investigated.

Dioxins/furans are products of incomplete combustion (PICs) common within incineration processes. Baseline emissions data from WERF indicate that the D/F emissions rate is 20 to 200 times greater than the proposed limit. Unfortunately, the science associated with the formation of various D/Fs is highly complicated and partially dependent on the incinerator system design. The technologies and incinerator operating conditions for controlling their formation are primarily based upon what has provided relatively low D/F concentrations in similar applications. Basically, there are incinerator offgas temperature ranges and gas residence times that are favorable for D/F formation.

The hazardous waste incinerator industry approach to D/F control includes increasing the efficiency of the combustion process and minimizing the time a given offgas stream resides in a temperature range of 480°F–930°F. Although improved waste feed control may also reduce D/F formation, it is not a satisfactory option until definitive D/F formation mechanisms and chemical compounds that contribute to the formation of these PICs are identified. This investigation identified offgas treatment processes that are used to minimize D/F formation, and those that are designed to remove them from the offgas should they be generated.

AIR POLLUTION CONTROL SYSTEMS CONSIDERED FOR UPGRADING WERF TO MEET MACT

The study team evaluated many APC technologies for applicability to meet the MACT criteria for HCl, Hg, and D/F control. After analyzing the technology and researching the chemical and physical properties for the contaminants of concern, it was concluded that no single APC technology could meet the proposed MACT limits for all three species. Rather, an APCS consisting of different APC technologies is required. At this point in the evaluation process there were several technologies that were discontinued from further consideration:

- Most of the wet scrubbers because they require too much water or power—the packed bed, venturi, and wet electrostatic precipitator scrubbing technologies were retained as possible alternatives
- Dry fluidized bed scrubber because it has limited commercial application
- Gold amalgamation for Hg control because it also has limited commercial experience
- Carbon injection for Hg control because of potentially causing a baghouse fire and was considered too inefficient
- Activated carbon because of low Hg loading when compared to the sulfur-impregnated carbon.

The WERF Feasibility Study Project Team has developed four practicable offgas treatment processes, which if installed, would enable the WERF to meet the anticipated emission limits of the pending MACT rule. The offgas treatment processes under consideration are combinations of several of the various offgas treatment technologies evaluated by the project team. Figure 2 exhibits four block flow diagrams for the offgas treatment options under consideration, which include the Dry Sorbent Injection (Option 1), Spray Dry Absorption (Option 2), Wet Scrubber

Located Downstream of Filtration (Option 3), and Wet Scrubber Located Upstream of Particulate Removal (Option 4).

Dry Sorbent Injection Process Description (Option 1)

A dry acid-gas removal system that could be implemented at the WERF consists of the components listed below. The following components would be installed downstream of the existing WERF Secondary Combustion Chamber (SCC): evaporative cooler (partial-quench), DSI, fabric filter baghouse, HEPA filtration, carbon adsorber, and induced draft fans and stack. The following is a more detailed component and operation description for the dry acid-gas removal system that could be implemented at the WERF.

Offgas cooling can be accomplished in an evaporative cooler, which is a vertical cylindrical, refractory-lined carbon steel vessel. Based upon the calculated offgas volumetric flowrates, an evaporator with an approximate outside diameter of 5 ft and a height ranging from 20–25 ft would be required. The hot offgas from the SCC flows into the top of the quench vessel equipped with a gas flow distribution system that is approximately 6–7 ft long. The distributor causes the offgas to flow downward with minimal swirling action. Water is added to the hot gas through dual fluid, air-atomizing nozzles that are located near the bottom of the gas distributor. The dual fluid nozzles use atomizing air to create finely dispersed water droplets (less than 800 μm), which create the surface area necessary for efficient heat transfer from the gas to the liquid water droplet. As the hot gas and water droplets flow downward through the quench vessel, the offgas is cooled and the water droplet disappears due to evaporation. This offgas cooling is effectively achieved within 0.5–1 second after the gas enters the vessel.

Under maximum offgas temperature and flow conditions, preliminary design calculations indicate that 7.5 gpm of water is required to control the offgas temperature exiting the quench vessel cooler to 350°F. Adding water to the offgas increases its moisture content from 6 volume percent (vol%) to 37 vol%. It is important to maintain the offgas temperature above the dew point temperature to avoid condensation in the baghouse located downstream. The cooler is usually equipped with a bottom sump to collect any condensate that may form during an upset of operating conditions. This condensate would re-evaporate once proper operating conditions are restored, or it may be possible to recycle the condensate back to the top of the evaporative cooler.

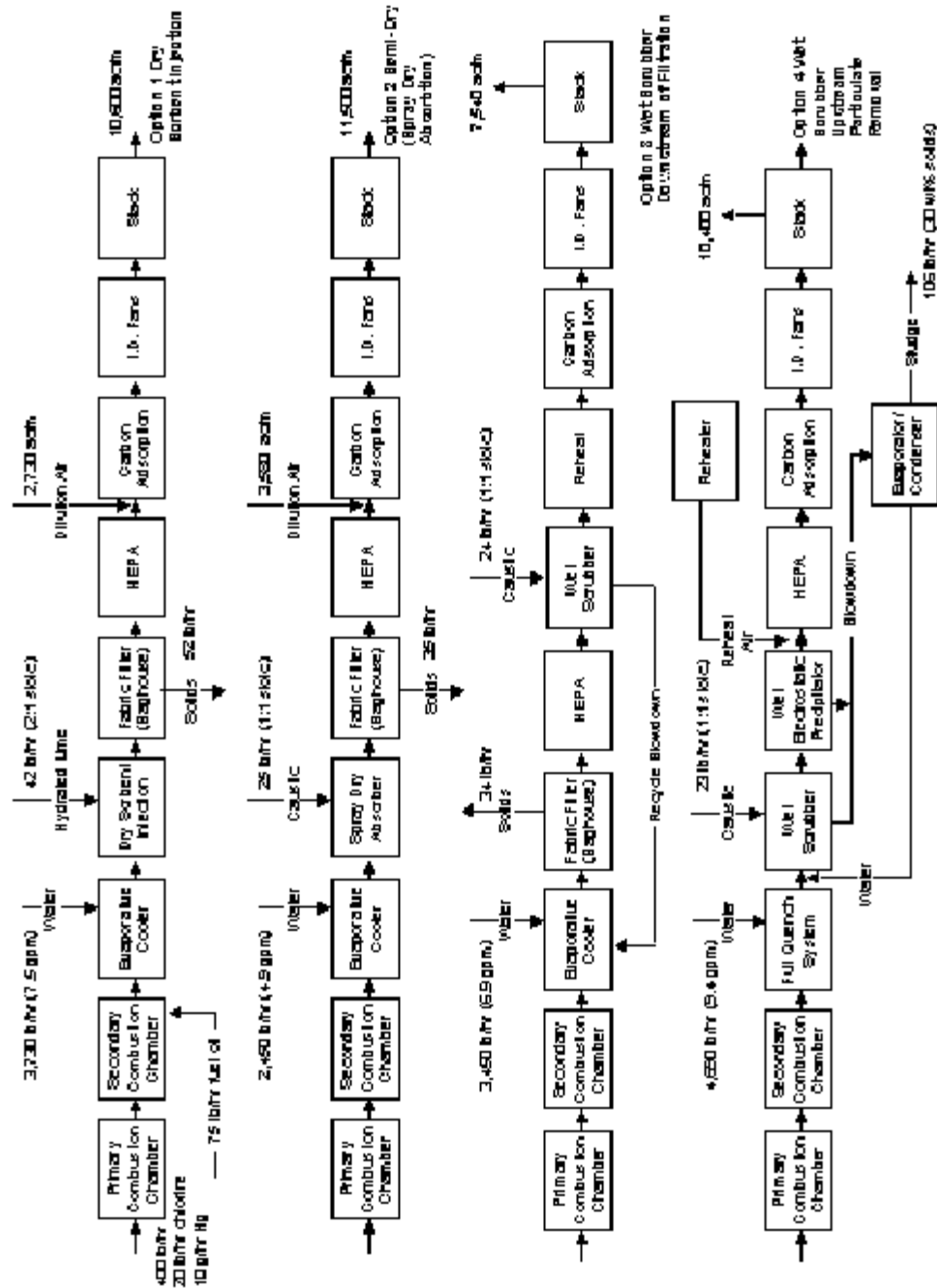


Figure 2. Proposed air pollution control system options.

In a dry sorbent injection (DSI) process, a dry powder sorbent (i.e., an alkali reagent) is injected into the offgas at a point where the sorbent can react with the acid gases that are present. A common method of sorbent injection is via pneumatic transport through a nozzle, but gravity fed mechanical feeders, such as augers, are also used. In Option 1 the dry sorbent is added upstream of the baghouse allowing the sorbent to build-up a porous layer on the fabric filters in the baghouse. Under these conditions, the baghouse is a dry reactor chamber that effectively causes the offgas to flow through the reagent. This feature provides the direct contact between the acid gas and solid reagent material, which is necessary to neutralize the acid gas. There are several alkali materials that could be used in DSI. The two most common reagents are hydrated lime and sodium bicarbonate.

The chemistry for calcium hydroxide reacting with hydrochloric acid is shown in the following equation:



where:

the subscripts (s) and (g) are solid and gas phases, respectively

Ca(OH)_2 = calcium hydroxide

HCl = hydrogen chloride

CaCl_2 = calcium chloride, a salt

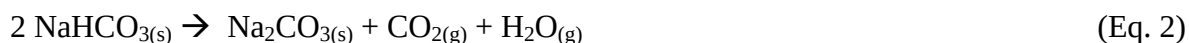
H_2O = water

The extent of reaction is a function of the stoichiometric ratio of lime-to-HCl, the lime particle size, the acid gas concentration, and the offgas relative humidity.(4) The above reaction is dependent upon the HCl in the gas phase contacting the solid hydrated lime. Some contact will occur where the hydrated lime is introduced into the offgas. However, most of the HCl will come in contact with the accumulated solid sorbent as the offgas passes across the filter bags where the solid cake has accumulated on the outer surface of the filter.(4,5) The reaction occurs initially at the surface of the solid particles. Subsequent reaction on the particle cannot occur until the gas diffuses across the reaction product on the particle surface to unreacted material beneath it. Because not all of the lime can easily come in contact with the offgas, it is necessary to feed in excess of the stoichiometric feed rate (from 100 to 200%) to achieve a desired acid gas removal efficiency. More complete alkali consumption is ensured when using the smaller hydrated lime particles, which provide greater surface area per sorbent mass for the gas-solid reaction. In general, the process is effective when the gas stream is cooled in a range of 300–350°F and is partially saturated. It is important to keep the offgas temperature above the dew point and not let the gases become saturated because wet surfaces from condensation will cause problems, such as filtercake buildup and baghouse corrosion.

A potential operational problem is caused by the deliquescent nature of calcium chloride that results in the removal of moisture from the ambient gas surrounding it. This phenomenon occurs when the gas and solids temperature is less than the estimated dew point temperature of 266°F.(4) Liquids can accumulate in the baghouse and hopper presenting a material handling problem and increasing the potential for localized corrosion. If the moist material is present on

the baghouse filter bags, blinding of the bags may occur when dried by the hot offgas. The WERF shut down procedure calls for ambient air to be drawn through the APCS so that the building air can be vented through the HEPA filter located downstream of the baghouse before it is sent to the exhaust stack. Building air will contain moisture that can be absorbed by calcium chloride. Since it is impossible to remove all the calcium chloride from the baghouse prior to shutdown, a by-pass duct with valving and blinds will be used during WERF shutdowns. The baghouse will be kept under negative pressure with minimal in-leakage to prevent liquid accumulation in the unit.

A second reagent under consideration is sodium bicarbonate, which decomposes to sodium carbonate upon heating.



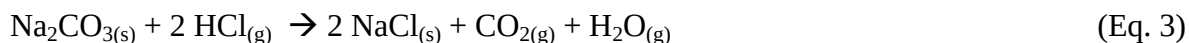
where:

NaHCO_3 = sodium bicarbonate

Na_2CO_3 = sodium carbonate

CO_2 = carbon dioxide

As the decomposition products of water and carbon dioxide exit the sorbent particles, they expose fresh material surface of activated sodium carbonate to react with acid gases.



where:

NaCl = sodium chloride

The reaction of sodium carbonate and acid gas, as well as release of water and carbon dioxide during heating, ensures high surface area for the rapid reaction. In this way, virtually all of the sorbent used is consumed. The technology is similar, in principal, to that of dry lime injection technology in that acid gas removal is directly related to the contact time between the offgas and the dry particles. Factors influencing acid gas removal efficiency include cake thickness on baghouse filter bags, reagent particle size, gas velocity, and the baghouse air-to-cloth ratio. HCl removal efficiencies ranging from 95–99% have been achieved.(6,7) Higher efficiencies are associated with greater particulate feed rates. Stoichiometric ratios on the order of 150% may be required. Advantages of the different sorbents are as follows:(6)

- For a given filter cake thickness, the porous nature of sodium bicarbonate particles during reaction results in lower pressure drop across fabric filter (for same cake thickness).
- Sodium bicarbonate particulates are inherently benign, unlike lime, which can react with moisture, such as an operator's perspiration, to produce a strong alkali.
- Sodium bicarbonate sorbent is less erosive than lime, resulting in lower maintenance costs associated with gas flow (eductor, filter bags).

- Sodium chloride produced from sodium bicarbonate will not become wet like the calcium chloride does during shutdown conditions, thereby reducing the potential to blind the baghouse filter cloths.
- In both cases, hydrated lime injection and sodium bicarbonate injection, the mixture of flyash, absorbent product, and excess sorbent have been stabilized to meet metal Toxicity Characteristic Leaching Procedure leaching requirements. However, lime is a more common waste stabilization reagent than sodium bicarbonate.
- Sodium bicarbonate costs are on the order of \$300 per ton compared to \$75–100 per ton of hydrated lime.

In general, dry reagents are not as reactive as wet alkali material, and vendor information indicates that it is necessary to use excess alkali material. If hydrated lime is used, it is proposed that 100% excess would be required for this application. Assuming a 97.2% HCl removal efficiency, a hydrated lime addition rate of 42 lbs/hr would allow for a continuous chlorine waste feed rate of 20 lbs/hr. In the case of sodium bicarbonate, assuming a 70% excess to achieve the same degree of HCl removal, 81 lbs/hr would be required for a chlorine waste feed rate of 20 lbs/hr.

The existing baghouse system installed at the WERF consists of two baghouse compartments that are installed in parallel with a common outlet plenum. Each baghouse is designed to continuously filter 8,000 acfm (at 400°F) of offgas. The units are dust-tight compartments, each containing 144 filter bags. Each bag is 4-5/8 in. in diameter and has a length of 100 in. (effective filtering length = 96 in.). Based upon the current operating conditions at WERF, the effective filtering area provides a 6:1 air-to-cloth ratio. When using a DSI system, an air to cloth ratio in the range of 2:1 or 3:1 is necessary. Eliminating the dilution air upstream of the baghouse in favor of an evaporative cooler reduces the offgas volumetric flow such that an air to cloth ratio of 3:1 can be obtained with the existing baghouse system. However, the existing baghouse filtration system will require the following modifications to support the dry sorbent process:

- Insulation is required in both the hopper and tube sheet areas to minimize condensation
- Addition of hopper heaters or heat tracing
- Addition of a hopper vibrator
- Reconfiguration of the baghouse hoppers to make the walls steeper
- Redesign the flow path of the incoming offgas
- Bag replacement using new fabric material more compatible with DSI, such as Gore-Tex
- Modification to the dust transfer system to accommodate increased particulate loading (60 lbs/hr).

The solids exiting the baghouse bottom hoppers are pneumatically transferred to a container located in the lower level of the WERF facility. The dust transfer system has been problematic for the WERF operations due to plugging of solids in the transfer line. Adding dry sorbent will significantly add to the amount of solids that need to be removed from the baghouse. The baseline cost estimate includes a simple solids transfer system. It is proposed that the solids

are gravity fed from the baghouse hoppers into containers located directly beneath them in the lower level of the facility. Rotary star valves will be used to control the solids flow from the hoppers.

The HEPA filtration system consists of a 304 stainless-steel housing, a HEPA filter rack holding an array of 16 HEPA filters, and a prefilter rack holding 16 prefilters. Nuclear-grade HEPA filters are constructed of acid-resistant media and stainless-steel frames. Industrial-grade prefilters with stainless-steel frames are installed upstream of the HEPA filters. The HEPA filtration system currently installed at the WERF is sufficient for DSI without modification.

Several Hg control technologies were considered. Based upon these studies, sulfur-impregnated carbon seems to be the best alternative for Hg capture. Carbon injection was not considered as a viable method because of process safety considerations and the known inefficiencies associated with the process. Therefore, a fixed carbon bed was chosen for volatilized Hg control. An added benefit for using carbon adsorption is that most D/Fs will also be adsorbed by the carbon.

The sulfur-impregnated activated carbon suppliers indicate that Hg removal efficiencies improve with increasing offgas temperatures until volatilization of the impregnated sulfur occurs. The temperature at which the sulfur volatilizes from the activated carbon varies with manufacturer. One type of sulfur-impregnated activated carbon has been identified that has minimal sulfur loss up to 200°C (390°F). This adsorbent has been successfully used at offgas temperatures as high as 250°F. Sulfur-impregnated activated carbon is typically placed in a fixed-bed configuration designed to ensure a maximum contact time between the offgas and carbon. To prevent the carbon beds from plugging, they are typically placed downstream of the particulate removal device (i.e., baghouse and HEPAs).

A second operating constraint is to have temperature of the offgas entering the carbon adsorber well above the offgas dew point temperature to avoid water condensation. Water condensate in the bed will decrease its adsorption capacity, and the gas flow differential pressure across the beds will increase. If this should occur, the carbon suppliers have stated that the performance efficiency of the carbon bed can be recovered by drying out the bed.

The carbon adsorption arrangement proposed for this system is a fixed bed process where the offgas will flow down through a single bed of sulfur-impregnated carbon. Prior to entry into the carbon bed, the offgas will be conditioned with approximately 3000 acfm of dilution air to lower the offgas temperature to approximately 250°F and the dew point to about 130°F. The source of the dilution air could be the building air (second dilution), which is currently added upstream of the baghouse.

Preliminary design calculations indicate that a 4-ft thick carbon bed having a surface area of approximately 210 ft² is required to achieve the desired offgas residence time in the carbon bed. At these conditions, a minimum Hg removal efficiency of 99.4% is expected. The carbon adsorber bed has been sized to control Hg emissions based upon a continuous mercury waste feed-rate of 10 g/hr for 57,600 hrs of WERF operations before the bed will need to be replaced. With this configuration and the design offgas volumetric flowrate, it is anticipated that the carbon bed will cause 10 in. of water column pressure loss.

The induced draft fans currently installed at the WERF do not have the capacity for the APCS configurations being considered. The existing fans are rated for 20 in. of water column static pressure at 8,000 acfm and 350°F. Although a slightly reduced offgas temperature (250°F) will increase the density of the offgas, which consequently increases the fan static pressure rating. The increase is not adequate to compensate for the additional pressure drop associated with the proposed APCS modifications. The fans must be rated to accommodate the maximum anticipated system pressure drop that is based upon the following estimates:

- Carbon bed—10 in. of water column
- HEPA filters—5 in. of water column
- Prefilters—5 in. of water column
- Baghouse—8 in. of water column
- Evaporative cooler—2 in. of water column
- Miscellaneous system losses—5 in. of water column
- Contingency—5 in. of water column
- Total—40 in. of water column.

One of the induced draft fans is connected to an emergency power diesel generator to ensure that the APCS continues to operate during power outages. A review of this indicates that the diesel generator has 82 kW of excess capacity available for incinerator operations.(8) This equates to approximately 110 HP. The power requirement for the existing induced draft fan motor is 65kW (87 HP).

Spray Dry Absorber (Option 2)

Option 2, as shown schematically in Figure 2, involves replacing the DSI system in Option 1 with an spray dry absorber (SDA). The SDA is commercially proven technology for semidry acid-gas removal. An SDA semidry acid-gas removal system that could be implemented at the WERF consists of the components listed below. These components would be installed downstream of the existing SCC: evaporative cooler, spray dry absorber, fabric filter baghouse, HEPA filtration, carbon adsorber, and induced draft fans and stack. The following paragraphs describes the critical design and operating features for the SDA. The remaining APCS components listed are similar to those described in Option 1.

Spray dryer absorbers are typically configured as cylindrical vessels. Water and alkali reagents are mixed to form a solution that is injected into the reactor vessel as a finely atomized spray produced by dual fluid nozzles or mechanical rotary atomizers. The caustic mixture is sprayed into the top of the SDA to flow co-currently with the offgas. The offgas enters the reactor vessel where the acid gases are absorbed into the small liquid droplets and react with the alkali reagent to form a salt. As the droplets pass through the reactor, heat from the offgas evaporates the water, cooling the offgas and forming solid particles of salt, unreacted alkali, and flyash. Acid gas in the offgas continues to react with the dry alkali. The dry solids are then collected downstream of the reactor in the baghouse. To allow for complete moisture evaporation and maximize acid conversion, offgas residence times in the SDA vessel range from 4–20 seconds.

The SDA considered for the WERF is based on an existing vessel design. The reactor vessel for the WERF SDA has been installed and is sized to accept a gas flowrate of 13,179 acfm at 750°F, while maintaining a gas residence time of 18 seconds. The original gas flowrate design was based on processing both the first and second dilution air streams currently used at WERF to cool the offgas, but without using the heat exchanger. Operating the SDA under these conditions would promote D/F formation similar to the existing three-step cooling process. Additionally, using large dilution airflows to cool the offgas makes carbon adsorption treatment expensive because more surface area is required for a given gas residence time. In order to mitigate these problems, an evaporative cooler located between the secondary chamber and the SDA is part of this option. Consistent with the existing SDA design, sodium hydroxide would most likely be used as the alkali reagent. Although slaked lime can be used instead, the slaking operation can be untidy and troublesome to operate, especially in the winter. The design calculations show that when processing 20 lbs/hr of HCl in the offgas, 45 lbs/hr of NaOH mixed with water will be required to achieve 99% HCl removal.

The main advantage for using the SDA versus DSI is that the SDA neutralizes acid gas more efficiently than the dry system. The disadvantage is the difficulty of operating the system in the proper conditions to control droplet size. If the particles are too small, they will dry out before sufficient absorption can take place. If the particles are too large, there is less surface area per volume, and gas mixing is reduced. The droplet size also affects the size of solid particles that are produced. If the droplets are too small, a very fine particulate is produced and particulate removal is difficult. Large particles may result in insufficient evaporation and may actually lead to a coating or buildup inside the reactor vessel.

Wet Scrubber Downstream of Particulate Filtration (Option 3)

Option 3 is schematically shown in Figure 2. Since the proposed MACT emission standard for HCl is based upon wet scrubber technology, Option 3 was investigated for implementation at the WERF. The Option 3 APCS consists of the following components and would be installed in the order listed downstream of the existing SCC: evaporative cooler, fabric filter baghouse, HEPA filtration, packed bed scrubber with saturator, offgas reheater with dilution air addition, carbon adsorber, and induced draft fan and stack. The descriptions for the evaporative cooler, baghouse, HEPA filter, and carbon adsorber are similar to those listed under Option 1. The induced draft fans for this option would require slightly more horsepower for the extra pressure drop over the wet scrubber and gas reheater.

The packed bed scrubber is designed to remove acid gases (typically hydrochloric acid and sulfur dioxide) from the offgas by contacting them with a caustic scrub solution. The solution pH is maintained between 8 and 10 to prevent the absorption of carbon dioxide into solution. When operating in this pH range, there is a risk that oxidized Hg will be converted back to the more volatile element, Hg.

To prevent the accumulation of the salt products in the scrubber solution, a portion of the solution needs to be withdrawn (blow-down) and replaced with fresh make-up scrubber solution. The purged scrubber solution can be treated by evaporating the excess water and stabilizing the resulting sludge for disposal, or it can be recycled back to the evaporative cooler. However, evaporating or recycling the blow-down could re-volatilize the low boiling point contaminants

including mercury. Under blow-down recycle conditions, the volatile metals could accumulate within the APCS to such a degree that either carryover of the metals from the wet scrubber will occur or the wet scrubber solution will need to be replaced. The remaining salts, including sodium chloride, in the blow-down will be dried in the evaporative cooler and collected in the baghouse.

Since the offgas exiting the wet scrubber is saturated, it must be reheated before it enters the carbon adsorber. In order to avoid D/F reformation associated with direct-fired heating of the offgas, a separate dilution air stream is heated in a direct-fired heater and added to the offgas.

Wet Scrubber Upstream of Particulate Removal (Option 4)

Option 4 represents the state-of-the-art APCS, which is a wet scrubbing system with zero liquid discharge. Option 4, as shown in Figure 2, is an APCS that uses a wet scrubber located upstream of the particulate control mechanism. In this case, the baghouse is replaced with a wet electrostatic precipitator, and the wet scrubber design includes the ability to process offgas containing particulate matter. The Option 4 APCS consists of the following components; they would be installed in the order listed downstream of WERF existing SCC: full-quench evaporative cooler, venturi wet scrubber, wet electrostatic precipitator, evaporator, condenser, offgas reheater with dilution air addition, HEPA filtration, carbon adsorber, and induced draft fan and stack.

A full-quench evaporative cooler is designed to cool the offgas to a completely saturated state. This is accomplished by introducing an atomized spray of water co-currently into the offgas exiting the SCC. In addition, excess water introduced into the evaporator as an atomized spray or along a wetted wall to ensure the offgas is cooled to its saturation temperature. Unlike in a partial-quench evaporative cooler, it is not undesirable if water is entrained in the offgas.

A venturi wet scrubber is designed to bring into intimate contact a gas and liquid stream to remove particulate greater than 1 micron in diameter with high efficiency. In addition, by controlling the solution pH, acid gases can be removed with high efficiency. These functions are achieved at the expense of a large pressure drop (on the order of 30 in. water column) across the venturi scrubber.

In a wet electrostatic precipitator, a strong electric field is maintained between high-voltage discharge electrodes and grounded collecting electrodes. The discharge electrodes are made of wires or rigid frames, and the collecting electrodes are plates. A corona discharge from the discharge anode ionizes the gas passing through the precipitator, and the gas ions subsequently ionize the undesired particles. The negatively charged particles are then captured on the collecting electrode. Wet electrostatic precipitators use a water spray to remove the captured particulate. Wet electrostatic precipitators are useful for removing gaseous fumes and mists, as well as fine particulate. In Option 4, the wet electrostatic precipitator would remove fumes and mist from the offgas exiting the venturi wet scrubber. The liquid collected in the bottom of the wet electrostatic precipitator is reused by pumping the solution back to the top. A small bleed stream must be removed and replenished with fresh water to prevent solids build-up within the unit. The bleed stream is evaporated to recover the solids as waste. The bleed stream cannot be sent back to the evaporative cooler like in Option 3 because the volatile metals will

simply re-volatilize and flow back through the wet scrubber and wet electrostatic precipitator. The volatile metals would eventually accumulate within the liquid phase and carry-over with the offgas into the downstream HEPA filter and carbon adsorber and potentially out of the stack.

There are several evaporator designs including forced-circulation and falling film evaporators, which could be used for removing the excess water from the wet scrubber and wet electrostatic precipitator blow-down streams. The primary disadvantage for using an evaporator to remove the water to such a degree that the dissolved solids form a dry product is the complexity of the process. Typically force-circulation evaporators have a heat exchanger with steam flowing through the shell side and the fluid being heated flowing through the tube side. The heated liquid is sent to a vessel where some of the water flashes into steam, which is sent to HEPA filtration along with heated dilution air to avoid condensation and subsequent plugging of the filters. The liquid phase is recycled back to the heat exchanger along with fresh make-up (blow-down feed) and reheated. As the solids within the liquid phase increase, the boiling temperature and associated vapor pressure of the solution increases due to increasing solids concentration. The viscous concentrated liquid is re-circulated at high flowrates and system pressures to avoid scale formation on the heat transfer surfaces. Periodically, part of the liquor is removed from the evaporator, and it solidifies upon cooling.

In order to prevent moisture condensation in the saturated offgas downstream of the venturi scrubber, water is removed from the offgas by cooling the offgas. The resulting condensate is recycled back to the venturi scrubber to make up for particulate-laden blowdown sent to the evaporator for concentration.

Selection of Recommended Air Pollution Control System

The APCS, described as Options 1, 2, 3, and 4, were each assessed in terms of the following: technical feasibility, relative cost, physical requirements, and impact on the WERF WAC. The evaluation was performed by the MACT Feasibility Task Team, which included WERF engineering, WERF Burn Plan Engineer, and chemical/mechanical process engineers assigned to this study. Collectively, the team members are very knowledgeable of the APC technologies that are commercially available for treating offgas produced by mixed waste incineration.

Each APCS under consideration was evaluated in terms of its potential ability to meet the proposed MACT standards for HCl, Hg, and D/F emissions. This assessment was based upon literature information and published historical data (i.e., track record) for the various APC devices that make up each system. Technical feasibility also includes effectiveness. Although all the APC options under consideration will meet or exceed the MACT rule, some systems will operate more efficiently than the others. When considering efficiency, the complexity, type, and number of equipment items were taken into account, along with the amount of material that needs to be handled.

This evaluation category includes the infrastructure and environmental conditions necessary to install and operate each APCS under consideration. The required floor space or

footprint for each system along with its utility requirements were taken into account during the evaluation process. Although all the APCSs under consideration can be installed within the existing facilities and utility limits at WERF, this criterion was included in the evaluation process to ensure that it was taken into account. Each APCS is designed to improve the control for HCl, Hg, and D/F emissions. Some APCSs can accomplish this control with more restrictive waste feed limits for these constituents than is currently in the WERF WAC. Although none of the APCSs under consideration would unduly restrict the WERF WAC after the MACT rule is implemented, this criterion was included in the evaluation process to ensure that it was considered.

To evaluate the capital cost, order-of-magnitude equipment costs were used because preliminary project cost estimates for each option would require more than the budgeted engineering and design time necessary to develop such cost estimates. This strategy is acceptable given that the total equipment cost for each option is relatively distinct from any of the others. A preliminary budget authorization-type cost estimate was made for the selected APCS option.

The order-of-magnitude equipment cost estimates that were used to evaluate the capital costs for each APCS option are listed in Table 3. These equipment costs do not include freight or installation expenses and are based upon historical equipment cost data and minimal process knowledge. The accuracy for these estimates may exceed $\pm 30\%$, but are considered sufficient for the technology decision process. Some of the equipment costs were calculated using the 7/10 rule. This involves estimating the cost of an item based upon the estimated cost of a similar piece of equipment with a correction for throughput, size, or power. In the case of equipment processing a flowrate twice as great as equipment costing \$10,000, the cost of the larger equipment is estimated to be $\$10,000 (2/1)^{0.7}$ or \$16,250. All equipment costs were corrected to first quarter, 1998 costs using the average Marshall & Swift Equipment Cost Index for process industries. A computer software program called Criterium Decision Plus was used to organize the APCS selection process and document the results. The software is designed to provide quantitative results to a qualitative decision-making process. Figure 3, a chart developed by Decision Plus, shows the technology evaluation criteria hierarchy along with their respective significance or weight factors. These factors, as assigned by a consensus of the team members, were used to calculate a rating score for each APCS option.

Option	Evaporative Cooler	Spray Dry ^a Absorber	Dry Sorbent Injection	Fabric Filter ^b	Wet ESP	Carbon ^c Adsorber	I.D. Fans	Wet Scrubber	Reheater	Evaporator	Total Equipment Cost
Dry Sorbent Injection (Option 1)	\$89,000		\$15,000	\$55,000		\$103,000	\$30,000				\$292,000
Spray Dry Absorption (Option 2)	\$89,000	\$150,000		\$60,000		\$115,000	\$33,000				\$447,000
Wet Scrubber Downstream of Baghouse (Option 3)	\$89,000			\$43,000		\$76,000	\$24,000	\$136,000	\$26,000		\$394,000
Wet Electrostatic Precipitator	\$89,000				\$500,000	\$76,000	\$24,000	\$136,000	\$26,000	\$175,000	\$1,026,000
Upstream of Baghouse (Option 4)											

a. Cost includes modifications necessary to use the existing unit.

b. Cost is to modify existing baghouse.

c. Cost is for vessel plus MEESORB @ \$4.50/lbs.

Table 3. Equipment cost summary for APCS options.

Each criterion listed above was subdivided into second level criteria, which were also assigned relative weight factors by the team. The only second level evaluation criterion that required further classification was Operating Cost, which was divided into third and fourth level criteria. Please note that the weight factors for the first level criteria add up to unity, and the lower tier criteria sum to the value assigned to the corresponding next higher level parameter. For example, technical feasibility with a weight of 0.415 means that when evaluating the APCS options, this criterion makes up 41.5% of the total score. Technical feasibility was further subdivided into track record and performance. The team then compared track record to performance using the following sentence: "With respect to *Technical Feasibility*, on a scale measuring *Importance and Ranging from Absolutely Better to Equal*, *Track Record* rates *Weakly Better than Performance*." Criterium Decision Plus then assigns a weight factor of 31.1% to track record and 10.4% to performance, which sum up to 41.5%.

After establishing the weight factors for the sub-criteria, each APCS option was rated by comparing it to the other three in a pair-wise fashion using the lowest sub-level criteria. Table 4 lists the lowest level criteria scores for each option. (Note: When all the options for a given criterion have a rating of 0.25, this means they were all rated equal for that criteria.) The criteria with the most influence on the outcome include the following: capital cost (0.215), performance (0.104), and track record (0.311) or commercially proven technology. Ease of implementation (0.126) or constructability also has a significant weight assigned. However, all the options considered were judged to be similar for evaluating this criterion. The composite score for each option is the sum of the multiplication products of the criteria weight factor and the respective score each option received for the criteria. Options 1 and 4 have the highest composite score of 32%, and Options 2 and 3 have scores of 12.7% and 23.9%, respectively. Option 1 has the highest individual scores for lowest capital cost (0.68), secondary waste issues (0.69), manpower requirements (0.58), and simplicity (0.57).

Secondary waste issues include quantity, type, and difficulty to treat and dispose. Option 4 is rated highest in reliability (0.38), performance (0.49), and track record (0.57), which indicates that Option 4 has the highest rating for technical feasibility. These results are as expected. Option 4 is the state-of-the-art facility for APC and is technically superior to Option 1. However, after adding the costs for equipment installation, utility and facility modifications, engineering and construction, the total project cost would considerably exceed the \$5 M limit for General Plant Project funding. Therefore, Option 1 is considered to be the preferred alternative because it can be implemented for less than \$5 M while meeting the technical objectives for the project.

After choosing DSI (Option 1) as the preferred alternative for this study, site trips to facilities using this offgas treatment process were taken. The two facilities visited had incinerators similar in design to the WERF system. Both units were designed to treat medical waste and were equipped with evaporative coolers followed by DSI system using hydrated lime. Neither system was equipped for Hg control.

Based upon trial burn data, each facility is able to remove 96–98% of the waste feed chlorine as calcium chloride in the baghouse solids stream. As mentioned previously, all the options considered would use fixed-carbon bed adsorbers for Hg control. Therefore, this technology was not a deciding factor when choosing which APCS option to recommend.

However, it should be noted that Hg control is a developing technology. Of the Hg control technologies considered, sulfur-impregnated carbon adsorption has the least technical risk. There is minimal commercial operating data available to confirm the vendor information provided by Nucon. Thus, the design proposed here is conservative with respect to gas residence time and operating temperature. If the vendor information is correct, then Hg emissions should be well below the proposed MACT limit.

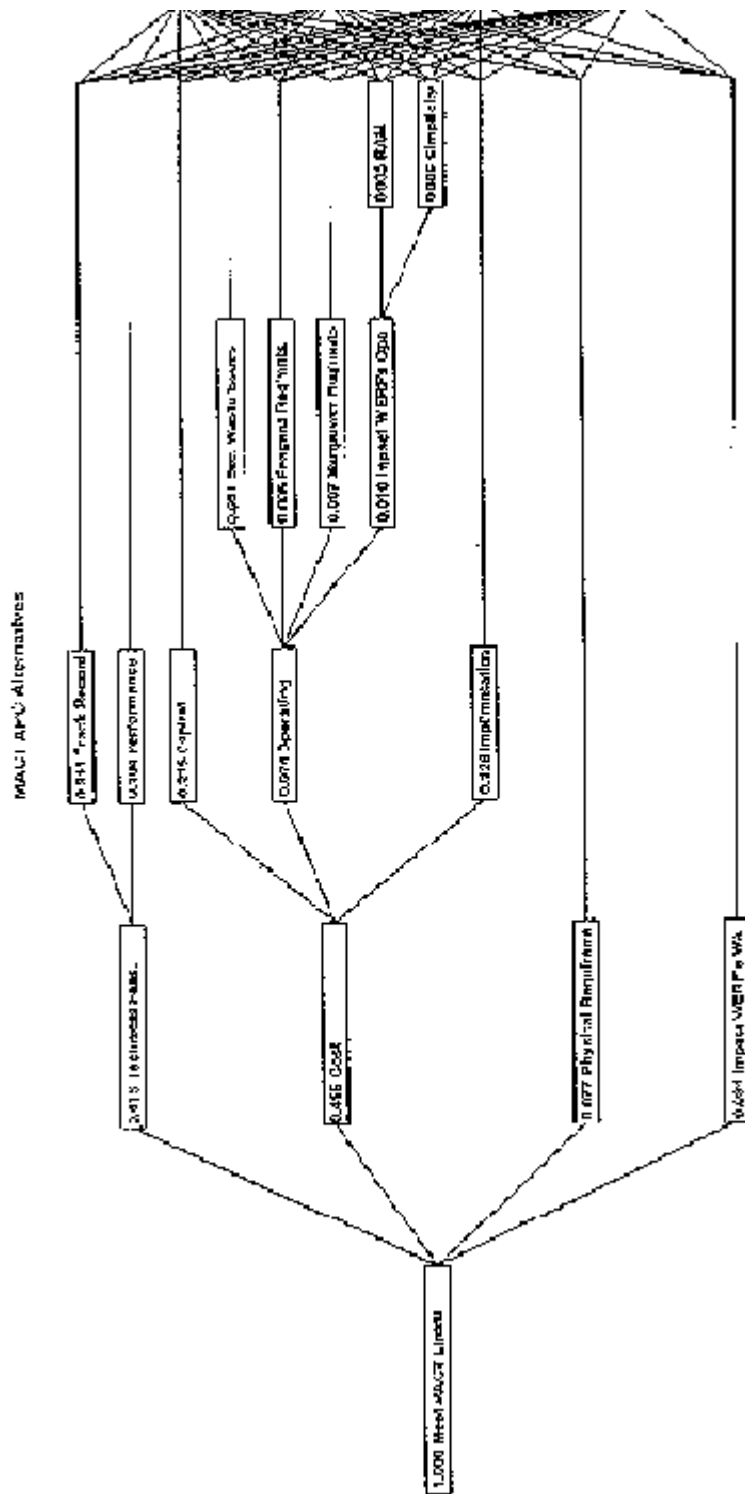


Figure 3. Technology evaluation criteria hierarchy.

Table 4. Criterium decision plus scores.

Lowest Level Criteria	Criteria Weight Factor	Option 1	Option 2	Option 3	Option 4
Impact on the WERF WAC	0.094	0.25	0.25	0.25	0.25
Capital	0.215	0.68	0.09	0.2	0.03
Secondary Waste Issues	0.051	0.69	0.09	0.17	0.06
Reagent Requirements	0.005	0.1	0.3	0.3	0.3
Manpower Requirements	0.007	0.58	0.17	0.17	0.08
Reliability, Availability, Maintainability	0.005	0.13	0.13	0.38	0.38
Simplicity	0.005	0.57	0.14	0.14	0.14
Implementation (Retrofit)	0.126	0.25	0.25	0.25	0.25
Performance	0.104	0.11	0.11	0.3	0.49
Track Record	0.311	0.14	0.05	0.25	0.57
Physical Requirements	0.077	0.25	0.25	0.25	0.25
Results		0.32	0.13	0.24	0.32

SUMMARY

As discussed in this report, the WERF Feasibility Study Project Team developed four practicable offgas treatment processes, which, if installed, would enable the WERF to meet the anticipated MACT emission limits for HCl, Hg, and D/F. The selected option is the partial quench with DSI for HCl removal followed by carbon adsorption for Hg control. This option can be implemented within the \$5 M General Plant Project funding limit.

Technical Risks and Risk Mitigation

The following is a discussion of the perceived technical risks associated with the project along with the information used to mitigate the risks. Dry sorbent injection is an HCl control technology commonly used for medical waste incinerators similar in design to the WERF incinerator. When feeding 20 lbs/hr of chlorine to the WERF incinerator, the assumed design parameters of 97.2% HCl removal can be readily supported by trial burn information from existing facilities when hydrated lime is used as the neutralizing reagent with a stoichiometric ratio of 2 to1. (Note: Sodium bicarbonate or sodium carbonate can also be used to neutralize HCl.) INEEL personnel visited two commercial medical waste incinerators equipped with DSI systems similar to the chosen option. The visitations confirmed that the required equipment is commercially available and relatively simple to operate.

A fixed bed of sulfur-impregnated carbon is the technology of choice for Hg control, and information provided by Nucon was used to size the carbon adsorption bed. Although confirmation of the vendor data was not possible, using excessive quantities of activated carbon for Hg control is well known and documented. The advantage for using sulfur-impregnated activated carbon is that much smaller quantities are required. The carbon bed was conservatively sized for a total Hg capacity in excess of a 10-year life span when feeding 10 g/hr of the volatile metal.

There are two features of the proposed APCS that will enable the WERF facility to meet the MACT standard for D/F emission. The first is the use of a partial quench to quickly cool the

offgas. Cooling the offgas from 1900 or 2000°F to 350°F in 0.5 to 1 second will minimize the formation conditions (long gas residence times in the 400 to 900°F range) for D/F. The second method for D/F control involves the carbon bed that is designed for the Hg capture. Should D/F form, the activated carbon will adsorb most of them in addition to the Hg. As stated above, the carbon bed is conservatively sized such that co-adsorption of D/F will not adversely affect the Hg capture efficiency.

A preliminary process hazards analysis was performed for the recommended option. Although the analysis was based on limited process design information, no “show-stoppers” were identified. The critique did reveal that redundant process control is required for the gas quench system to avoid damaging downstream equipment. If implemented, the DSI system will be retrofitted into the existing process and facility. A review of the WERF facility was conducted to ensure that there are no other site or mechanical conditions that would require significant equipment repair or replacement that would adversely affect the project. The facility analysis revealed no significant structural or mechanical problems that would oppose the decision to implement the chosen alternative for complying with the MACT rule.

The planning cost estimate for implementing the DSI system is \$4.2 M, which includes the design, procurement, and installation of a new offgas cooler, a DSI system with reagent storage, a fabric filter baghouse, a carbon adsorber, and two offgas induced draft exhaust fans. Except for the induced draft fans, vendor quotations were obtained for these equipment items. Preliminary equipment layout drawings and material take-offs were also used to estimate the cost for installing the recommended APCS. The cost estimate includes a 24% contingency. This contingency is within the accuracy of the cost estimate, which is considered to be -25 to +30% of the total cost without contingency.

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