Program Manager for Chemical Demilitarization

Technology Evaluation for Chemical Demilitarization

Assessment of Plasma Arc Technology for Processing of Chemical Demilitarization Wastes

Contract: DAAD13-01-D-0007
Task: T-02-AT-003

Final

Science Applications International Corporation

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by other authorizing documents

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EXECUTIVE SUMMARY

Introduction

Plasma arc (PA) technology has been used predominantly for steel making in electric arc furnaces. Several commercial-scale facilities were built as the result of efforts in the early 1970s to use PA for processing hazardous waste, including low-level mixed waste, medical waste, contaminated soils, and industrial wastes. PA technology was also evaluated for destruction of chemical warfare agents in the early stages of the U.S. Chemical Demilitarization Program (CDP). Through the 1990s, PA technology was investigated by several federal agencies for treating various wastes, including chemical warfare agent simulants and surrogate agent neutralent solutions.

The heart of PA technology is sustaining an electric arc by passing an electric current through a diatomic gas. High temperatures are achieved as the resistivity of the gas converts electrical energy to heat energy. The gases dissociate into their atomic state at 2,000°C, and ionize, as electrons are stripped away at 3,000°C. Electrically generated plasmas can achieve temperatures of 20,000°C while burning of fossil fuels has an upper practical limit of 2,000°C. In a PA system, organic constituents are volatized, pyrolyzed, or combusted, while inorganic material and non-volatized metals are bound in the molten pool. Offgas from the PA furnace typically contains products of incomplete combustion, volatized metal, particulates, hazardous oxides, and acid gases that require further treatment in a pollution abatement system.

The purpose of this report is to provide a review of significant advancements in PA technology during the last 2 years, and assess its applicability for processing secondary and closure wastes generated by CDP activities. The assessment compares the planned incineration-based process to be used at the majority of the baseline sites to using a PA system in place of, or in conjunction with, the incinerators for processing secondary and closure wastes, and the impact on cost and schedule.

Burns and Roe conducted demonstration tests with a Startech Plasma Waste Converter (PWC™) under the Assembled Chemical Weapons Assessment (ACWA) Program in 1999. This testing verified that PA would destroy secondary wastes. However, several design and operational problems prevented the demonstration from meeting all of its objectives, and led to the conclusion by both the U.S. Army and the National Research Council that the process was too immature for further consideration for the destruction of chemical warfare materiel.

Technology Update

Plasma arc is a proven and mature technology for metallurgical applications (such as base and special metal recovery, titanium manufacture, nickel based powder manufacture, super conducting alloy manufacture, and ore processing). However, it is considered to be an emergent technology in the waste processing field that has not yet seen many commercial applications, predominantly due to the lack of any financial advantages over incineration.

There are two PA systems manufactured by U.S. companies with substantial commercial experience. These are the Retech Systems LLC plasma arc centrifugal treatment (PACT™) system and the Integrated Environmental Technology (IET) LLC Plasma Enhanced Melter (PEM™). The PACT™ torch is widely used to process titanium in an inert atmosphere while the PEM™ solid graphite electrodes are used to process ferrous metals.

Other recent commercial successes include:

- Zwilag Radwaste Vitrification Facility, using a PACT-8™ furnace in Würenlingen, Switzerland, received its license to process low and medium radioactive wastes in March 2000 making it the first fully licensed PA facility in the world to process such waste.

- MGC/Retech Waste Vitrification Facility in Muttenz, Switzerland, demonstrated the applicability of PA technology to process low and medium level radioactive wastes, contaminated soil, and medical waste.

- MGC Plasma Waste Processing Facility in Munster, Germany, processed contaminated soils and residuals from the soil washing process, including soils contaminated with arsenicals and viscous mustard (HD) chemical agents.

- Allied Technology Group (ATG), Inc. facility in Richland, Washington, using GASVIT™/PEM™, was designed to process mixed waste solids and liquids and has undergone extensive startup testing and modifications.

Four examples of recent assessments performed for U.S. Government projects are as follows:

a. Tests were conducted in January 2001 on the MGC PLASMOX™ equipment at their facility in Muttenz, Switzerland, for Non-Stockpile Chemical Materiel Product. The two liquids tested simulated the neutralent from chemical treatment of the sarin (GB) and HD with a monoethanolamine (MEA)-based chemical treatment process. Six tests were conducted for a total of about 44 hours operating time. Although the unit experienced an electrode cooling water failure, the proprietary design mitigated any steam over-pressurization, thus preventing any damage to the equipment. Most of the encountered problems appear solvable with either existing technology or by optimizing the design. Solids depositing in the offgas piping was probably the most serious problem that may require significant development to solve. Overall, the tests were considered successful, and resulted in a 99.99 percent destruction removal efficiency (DRE) for monoethanolamine, and produced slag that met the Swiss toxic leaching standards.

b. MSE Technology Applications, Incorporated (MSE) designed and constructed the Plasma Ordnance Demilitarization System (PODS) for Hawthorne Army Depot (HWAD). An air permit has been issued, and the Resource Conservation and Recovery Act (RCRA) permit application, was issued for public viewing in June 2002. The PODS incinerator will treat small caliber, and hand-emplaced pyrotechnics, smokes, and flares, canisters removed from 155mm projectiles, and munition components containing small quantities of high explosives.

c. PyroGenesis, Incorporated, has developed and operated a full-scale pilot system at their Montreal, Canada, site as part of the U.S. Navy's Advanced Technology Demonstration (ATD) program. This system consists of a material pretreatment system, a patented plasma-fired eductor (PFE), a secondary combustion chamber (SCC), and an offgas treatment system. The PFE/SCC is a unique design that has no melt pool, and does not use any refractory lining. This results in a small footprint system that is easier to control and maintain. In addition, the use of a water-cooled metal shell with an air-cooled liner results in proven startup and shutdown times of less than 10 minutes. The system was designed for, and has successfully demonstrated, the capability to treat the solid wastes including paper, cardboard, food, wood, textiles, and plastics. The full-scale demonstration system has operated for over 300 hours at a nominal feed rate of 360 pounds per hour and DRE of 99.6 percent.

d. Vanguard Research Institute (VRI) owns and operates two Plasma Energy Applied Technology (PEAT) Plasma Energy Pyrolysis System (PEPS®) systems in Lorton, Virginia. One is a fixed prototype and the other a mobile system. These systems were developed for a project under the auspices of the United States Army Environmental Center and United States Army Construction and Engineering Laboratories for treating various solid hazardous wastes at Department of Defense sites. During

tests conducted by VRI in 1999 and 2000, over 5 tons of hazardous waste were successfully destroyed. A DRE of greater than 99.99999 percent was achieved for hexachlorobenzene, which was spiked into the waste to determine the efficiency of the system. The system achieved an uptime of over 85 percent during 250 hours of operation. The stack gas met all proposed U.S. Environmental Protection Agency (USEPA) Maximum Achievable Control Technology (MACT) Standards. Similarly, Toxicity Characteristic Leaching Procedure (TCLP) results for the slag were below the USEPA toxicity characteristic (TC) limits for all metals tested (arsenic, cadmium, chromium, lead, selenium, silver, and mercury).

Potential Use of PA Technology for Program Manager for Chemical Demilitarization (PMCD)

Wastes

The CDP generates a variety of wastes that can be broadly grouped into three categories: primary, secondary, and closure. Primary wastes are created directly from the process for destroying chemical weapons, including all agent, solutions that contact the weapons or agent, and all materials from the weapon. Secondary wastes include all of the material generated during the destruction process and packaging waste from the storage and transport of the munitions, such as expended demilitarization protective ensembles (DPEs), pallets, dunnage, maintenance and laboratory wastes, and spent filter media. Closure wastes encompass all of the equipment, building materials, and additional wastes generated during the post-mission closure process.

Processing Primary Waste

Of the nine stockpile chemical agent disposal sites, five are using incineration for destroying primary waste. These are:

- Anniston Chemical Agent Disposal Facility (ANCDF)

- Johnston Atoll Chemical Agent Disposal System (JACADS)
- Tooele Chemical Agent Disposal Facility (TOCDF)
- Umatilla Chemical Agent Disposal Facility (UMCDF)
- Pine Bluff Chemical Agent Disposal Facility (PBCDF).

The first four sites are completed and PBCDF is near completion.

Chemical neutralization, followed by offsite disposal, will be used at Newport Chemical Agent Disposal Facility (NECDF) and Aberdeen Chemical Agent Disposal Facility (ABCDF) for processing primary wastes. Similarly, Pueblo Chemical Agent Disposal Facility (PUCDF) will use chemical neutralization followed by onsite immobilized cell bioreaction. The design process is well underway for all of these sites.

Blue Grass Chemical Agent Disposal Facility (BGCDF) will use either a baseline incineration technology or one of three alternative technologies: neutralization followed by supercritical water oxidation (SCWO), gas phase chemical reduction (GPCR), or electrochemical oxidation. The Notice of Availability of the Draft environmental Impact Statement was issued on 30 May 2002.

Treatment facilities are also planned for processing non-stockpile recovered chemical weapons materiel at Pine Bluff, Arkansas, and Aberdeen, Maryland. Chemical neutralization, followed by offsite disposal, is also planned for both facilities. The Munitions Assessment and Processing System at Aberdeen is under construction, and the facilities at Pine Bluff are in various stages of design.

At this time, considering the use of PA technology for processing primary wastes would impose either significant cost penalties or significant schedule delays or both. Therefore, this evaluation does not discuss the use of PA for processing primary waste at these nine sites.

Processing Secondary Waste

All agent-contaminated secondary waste from five stockpile incineration sites (TOCDF, UMCDF, JACADS, PBCDF, and ANCDF) will be processed in an existing incinerator (possibly with some additional preprocessing), or chemically decontaminated and disposed at an offsite treatment, storage, and disposal facility (TSDF). All non-contaminated secondary waste will be disposed at an offsite TSDF.

The plan at ABCDF and NECDF is for agent-contaminated DPE and plastic wastes to be decontaminated through low temperature thermal desorption followed by disposal at a permitted landfill. All other agent-contaminated waste will be chemically decontaminated and disposed at an offsite TSDF. All non-contaminated secondary waste will be disposed at an offsite TSDF.

The plan at PUCDF is for all agent-contaminated waste to be thermally decontaminated in a superheated continuous steam treater (CST), and disposed at an offsite TSDF. All non-contaminated secondary waste will be disposed at an offsite TSDF.

It is intended that all agent-contaminated secondary waste will be processed onsite at BGCDF. However, the processes to be used will be dependent upon what process is selected for treating the primary wastes.

Several options are being explored for treating the secondary waste at the Pine Bluff non-stockpile facilities, including low temperature thermal decontamination, chemical decontamination, disposal at an offsite incinerator-based TSDF, and disposal at an offsite non-incinerator-based TSDF.

The use of PA or any other technology or approach different from what has already been established as the secondary waste management approach at various CDP sites would have to offer a significant schedule or cost advantage. This evaluation compares and quantifies the use of PA at these sites. The result of that evaluation shows that although PA is cost effective for processing some of the secondary waste at two of the

baseline incinerator sites, the resulting schedule delay is too great to consider its use for processing these wastes at any of the CDP sites.

Processing Closure Waste

The current approach is to maximize the use of existing onsite equipment to process closure wastes and thus minimize the need for additional treatment systems.

In general, the effort will be made to segregate closure wastes according to agent contamination. All non-contaminated waste will be sent offsite for disposal. Contaminated metal waste will be chemically decontaminated to a 3X condition and either disposed of at an onsite landfill or shipped to a smelter facility. The remaining contaminated waste will be processed in the metal parts furnace (MPF) at the incinerator sites. All of the contaminated waste will be processed in the CST at PUCDF. At BGCDF, a SCWO or an electrochemical oxidation system can be used to process plastic, wood, and spent charcoal. However, it would be very difficult and impractical to process concrete, soils, and spent blast media in either of these systems. A GPCR system could be used to process all of the contaminated closure waste at BGCDF.

PA is well suited for processing inorganic wastes with trace amounts of organic contaminants, and there is significant commercial experience in using it for this purpose. Therefore, contaminated concrete, spent blast media, glass, insulation, tank sludge, and soils all appear to be a very good match with PA processing capabilities.

The plan to process all non-contaminated closure waste at an offsite facility is economically far superior to using any of the current processes, including PA. If offsite disposal cannot be accomplished for some reason, the use of PA technology for processing some closure wastes appears economically attractive and can be implemented within the existing schedule for three sites (ANCDF, TOCDF, and UMCDF). Specifically, a PA system could be used to process a portion of the inorganic wastes. The savings in operations cost, through shortening the duration of the closure task, could more than offset the $20 million total estimated cost for a PA system,

resulting in savings ranging from $5.7 million at ANCDF to $10.2 million at UMCDF. The apparent cost savings, although substantial, are still less than the error range around this rough order of magnitude (ROM) estimate. A detailed cost and schedule study would be necessary to confirm the feasibility and value of implementing a PA system. This should include the possible sharing of existing offgas pollution abatement equipment and facilities and a sensitivity study on matching the size of the PA system to the waste generation rate. Also, schedule risks associated with attempting a construction project adjacent to an operating facility need to be examined.

Conclusion

All of the stockpile sites except BGCDF have established the process for disposal of all secondary wastes, and the choices at BGCDF have been narrowed to three options. Based on these chosen technologies, current schedules, and costs, there is no apparent benefit in using PA technology at any of these sites for processing secondary wastes. PA technology should be investigated for treating metal at non-stockpile sites in the event that further processing is necessary to achieve an acceptable condition for offsite disposal.

Offsite disposal of non-contaminated secondary and closure wastes is significantly less expensive than any of the onsite options. If offsite disposal cannot be accomplished, the use of PA technology for processing closure wastes in conjunction with the MPF shows some economic advantage at three sites (ANCDF, TOCDF, and UMCDF) within the assumptions and limitations of this ROM estimate. Similarly, any significant changes in the schedule or processing plans at these sites warrant another study of the potential use of PA.

It is recommended to continue to periodically monitor the status of PA technology in relation to PMCD needs by application of the technical evaluation criteria. It is also recommended to develop a conceptual design and cost estimate for a small PA system to treat the metal waste from the Pine Bluff Non-Stockpile Facility to a 5X condition in the event that the planned chemical decontamination proves to be insufficient. Finally,

given the promise of significant cost savings indicated by the preliminary economic analysis presented in this report, it is recommended to perform a more detailed and definitive study of potential application of PA system to process closure wastes at ANCDF, TOCDF, and UMCDF.

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SECTION 1
INTRODUCTION

1.1 Introduction

The first documented industrial use of thermal equilibrium plasma arc (PA) technology was by Siemens for metal recovery in 1878. PA technology has predominantly been used for steel making in electric arc furnaces.

Efforts to explore the use of PA to process hazardous waste began in the early 1970s, predominantly for resource recovery. As the result of this effort, several commercial-scale facilities were built to process a variety of wastes, including low-level mixed waste, radioactive waste, medical waste, contaminated soils, and industrial wastes. PA technology was also evaluated for destruction of chemical warfare agents in the initial stages of the U.S. Chemical Demilitarization Program (CDP); one early evaluation, conducted in 1987, indicated that the PA process did not offer significant advantages over baseline incineration for destruction of agents O-ethyl-S-(2-diisopropylaminoethyl)methylphosphonothioate) (VX), mustard (HD), and sarin (GB) (Lorton et al., 1987). Through the 1990s, PA technology was investigated by several federal agencies for treating various wastes, including tests for processing chemical warfare agents, agent simulants, and surrogate agent neutralent solutions.

The purpose of this report is to provide a review of significant advancements in PA technology during the last 2 years, and assess its applicability for processing secondary and closure wastes generated by CDP activities. This assessment was conducted by reviewing available information on the status and performance of current commercial and military domain applications of PA technology with focus on the successes achieved and problems encountered.

In addition to the review, this report also compares the use of PA technology to existing, incinerator-based methods for treating secondary and closure wastes from stockpile

sites. The evaluation considers the existing or established waste management approach, overall suitability of PA technology from the standpoint of accumulated experience, and possible cost and schedule advantages and disadvantages.

1.2 PA Technology Background

PA technology relies on a stable electric arc discharge through a flowing gas to produce high temperatures enabling the thermal decomposition of injected waste material. Organic constituents are volatized, pyrolyzed, or combusted, while inorganic material and non-volatized metals are amalgamated into the molten pool. Decomposed species recombine and react in cooler regions outside of the arc discharge to form offgas that typically requires further treatment.

1.2.1 Principle of Operation. The main components of the process include a processing vessel, plasma torch or electrode, melt removal system, and offgas treatment system. The configuration of the offgas treatment system may differ widely—the reactor may be followed by an oxidation chamber, quench and offgas cleanup system; conversely, offgas may be cleaned prior to its combustion in a flare, thermal oxidizer, boiler, or in an internal combustion engine.

A typical plasma arc reactor (PAR), as depicted in figure 1-1, is a fully enclosed refractory-lined chamber that operates at pressures slightly below atmospheric. It accommodates a material feed system, a plasma generator system, a crucible holding the molten pool, and a melt-draining mechanism. The function of the PAR is to thermally decompose feed molecules by exposing them to high temperatures generated by the electric arc discharge. Decomposition products include free radicals, atomic species, and ions. Breakup into free radicals occurs first, followed by breakup into atoms at 2,000°C. Ultimately, atomic species become ionized at temperatures above 3,000°C. Maximum temperatures in the reactor can reach 10,000° to 20,000°C with a typical range between 4,000° and 7,000°C. The resulting hot ionized gas (thermal plasma) is electrically conductive, which allows it to be confined and shaped by electromagnetic fields. Also, thermal plasma is quite viscous approaching liquid-like

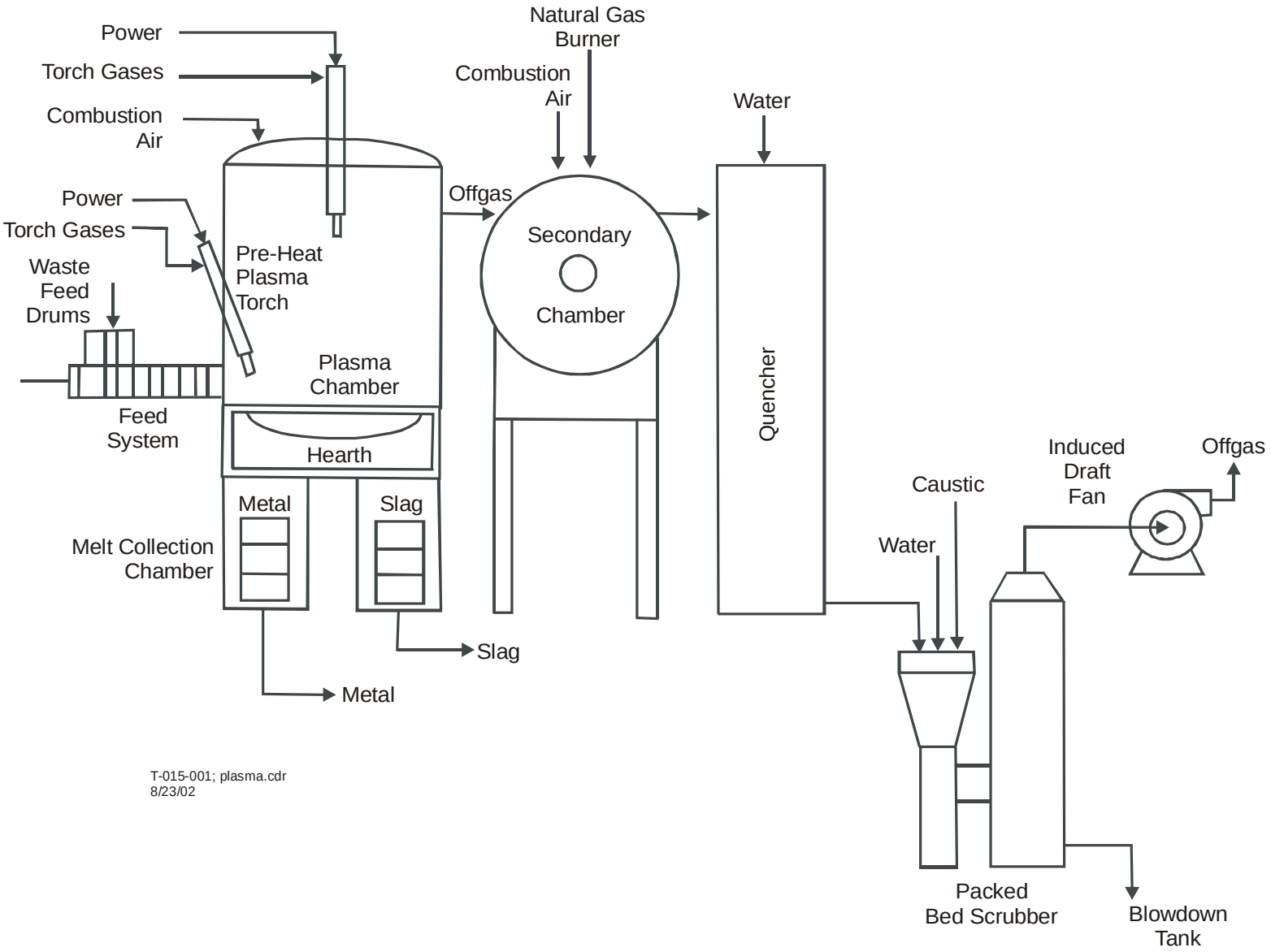

Figure 1-1. PA Process Schematic

viscosities. In thermal plasma, all species are in thermal equilibrium at the same effective temperature. This contrasts with “cold” or non-thermal equilibrium plasmas, such as what occurs in a fluorescent lamp, where the effective temperature of the electrons is much higher than that of the ion.

The PAR furnace designs vary, but all of them aim toward generating stable and sustained thermal plasmas using electric arc discharge in a gaseous atmosphere. A number of designs have been applied or tested, including stationary hearth, rotating hearth, tilting furnace, and tilted furnace. There is also variability in the design of plasma generators. In its most simple form, an electric potential is applied across two electrode rods. Plasma arc discharge is started when the rods are brought sufficiently close together and the gas gap between the rods becomes ionized. Upon starting the arc, the rods can be moved apart from each other. Graphite rod electrodes are mainly limited to a direct current (DC) anode for transferred arc applications. In order to increase the electrode life and improve plasma stability, water-cooled hollow copper anodes and co-planar tubular electrodes have been developed.

In general, plasma can be generated in the transferred or non-transferred mode. In the transferred arc mode, the arc is developed between the torch electrode (anode) and the conducting molten pool (cathode). The electrode can act as either the anode or cathode; however, it is anodic in virtually all applications due to a much greater corrosion rate at the cathode. Transferred arc works well in situations where a large heat source is needed, for example, in metallurgical processing or mixed waste vitrification. It is also often used in hazardous waste processing applications where the waste is introduced onto the molten pool near the plasma arc. Both graphite and water-cooled hollow copper anodes can be used to generate transferred arc plasmas. In water-cooled hollow copper anodes, the carrier gas, such as nitrogen (N_2), is injected into the well cavity tangentially to promote gas vorticity, which helps move the arc around the electrode surface to minimize localized erosion. Transferred arc designs are further categorized into long arc, short arc, and submerged arc.

DC graphite electrodes are consumable and designed to be continuously fed into the torch assembly. In contrast, water-cooled copper electrodes are designed to provide maximum life, which is especially challenging in the non-transferred mode of plasma generation. Electrode life has been one of the key issues in PA technology development. Water-cooled hollow copper electrodes offered by Retech Systems, LLC, are claimed to achieve typical life of 200 hours. Europlasma has a commercial, 7-metric ton per day fly ash vitrification PA system, in Bordeaux, France, that has exceeded 400 continuous operating hours without torch maintenance (Girold et al., 2002). Aerojet General Corporation tested platelet-cooled electrodes that are claimed to offer ten times the longevity of water-cooled copper electrodes (Counts et al., 1999). Failure of water-cooled electrodes can result in introduction of cooling water directly into hot PA furnace leading to pressure excursions. Graphite electrodes do not have this problem; however, they are consumed much faster than copper electrodes, especially in the oxidative atmosphere (for that reason, all graphite electrode systems operate under inert/reducing or steam-reforming atmospheres).

In the non-transferred mode, both electrodes are in the torch assembly above the melt. Carrier gas is injected into the torch, flows through the arc region, and is ejected as a hot plasma jet from the end of torch. The material to be processed can be introduced either onto the melt near or under the torch or directly inside the plasma torch downstream of the electrodes, thus ensuring complete exposure to maximum PA temperatures. The non-transferred arc torches are commercially available from 1 kilowatt (kW) to over 6,000 kW and have been successfully used in scrap metal recovery, plasma spraying, metal cutting, aerospace heat shield testing, chemical synthesis, and organic waste processing. The non-transferred arc plasma is generated using water-cooled co-planar tubular electrodes with external magnetic coils to promote arc rotation that results in a more uniform wear. It requires higher gas throughput than transferred mode arc. Recently, Retech Systems, LLC, introduced a dual mode electrode that is capable of operating in both transferred and non-transferred mode.

Both DC and alternating current (AC) can be used to generate plasma. DC is used with all electrode-based plasma generators. High frequency AC is used in induction-coupled

plasma generators that do not use electrodes and are free of electrode deterioration problems; however, they suffer from somewhat lower melting efficiencies and are not as common as electrode-type plasma generators.

In general, three types of PA environments can be distinguished: oxidizing, reducing/inert, and steam-reforming.

In the oxidizing environment, air is typically used as the carrier gas inside the PAR. The advantages include lower concentrations of non-oxidized or partially oxidized species in the offgas, and reduced electric energy input per unit feed due to heat released by exothermic oxidation reactions. The disadvantages include high offgas volume, high nitrogen oxides (NO_x) generation, higher corrosion potential, and reduced electrode life.

In the reducing/inert environment, an inert carrier gas such as N_2, argon, or helium, is used to enable thermal decomposition to occur under the reducing conditions without oxygen (O_2). The advantages include very low NO_x formation, small offgas volume, improved electrode life, and the ability to generate syngas or fuel gas for beneficial use after cleanup. The disadvantages include a potentially complex offgas cleanup train, carbon formation, and generation of hazardous gas cleanup residuals.

In the steam-reforming environment, steam is used as a source of O_2 to promote steam-reforming reactions. The advantages include the ability to co-process aqueous wastes along with organic-rich wastes, reduced carbon formation, and low NO_x formation. The disadvantages include potential for cold-spotting, increased corrosion potential, reduced electrode life (especially for carbon electrodes), and high offgas volume.

Depending on the PA environment, the ions, atoms, and free radicals exiting the plasma torch region can recombine into molecules that are smaller and simpler than the original feed molecules, undergo oxidation reactions if O_2 is present, or undergo reactions with steam to form carbon oxides and hydrogen (H_2). In practice, all three types of reactions occur. In the inert/reducing and steam reforming atmospheres, some direct oxidation

will occur because air in-leakage is unavoidable in reactors operating at slightly below atmospheric pressure. Also, because most wastes do contain some water, steam-reforming reactions will occur in both air and inert gas blown plasma reactors. Some PARs are designed to operate in a hybrid mode; for example, where both steam and air are introduced along with N_2. Hot reactor offgas is typically a mixture of carbon monoxide (CO), carbon dioxide (CO_2), water (H_2O), H_2, N_2, and methane with lesser concentrations of organic species that may be partially oxidized. The gas typically contains solids that are formed because of reactions (such as carbon black or phosphorus pentoxide) or present due to physical entrainment (slag or salt droplets or particles).

Inorganic compounds in the waste typically partition between the melt and the offgas, depending on volatility and reactivity. Settled salts may undergo reactions with molten ceramic compounds or glasses contained in the slag; the salts carried out with the offgas are removed in the offgas cleanup train. Depending on the application, it may be desirable to inject alkaline compounds, such as calcium carbonate, along with glass to make the slag more alkaline and tie up acidic species, such as hydrogen fluoride and sulfur dioxide, or to use additives designed to lower the melting point and viscosity of slag. Choice of slagging materials is of particular importance when vitrifying radioactive wastes where the aim is to incorporate radioactive nuclides and heavy metals in a non-leachable glass matrix. Both slag and metals are removed periodically using hot tap, thermal valves, and other techniques. The Retech Systems, LLC, plasma arc centrifugal treatment (PACT™) centrifugal furnace is unique with respect to melt drainage: during normal operation, the rotation of the furnace and the resulting centrifugal force keeps the melt away from the centrally located drainage port in the furnace bottom; upon slowing down the furnace rotation, the melt can be drained in a controlled fashion into forms.

1.2.2 Offgas Process Configuration Options. Two basic offgas process configuration schemes are distinguished:

a. A PAR followed by a thermal conditioning chamber, gas cleanup train, and combustion as a synthesis gas (syngas)

b. A PAR followed by combustion, followed by the gas cleanup train.

In the first scheme, the PAR offgas is partially oxidized under reducing conditions in the thermal conditioning chamber to reduce concentrations of carbon and organic compounds before being cleaned and then combusted. The key advantage of this scheme is that the cleaned gas can be combusted beneficially, such as in an internal combustion engine or a waste heat boiler. Consequently, the system may receive a Resource Conservation and Recovery Act (RCRA) permit as a resource recovery device or a miscellaneous thermal treatment device and not as an incinerator, which may accelerate the schedule and enhance public acceptance of the project. A lower offgas flow rate may provide an additional advantage, resulting in smaller cleanup equipment.

The key disadvantage is that a complex cleanup train may be required since the offgas can contain significant concentrations of products of incomplete combustion (PIC), carbonyl compounds, cyanides, soot, halogen compounds, and phosphorus-bearing solids. Waste streams from the offgas cleanup train, such as separate soot and organics-contaminated scrubber blowdown streams, would have to be either recycled to the PAR, posing additional technical challenges, or disposed of separately. Examples of syngas processes include the Integrated Environmental Technology (IET) Plasma Enhanced Melter (PEM™) and Burns and Roe/Startech Environmental Corporation Plasma Waste Converter (PWC™). A PEM™ system was tested with binary precursor simulants and is also part of a commercial plant in Richland, Washington, for processing of mixed wastes that has recently undergone shakedown testing and startup, albeit with problems. A PWC™ system was tested at the Aberdeen Proving Ground-Edgewood Area, under the Assembled Chemical Weapons Assessment (ACWA) program.

In the second scheme, hot PAR offgas is combusted in the direct thermal oxidizer before cleanup. The advantages include complete oxidation of organics, reduced compounds, soot, and phosphorus compounds. This significantly simplifies the design of the cleanup train and makes its operation and performance more predictable, reliable, and robust. Also, scrubber blowdown is composed primarily of inorganic salts and, as such, can be easily treated using conventional means, such as evaporation or pH adjustment. The disadvantages include heightened similarity to traditional incineration systems normally resulting in being permitted under the RCRA Subpart O incinerator requirements, larger offgas cleanup equipment, and limited energy recovery. A waste heat boiler can be used to recover heat from the thermal oxidizer; however, to preclude formation of dioxins and furans, it is often preferable to fast-quench the thermal oxidizer offgas without energy recovery. Examples of the second scheme include the PACT™ system, the MGC-Plasma AG (MGC)/Burns and Roe PLASMOX™ system, and the Exide Super-High Temperature Metal Recovery System, which is based on the Asea Brown Boveri electric arc steel-making furnace that incorporates induction coils for stirring the melt.

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SECTION 2
SUMMARY OF PRIOR EVALUATIONS

2.1 Previous Evaluations

Burns and Roe/Startech PWC™ System Demonstration Project for ACWA Program

The Startech PWC™ technology employs an N_2-blown PA torch operating in a transferred arc mode inside the refractory-lined furnace containing a pool of molten metal and slag. The liquid agent or waste is pre-mixed with steam and introduced directly into the furnace. Solid wastes, such as shredded dunnage, spent carbon, and demilitarization protective ensemble (DPE) suits would be placed into cardboard containers and introduced into the furnace via a conveyor feed system. This conveyor feed system could also be used to introduce other solid waste, including metal parts and glass. Steam is the primary reactant with volatilized and dissociated organic and inorganic compounds. The furnace offgas primarily contains CO, CO_2, H_2, N_2, and O_2. Oxygen is present mainly from air infiltration into the furnace that is maintained under a slight negative pressure (0 to -5 inches of water column [in. w.c.]). In the gas polishing system (GPS), the plasma converter gas (PCG) undergoes a rapid quench, passes through a venturi to remove particulates, and then is routed through a countercurrent two-stage packed scrubber irrigated with caustic solution to remove acidic species, such as hydrochloric acid, hydrofluoric acid (HF), and phosphorous acid. After passing through a demister, the gas is sent through a high efficiency particulate air (HEPA) filter and then to a thermal oxidizer to fully oxidize combustibles such as CO, H_2, and other species (formaldehyde and carbonyl sulfide were detected in the offgas at trace concentration levels [ACWA, 1999]). The system is also equipped with a Hold, Test and Release/Rework (HT&R) Tank to quarantine the PCG prior to release to the thermal oxidizer. In the ACWA test setup, the HT&R Tank was used for holding gases resulting from explosive deactivation of munitions in a detonation chamber for processing through the PWC™ furnace.

During ACWA tests in 1999, the PWC™ system experienced a series of performance problems including a failure of the electrode cooling system that resulted in the release of cooling water into the hot furnace, leading to over-pressurization of the furnace and release of offgas into the operating room. Encountered problems caused numerous process configuration changes, such as the use of N_2 instead of argon or CO_2 as the plasma gas, use of transferred arc instead of non-transferred arc, and use of a side injection port instead of introducing the feed through the torch. Overall, the system was found capable of effective destruction of ACWA feeds; however, performance problems experienced during the testing drastically lowered the evaluators' level of confidence in technology maturity.

The PWC™ test system at Aberdeen Proving Ground-Edgewood Area successfully demonstrated its ability to process a one-quarter-scale replica of a chemical agent identification set (CAIS) with chloroform ampoules (Hale et al., 2000). The furnace pressure remained negative throughout the test. The pressure spike due to gas evolution from the chloroform ampoules was less than that registered when the furnace top port was opened for insertion. No chloroform was detected in the scrubber offgas or in the scrubber liquor. The overall destruction removal efficiency (DRE) was 99.9989 percent.

Based on a post-testing inspection of the system and review of supplemental information, it appears that uncertainties and problems encountered during ACWA testing can be resolved through use of proper engineering controls and additional testing and development. Specifically, the following observations were made:

a. Control of air infiltration must be improved to limit the O_2 concentration in the PCG to prevent combustion or an explosion. Improved control of O_2 levels also reduces the formation of soot and the associated plugging of downstream equipment, and would increase the heating value of PCG.

b. It may be necessary to provide a wet electrostatic precipitator (or an equivalent control device such as reverse jet scrubber) to control

emissions of submicron particulates that may contain phosphoric acid and arsenic. It is noted that localized atmospheric haze was observed during thermal oxidizer operations near the exhaust stack. Similarly, high NO_x concentrations in the thermal oxidizer offgas warrant the use of the selective catalytic reduction or an equivalent process to abate NO_x emissions.

c. It is unlikely that the PCG heating value and the level of toxic contaminants, such as formaldehyde, will allow the PCG to qualify as a waste-derived boiler fuel.

d. An efficient and safe electrode changeout system is needed to improve worker's safety.

e. An improved feed system is needed to prevent premature feed ignition and to accommodate non-containerized feed materials, such as deactivated munition carcasses.

f. An improved system for safe emptying of molten metal and slag that minimizes worker intervention should be developed.

g. The near-catastrophic electrode failure indicates the need for the system to be upgraded to current practices to prevent a pressure excursion.

Overall, the Startech PWC™ technology requires significant additional development and demonstration testing. The ACWA program abandoned further pursuit of the Startech PWC™ technology.

2.2 National Research Council (NRC) Position

The NRC assessed the capability of PA technology for destroying both primary and secondary wastes based on the system described in paragraph 2.1. They concluded

that the Burns and Roe process was too immature to be considered as a viable solution for the destruction of assembled chemical warfare weapons (NRC, 2000).

A dunnage and secondary waste campaign was conducted as part of the demonstration tests. The feed consisted of carbon filter media, DPE, wooden pallets spiked with 4,000 parts per million (ppm) pentachlorophenol, decontamination solution with carbon filter media, and M55 rocket shipping and firing containers. A mix of the material was processed in six separate tests. The pentachlorophenol was destroyed in all of the tests (no DREs were provided). The report noted that the offgas in only one of the tests had any appreciable fuel value. Also, a level of 5 to 7 percent O_2 in the offgas indicated problems throughout all of the tests with air leakage into the system. This high level of O_2 mixed with combustible gases was noted as a significant safety concern. A final comment was that "…the committee is concerned about the appropriateness, reliability, and robustness of the measurement and control systems."

Some of the key findings of the NRC are:

a. Scale-up from pilot scale to full-scale would likely present significant challenges.

b. Selection of the plasma feed gas will significantly affect performance based on the physical and chemical properties of the gas.

c. Recycling the scrubber liquors to the PAR may not be viable. Some constituents may again volatize into the offgas. In addition, they noted the risk of sodium chloride and sodium fluoride salts reacting with silicon dioxide to produce hazardous chemicals (tetrachlorosilane and tetrafluorosilane).

d. Pressure excursions may occur in the PAR from such causes as torch cooling water leaks and trace explosives.

e. The offgas may not meet the stringent U.S. Environmental Protection Agency (USEPA) requirements for classification as an exempted syngas. It was noted that none of the offgas from the demonstration tests met the USEPA requirements.

f. It is likely that a PA system would be permitted as an incinerator.

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SECTION 3
TECHNOLOGY UPDATE

3.1 Overview

Plasma arc is a proven and mature technology for metallurgical applications (such as base and special metal recovery, titanium manufacture, nickel based powder manufacture, super conducting alloy manufacture, and ore processing). However, it is considered to be an emergent technology in the waste processing field that has not yet seen many commercial applications, predominantly due to the lack of any financial advantages over incineration.

There are two PA systems made by U.S. companies with substantial commercial experience. These are the PACT™ system and the PEM™ system. Both systems have plasma generators with proven performance in the metals industry. The PACT™ torch, a hollow copper electrode, is widely used to process titanium in an inert atmosphere. The PEM™ solid graphite electrodes are used to process ferrous metals.

The commercial PACT™ systems for waste processing have operated primarily under oxidative conditions, with the exception of a system recently installed in Japan that operates under reducing conditions. Both installed commercial PEM™ systems operate under reducing or steam-reforming conditions as graphite electrodes are rapidly consumed if the concentration of O_2 increases above a few percent. Regulators and public officials in the state of Washington, who have been long opposed to incineration systems, have accepted the IET PEM™ system, operating under reducing conditions, as an alternative to incineration.

The following systems have made recent progress in technical advancements or maturity of the process. Descriptions include a brief overview of the system, its performance, and status.

3.2 Allied Technology Group, Incorporated (ATG) GASVIT™/PEM™

This $30 million commercial PA system was built and permitted in Richland, Washington, by ATG for treatment of radioactive and hazardous wastes. The plant processed thousands of pounds of waste during startup and shakedown, accumulating hundreds of hours of operation. Financial problems and contributing technical difficulties caused the firm to close the operation and file for bankruptcy in December 2001 (Smith, 2002). The system was designed to treat 1,050 tons per year of a variety of low-level mixed waste. It consisted of a PEM™ 1.2-megawatt (MW) PA system provided by IET. The system was designed to operate in a hybrid steam-reforming/inert/controlled oxidation mode and utilized DC graphite electrodes for plasma generation and submerged AC electrodes for joule heating of the melt.

Three feed injection subsystems were provided: a canister feeder for injection of containerized solid wastes (up to 350 pounds per hour [lb/hr]), a screw feeder for injection of friable bulk solids (350 lb/hr), and a liquid injection lance with a centrifugal pump for feeding liquid wastes, including polychlorinated biphenyls, at a rate of 250 lb/hr. The reactor offgas was routed to the thermal residence chamber (TRC) equipped with O_2 injection ports, then to a partial quench, filter baghouse, acid gas scrubbers, mist eliminator, HEPA filters, mercury filters, and a flameless thermal oxidizer provided by Thermatrix. The oxidizer offgas was fully quenched and then mixed with the building exhaust before being routed through additional HEPA filters, followed by carbon filters, induced draft fans and a stack. Scrubber blowdown was evaporated in a shallow pan evaporator. Evaporated water was condensed and fed into the boiler to generate steam for the PAR. Several modifications to the system occurred during the initial testing. These changes included replacing a peristaltic pump with a centrifugal pump for liquid injection, adding air or O_2 injection ports to the PAR and TRC, and adding Teflon®-coated bags to the filter baghouse.

The main problems encountered during shakedown and startup included:

a. Excessive soot formation in the PAR (especially when processing plastic waste) that could not be overcome by steam injection alone. Carbon black caused fires in the baghouse, clogging of the scrubber circulation lines and nozzles, and foaming in the scrubber, liquid evaporator, and steam generator. Oxygen injection into the PAR plenum, offgas exhaust line, or into the TRC proved to be a much more effective and reliable means to minimize soot formation. Operators learned to control soot formation by adjusting the O_2 and steam intake based on the color of the gas in the PAR plenum.

b. The system was not designed for handling hydrofluoric acid. Consequently, high corrosion rates were experienced in the heat exchanger cooling the circulating scrubber liquor, in the offgas duct between the baghouse, and in the scrubber. High corrosion rates were also experienced with liquid injection lances leading to their frequent replacement.

c. The melted metal drain supplied with the unit never worked satisfactorily. Slag drains that relied on thermal valves worked well, but required time and effort to adjust the melt viscosity or to coax out old glass before glass flow could be initiated.

d. The flameless thermal oxidizer did not develop stable temperature profiles. This led to frequent shutdowns and excessively high downtime. Several causes of instability were postulated, such as channeling, design deficiencies, and damage during installation; however, the exact cause of instability was not determined. It is planned to replace the flameless oxidizer with a more proven and robust direct thermal oxidizer before the plant starts up.

e. The PAR was damaged following a glass overflow episode, resulting in the operators monitoring glass melt level using dipsticks once a shift.

f. Shorting of the arc was experienced when processing spent activated carbon. In addition, the carbon feed rate had to be substantially reduced in order to avoid piling on top of the melt.

g. External arcing resulted in an electric-shock injury to one of the operators. It also created holes in the reactor shell and destroyed internal and external tubing. The causes of arcing were identified as direct ground (instead of floating ground) for the DC electrodes and bending of the taps of the electrical leads for the AC electrodes too close to a metal surface. These deficiencies were satisfactorily corrected.

h. Excessive foaming was experienced in the shallow pan evaporator.

i. Significant foaming and other problems caused severe operational problems with the steam generator. This was corrected by discontinuing the use of evaporator condensate as feed water makeup to the steam generator.

ATG's court-appointed trustee is working to overcome problems experienced during shakedown and startup. On the positive side, GASVIT™/PEM™ system has demonstrated its equivalency to incinerator performance with high DREs for the target compounds, acceptable stack emissions for particulates, hydrogen chloride and chlorine, and extremely low emissions of furans and dioxins (Smith, 2001).

3.3 IET PEM™ Process Tests

This project, under contract to Non-Stockpile Chemical Materiel Product (NSCMP), conducted limited testing of IET's PEM™ 1/2-ton system to treat simulant of methylphosphonic difluoride (DF). Tests were completed in the fall of 2001 to obtain

corrosion data on various materials of construction and to demonstrate stable "prototypical" operation (Stone and Webster, 2002).

The system was comprised of a 3.5-foot diameter refractory-lined horizontal 304SS vessel, a TRC, partial quench, baghouse, packed bed caustic scrubber, high efficiency mist eliminator, induced draft fan, flame arrester seal pot, and ground flare. The system operating conditions were 100 kW of energy to the DC graphite transferred arc electrodes, 30 kW of energy to the AC graphite joule heating electrodes, a 2-second gas residence time in the TRC with O_2 injection, and a melt temperature of 1,200° to 1,400°C. During initial test runs, the partial quench ducting and the baghouse were plugged with black tar-like material and white powder. Subsequently, the partial quench was converted into a full quench and the baghouse eliminated. Also, polyvinyl chloride (PVC) cooling water lines to the electrode holding blocks were replaced with stainless steel tubing following a failure of the PVC lines from condensed HF corrosion. Following modifications, the system achieved 90 continuous and stable hours of operation under inert/steam-reforming conditions with both N_2 and steam injected into the melter. The following summarizes the main findings and observations:

a. Organic compounds and particulates present in TRC offgas accumulated in the circulating quench liquor and in scrubber liquor. Particulates were removed with in-line cartridge filters. Analysis of the solids indicated high levels of total organic carbon (TOC), fluoride, and phosphorus plus the presence of polycyclic aromatic hydrocarbons (PAHs) up to 6,000 ppm. Analysis of liquid samples indicated the presence of TOC up to 2,000 ppm, PAH in the range of 0.2 to 0.5 ppm, fluoride, phosphorus, and cyanide. A layer of black material was found in piping between the TRC and quench and between the quench and scrubber.

b. Stack gas downstream of the ground flare showed significant presence of particulates (three times the regulatory limit), which was attributed to poor flare burner management. Stack gas concentrations of CO, NO_x, and SO_x

were below the regulatory thresholds, but the total hydrocarbons (THC) limit was exceeded.

c. Mass balance calculations revealed that phosphorus did not accumulate in the melt. Only 54 percent of input phosphorus was accounted for in the exit streams indicating a possibility of phosphorus accumulation inside the system. The fluorine balance closed at 81 percent.

d. All coupons tested (304L, 304, 316L, AL6XN, Hastelloy C-2000, and Hastelloy B-3) exhibited similar weight loss, except for Hastelloy B-3 where weight loss was more pronounced. No catastrophic failures were observed.

The report identified Hastelloy C-2000 and AL6XN as materials of choice for all wetted surfaces of a plasma system for treating DF. It recommended additional long-term performance tests to provide better corrosion data, to investigate methods to reduce or eliminate formation of PAH, to investigate the formation of particulates, and to collect sufficient data to enable a confident design of the offgas cleanup system. The report makes no recommendations on changes to process configuration to minimize PAH and solids formation or on what to do with separated solids or contaminated quench and scrubber liquors.

3.4 Zwilag Radwaste Vitrification Facility in Würenlingen, Switzerland

The Zwilag consortium, which is funded by four Swiss nuclear plants, is responsible for treating low and mid-level radioactive waste generated by nuclear plants (Wenger, 2002). Around 1993, Zwilag contracted with MGC-Plasma AG for a plasma thermal treatment facility to treat low- and mid-level radioactive waste. After several years of construction and systemization, the facility received its license to process low- and medium-level radioactive wastes in March 2000, making it the first fully licensed PA facility in the world to process such waste. When MGC entered bankruptcy, Zwilag took over construction and operation of the treatment facility. After Swiss regulators approve

the results of the testing with non-radioactive wastes planned for the fall of 2002, the unit will be used for commercial treatment of low-level radioactive waste. When fully operational, this Wüerlingen plasma thermal treatment facility will operate twice a year for 2 to 3 weeks to process radioactive waste from the nuclear plants. The facility is in the final stages of commissioning and is projected to be fully operational early in 2003. The plant is processing hazardous waste as part of its pre-commissioning activities.

The facility uses a Retech PACT™-8 furnace to treat whole 200-liter drums filled with solid waste under oxidative conditions at processing rates of 500 to 2,000 lb/hr followed by a secondary combustion chamber. The operating temperature of the gas within the reactor is 1,100 to 1,200°C. MGC and Zwilag have contracted with others for the feed and offgas treatment systems. The offgas section includes an electrostatic precipitator followed by a scrubber and finally HEPA filters.

Zwilag has significantly upgraded the components of the Retech system with little participation by Retech. The primary purposes of the upgrades were to increase the system reliability and simplify its maintainability for service with radioactive wastes. Major modifications included the complete replacement of the original refractory with a proprietary refractory, and the installation of a bottom drain that is closed during normal operation. Zwilag also plans to replace the electrical power supply supplied by Retech.

Recent runs have indicated that Zwilag has satisfactorily solved all operating problems observed in previous runs except for the draining of the melter. Zwilag's new and proprietary refractory has served well for over 1,000 hours of processing paper, plastic, wood, concrete, gas masks, and metallic parts, demonstrating better wear and electrical properties than the original.

Zwilag has demonstrated the capability to operate the system with minimum production of carbon black. Their basic concept is to start up with nitrogen as the sweep gas and then feed oxygen. It is critical that the oxygen feed begins at the right time and that the concentration is carefully controlled.

The puff effect from feeding full drums complicates the control of oxygen and requires a much larger offgas system than what would be necessary for a continuous system with the same throughput. Thus, Zwilag retrofitted the primary furnace with a torch to slice the drums into sections, permitting the contents to fall out more evenly. Previously the material fell out of the drums as the drum melted and lost structural integrity, which occurred over a comparatively short period. The solid material does not directly contact the walls when it falls into the reactor since the primary reactor bowl is always coated with a layer of slag, or glass at startup.

Although Zwilag has drained the reactor at least 20 times during startup, they have not solved the problems that prevent reliable draining. The drain has plugged several times, and at least once the whole system had to be shut down to chip the slag out of the drain line and melt it out with an oxygen lance. Zwilag is installing an oxygen lance that will allow drain plugs to be removed without shutting the melter down or physical intervention by an operator. Zwilag has learned how to minimize plugging the drain. After opening the drain, hot gases from the reactor are allowed to pass through the drain to heat the entire drain line into the mold. If the rotation of the bowl is slowed before the drain line has reached temperature, the line plugs. Similarly, Zwilag reported that the drain line will plug if they wait too long to begin slowing the drum after introducing the hot gases. The reason for this is unclear, but it may be because the gas temperature drops without fresh feed or the chemistry of the melt changes.

3.5 MGC/Retech Waste Vitrification Facility in Muttenz, Switzerland

This facility was built to demonstrate the applicability of PA technology to process a wide range of hazardous wastes, including low- and medium-level radioactive wastes, contaminated soil, and medical waste. It uses an 8-foot diameter rotating crucible and a 1.2-MW transferred arc plasma torch to accommodate batch feed of whole 200-liter drums. Both solids and liquids can be processed under oxidative conditions. The drums are punctured above the crucible to allow for gradual liquid feed. The facility has operated within the regulatory requirements.

3.6 MGC Plasma Waste Processing Facility in Munster, Germany

This 211 million Deutchmark facility was designed primarily to process contaminated soils and residuals from the soil washing process. It supplements activities of an existing 100-ton per year batch incineration plant designed to process chemical warfare agents from World War I era munitions and the associated wastes. The soils contaminated with arsenicals and viscous mustard first undergo classification into coarse, intermediate, and ultrafine (less than 20 micron) fractions. The ultrafine fraction is fed directly to the PAR. The fraction between 20 micron and 2 millimeters (mm) undergoes attrition and conditioning steps, followed by several wash and flotation steps. The flotation concentrate is injected into the PAR. Inside the PAR, the soils and inorganic materials are converted into slag, the organic materials are pyrolyzed, then oxidized in the secondary oxidation chamber. The offgas is quenched and cleaned in wet scrubbers before discharge. Soil throughput is about 1,000 kilograms per hour. The system is currently awaiting an operating permit.

3.7 Burns and Roe/MGC PLASMOX™ Technology Tests to Treat Chemical Warfare Materiel (under NSCMP)

This project conducted limited engineering scale testing of the Burns and Roe/MGC PLASMOX™ Plasma process to treat simulants of neutralents resulting from chemical treatment of HD and GB with monoethanolamine (MEA) (Stone and Webster, 2002). Six discrete tests were completed in January 2001 at the MGC facility in Muttenz, Switzerland, with the objective to collect performance data of the RIF-2 PLASMOX™ system and evaluate its ability to destroy neutralent streams containing significant concentrations of MEA and water. The five specific objectives were: (1) determine maximum throughput for each feed; (2) demonstrate continuous, stable operation for each feed; (3) establish whether effluents can be disposed of at a treatment, storage, and disposal facility (TSDF) without additional treatment; (4) determine the fate of phosphorus for GB-MEA simulant, and (5) obtain engineering data to support a preliminary design. The simulants used in the tests were not fully representative of

actual MEA neutralents of HD and GB—the MEA-HD simulant did not contain sulfur compounds, and the GB-MEA simulant did not contain fluorine compounds.

The test system incorporated the following equipment: a Retech-designed 200-kW rotary furnace melter with water-cooled, N_2 purged copper transferred arc electrodes, a stationary top section, and rotating crucible with a center discharge melt port), a rapid oxidation chamber (either air or O_2-blown down flow cyclonic combustor with a 2-second gas residence time and auxiliary burners), rapid quench (co-current horizontal spray section with cyclonic separator, liquor recycle, and external liquor cooling coil), acid scrubber, caustic scrubber, gas reheater, induced draft fan, and exhaust stack. The PAR was operated under inert/reducing atmosphere using N_2 as the carrier gas; however, O_2 was also fed to mitigate the formation of soot. In addition, significant water, present in the liquid feed to the reactor, contributed to steam reforming reactions. Liquids were injected using a lance—the first time that a RIF-2 PLASMOX™ system was ever tested with liquid feed. A lance was used to inject the liquids, which were initially aspirated with pulsed air before being injected in the PAR.

An electrode failure during the workup test run resulted in cooling water leaking onto the melt. This led to a violent steam pressure excursion and excessive vacuum in the piping downstream of the rapid quench section of the offgas cleanup train. The reason for electrode failure was attributed to excessive localized arcing from aspirated liquids getting inside the electrode. Replacing the pulsed air aspiration system with a metering pump solved this problem.

Following modifications, the system achieved a total of 18.75 hours of operation in three separate runs with GB-MEA simulant at an average 145 kW torch power loading and a 12.3 liter per hour average liquid feed rate. With HD-MEA simulant, the system achieved 24.6 hours of operation at an average of 141 kW torch power loading and an 8-liter per hour average liquid feed rate. The following summarizes the main findings and observations made during the runs:

a. The RIF-2 unit operated continuously in all but one of six runs.

b. Slag deposition on the rim of the crucible caused it to bind up during one run. Examination of reactor design and additional testing was recommended.

c. Slag deposits were observed forming in the exhaust throat of reactor. The cause is uncertain, but localized cooling due to liquid injector proximity was theorized as a contributing factor. Locating the liquid injection lance near the gas outlet port also increased the possibility of feed material bypassing the reaction zone.

d. Examination of post-test electrode erosion indicated a strong possibility that the electrode life would readily meet MGC's expected 20-hour lifetime.

e. The reactor vessel was not damaged during the electrode failure and resulting steam pressure excursion. This was attributed to the small size of MGC's proprietary electrode, which uses a cooling water flow that is 4 times less than comparable designs. This small volume of cooling water limits the amount of water that can be released into the melt with an electrode failure, and the size of any resulting pressure excursion. To further protect the reactor from steam overpressure due to electrode failure, MGC designed their Munster and Zwilag systems with surge expansion tanks to accommodate excess steam.

f. Tests indicated a possibility that silicon-rich slag may be volatilized and deposited in the offgas piping given that the slag remaining after the 12-hour sustained HD-MEA simulant run had considerably lower silicon concentration than the slag remaining after the other five runs of 6 hours duration each.

g. Solids deposited in the reactor outlet piping were extensive, blocking more than 50 percent of the cross-sectional area. Three distinct phases were

found: dark green solids with the dominant presence of phosphorus and chlorine, light green solids with dominant chlorine, and white solids with dominant silicon and chlorine present. Carbon levels in all three phases were very low.

h. Scrubber liquor samples indicated TOC in the 12 to 30 ppm range, PAH in the 0.2 to 0.7 ppm range, and nitrates in the 0.4 to 184 ppm range. The maximum phosphorus concentration detected during GB-MEA simulant runs was 140 ppm. MEA and dimethyl methylphosphonate (DMMP) were not detected. Cyanide, formaldehyde, and acetaldehyde were detected at sub ppm levels. Dioxins and furans were detected at a 0.05 to 11 nanogram per liter level. Because they showed constant levels throughout the test, it was theorized that their presence was caused by equipment contamination from prior tests.

i. The slag passed the Swiss equivalent of the Toxicity Characteristic Leaching Procedure (TCLP) test implying it could be disposed in a nonhazardous landfill.

j. Missing data prevented the calculation of a phosphorus balance.

k. The scrubbers were only 65 percent efficient in removing phosphorus during GB-MEA simulant runs. Very high particulate and chromium loading in the stack gas indicated poor particulate removal by the offgas cleanup system. The presence of chromium was attributed to the crucible refractory. The suggested use of HEPA filters by Burns and Roe/MGC was not attempted after calculations indicated the HEPA filters would blind within 20 hours of operation.

l. Destruction of MEA was greater than 99.99 percent in all tests.

m. The maximum measured NO_x concentration in the stack gas was 217 ppm, which is below the Clean Air Act New Source Performance Standards regulatory threshold of 388 ppm (dry volume at 7 percent O_2). Carbon monoxide and hydrocarbons emissions were well within the regulatory limits.

n. Concentration of dioxins and furans in the stack gas was measured at 0.25 nanogram (ng) toxicity equivalent quotient per cubic meter (TEQ/m^3), which is above the National Emissions Standards for Hazardous Air Pollutants limit of 0.20 ng TEQ/m^3 for hazardous waste combustors. Their presence was attributed to potential prior contamination of the system.

Overall, the report recommends pilot testing of the prototype production system using NSCMP liquids and solid wastes to investigate various materials of construction and solid deposition phenomena.

3.8 MSE Technology Applications, Incorporation (MSE) Plasma Ordnance Disposal System (PODS) (Hawthorne Army Depot)

MSE designed and constructed the PODS for Hawthorne Army Depot (HWAD). The modified Title V Air Permit was issued to HWAD on 2 January 2002. Their RCRA permit application as a hazardous waste incinerator was issued for public viewing on 6 June 2002.

The PODS consists of a feed system, plasma furnace with air pollution control equipment, and a water treatment system. The reactor is refractory-lined, with a water-cooled stationary hearth that is not refractory-lined. The system uses a pair of DC, water-cooled, hollow-core copper torches for both transferred and non-transferred mode of operation depending on type of feed. It will operate in an oxidizing mode and includes a secondary diesel-fired combustion chamber. The offgas system includes a quench/absorber, wet scrubber, baghouse, catalytic NO_x removal system, and continuous emission monitoring equipment.

The unit will operate in a semi-batch mode, with a theoretical feed rate of 350 lb/hr. After the unit is filled, feed is discontinued for about 30 minutes to ensure full oxidation of crucible contents. Then the hot melt is poured from the crucible and feed is resumed.

The PODS incinerator will treat pyrotechnics and other ordnance considered hazardous primarily due to their reactivity (explosive content) and toxicity (metallic and explosive content). This includes small caliber, and hand-emplaced pyrotechnics, smokes, and flares, canisters removed from 155mm projectiles, and munition components containing small quantities of high explosives.

3.9 U.S. Navy ATD Program

The Naval Surface Warfare Center, Carderock Division (NSWCCD) has signed a Cooperative Research and Development Agreement (CRADA) and patent license agreements with PyroGenesis, Incorporated, as part of the U.S. Navy's ATD program. PyroGenesis has been supporting NSWCCD developing a Navy-patented PA waste destruction system prototype for treatment of shipboard solid waste. The company plans to commercialize this technology for cruise ships, and as part of the CRADA, NSWCCD personnel will provide technical expertise assisting PyroGenesis in this endeavor.

PyroGenesis has developed and operated a full-scale pilot system at their Montreal, Canada, site. This system consists of a material pretreatment system, a patented plasma-fired eductor (PFE), a secondary combustion chamber (SCC), and an offgas treatment system.

The PFE/SCC design offers several unique advantages over other PA systems. The small size (the PFE is about 3 feet in length and 2 feet in diameter) permits installing several units in parallel for improved reliability and maintainability. The PFE and SCC consist of water-cooled metal shells with an air-cooled liner. The liners, which have an expected life of 6 months, were demonstrated to be replaceable within 30 minutes. The lack of any refractory lining permits startup and shutdown times of less than 10 minutes.

The pretreatment system consists of several pieces of standard commercial equipment. Food, paper, and cardboard wastes are reduced to a size of less than 1/4 inch in a pulper. The slurry from the pulper is partially dried in a water extractor, where the solid content is increased from less than 1 percent to approximately 50 percent by weight. Wood, textile, and plastic wastes are sized-reduced in a shredder, then passed through a metal extractor and are blended with the slurry from the water extractor in a hopper/mixer. The contents of the hopper/mixer are discharged to a mill, where the material is pulverized to fine fibers approximately 15 microns in diameter, and further dried to a 4 percent moisture content. Then the fibers are air-conveyed into the PFE.

The PFE consists of a non-transferred plasma torch that generates a plasma plume in the throat of a water-cooled, lined eductor. The fibers are heated in the PFE to more than 1,100°C and partially oxidized as they pass through the plasma plume, breaking down into primarily H_2 and CO. The gases discharge from the PFE directly into the four-chamber SCC, where additional air is injected to achieve complete combustion of all of the gases. The temperature in the SCC is typically maintained between 1,000° to 1,100°C. The wall temperature of the SCC is kept above 750°C to prevent the formation of dioxins and furans.

The offgas treatment system consists of a rapid quench, where the gases are cooled to less than 100°C, a venturi scrubber, an oxidation tower for oxidizing nitric oxide to nitrogen dioxide, and an absorption tower for removing acid gases. The treated gases pass through an induction fan and are discharged through a stack equipped with a continuous emission monitoring system.

The pilot system has operated for over 300 hours at a nominal feed rate of 360 lb/hr and DRE of 99.6 percent.

3.10 Vanguard Research Institute (VRI)/Plasma Energy Applied Technology (PEAT) Plasma Energy Pyrolysis System (PEPS®)

VRI owns and operates two PA systems in Lorton, Virginia. One unit is a fixed prototype, and the second unit is a 3 to 5-ton-per-day mobile system on trailers. These systems were designed and built by PEAT, Incorporated, of Huntsville, Alabama, for a project under the auspices of the United States Army Environmental Center and United States Army Construction and Engineering Laboratories.

The PEPS® uses a screw auger with air locks to feed solid waste to a refractory lined, steel chamber. The system operates in a steam-reducing atmosphere with a non-transferred plasma torch. The design concept generates syngas, but for pilot tests, the offgas was combusted in a natural gas-fired thermal oxidizer. The fixed system uses a wet, caustic scrubber for quenching, particulate removal, and removal of acid gases. The offgas from the scrubber passes through an induced draft fan, which discharges into the thermal oxidizer. The offgas from the thermal oxidizer is released to the atmosphere through a stack equipped with a continuous emissions monitor.

VRI conducted pilot tests at their Lorton, Virginia, facility in 1999 and 2000 for the U.S. Army program. The waste processed during testing in August 1999 was agriculture blast media, consisting of ground walnut shell contaminated with paint particle pollutants containing low levels of cadmium and chromium. The feed consisted of approximately 9,000 pounds of agricultural blast media combined with about 46,000 pounds of water, glass, and other additives. The total 55,000 pounds of feed was processed at an average 194-lb/hr feed rate. This test involved about 250 hours of operations with a reported equipment uptime of 85.2 percent.

A second set of tests was conducted in August 2000, where mixed blast media was processed. This second test spanned 27 hours with 100 percent equipment uptime at a 204-lb/hr feed rate.

Arcadis, Geraghty and Miller, Incorporated, provided independent sampling and analyses. The feed was spiked with hexachlorobenzene to determine the DRE. The results of this testing was a DRE of greater than 99.99999 percent. Air emissions during the processing of both of the feeds met all proposed USEPA Maximum Achievable Control Technology (MACT) Standards. The dioxin/furan levels were 1 to 2 orders of magnitudes lower then the standard. Particulate matter was the only parameter of concern during the tests, at 34.1 milligrams per dry standard cubic meter, it was right at the limit of 34.0 milligrams per dry standard cubic meter. VRI reported that in previous demonstrations with similar materials the emissions from the thermal oxidizer were well below the USEPA New Source Performance Standards NO_x limits (250 ppm), and sulfur dioxide (SO_2) limits (55 ppm). They noted the measured values in these previous tests were between 50 ppm to 61 ppm for NO_x and between 0 ppm to 21 ppm for SO_2. The TCLP results for the slag showed below minimum detectable levels for all of the metals reported (arsenic, cadmium, chromium, lead, selenium, silver, and mercury). All of these values were well below the USEPA Toxicity Characteristic limits for these metals.

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SECTION 4
POTENTIAL CHEMICAL DEMILITARIZATION APPLICATIONS OF PA TECHNOLOGY

The CDP generates a variety of wastes that could be generally characterized as follows:

4.1 Stockpile Primary Wastes

Stockpile primary wastes are main process wastes generated by the stockpile destruction activities. These wastes are the principal focus of the stockpile destruction activities and include the following streams:

- Drained chemical warfare agents
- Spent decontamination solutions and rinsewater
- Munition carcasses
- Burster tubes, fuzes
- Empty ton containers.

Stockpile primary wastes will be generated at all nine stockpile sites. Five stockpile sites have been designed to process these wastes using incineration:

- Anniston Chemical Agent Disposal Facility (ANCDF)
- Johnston Atoll Chemical Agent Disposal System (JACADS)
- Pine Bluff Chemical Agent Disposal Facility (PBCDF)

- Tooele Chemical Agent Disposal Facility (TOCDF)

- Umatilla Chemical Agent Disposal Facility (UMCDF).

Three of the remaining four sites will use chemical neutralization of agents followed by a secondary treatment of the resulting hydrolysate using biodegradation or supercritical water oxidation (SCWO). These are:

- Aberdeen Chemical Agent Disposal Facility (ABCDF)

- Newport Chemical Agent Disposal Facility (NECDF)

- Pueblo Chemical Agent Disposal Facility (PUCDF).

Blue Grass Chemical Agent Disposal Facility (BGCDF) will use either a baseline incineration technology or one of three alternative technologies: neutralization followed by SCWO, gas phase chemical reduction (GPCR) or electrochemical oxidation. Overall, with the exception of BGCDF, the technology for treatment of stockpile primary wastes has already been established and is currently in various stages of implementation. Therefore, this evaluation will not discuss the use of PA technology for processing the primary wastes at these nine sites.

4.2 NSCMP Primary Wastes

NSCMP primary wastes are main process wastes generated by destruction of non-stockpile chemical materiel and include:

- MEA-based and sodium hydroxide-based agent neutralents

- 1,3-dichloro-5,5-dimethylhydantoin-based agent neutralents from the Rapid Response System (RRS) processing of CAIS materials

- Binary precursors DF and O, O'-ethyl diisopropylaminoethyl methyl phosphonite (QL) or their neutralents

- Spent decontamination solutions, spent rinsewaters, and scrubber blowdown

- Metal wastes, such as shrapnel, cut munition fragments.

Currently there are two non-stockpile materiel treatment facilities being implemented, one in Pine Bluff Arsenal, and one in Aberdeen Proving Ground.

At Pine Bluff Arsenal, the Munitions Management Device, Version 2 (MMD-2) equipment will be used at the Pine Bluff Non-Stockpile Facility (PBNSF) to access, drain, and neutralize agent, and clean the mutilated munition carcasses to a 3X level. All neutralent and secondary wastes are to be shipped to a TSDF, and 3X metal will be shipped to the Rock Island Smelter. The binary precursors, QL and DF, will be chemically neutralized at the Binary Destruction Facility and the resultant neutralents either shipped to a TSDF or further treated onsite. Similarly, all agent-containing CAIS items are to be chemically neutralized in the RRS, with the resultant neutralents and wastes shipped to a TSDF. Additionally, the Explosive Destruction System will be used for processing some select munitions.

This approach was selected after a conceptual design utilizing PA technology was completed. The decision by the Arkansas Department of Environmental Quality to permit the PA units as incinerators, and associated public concern on the use of incineration was a significant factor in dropping the PA technology concept. The additional schedule risks associated with the development and environmental permitting of the PA technology were additional factors in the decision. A detailed overview of this conceptual design is included in appendix C.

At Aberdeen Proving Ground, the similar Munitions Assessment and Processing System (MAPS) project provides for munition access, drain, and chemical neutralization followed by offsite disposal of all primary wastes at a TSDF.

Opportunities for use of PA technology or other competing technology for onsite treatment of NSCMP wastes currently appear limited.

In addition to processing secondary and closure wastes discussed in the following paragraphs, the only other potential application of PA technology in treating NSCMP wastes would be its use for processing metal waste to a 5X condition since the efficacy of chemical decontamination of shrapnel to 3X condition has not been demonstrated and remains unproven. Such application will not require demonstration testing or development since metal processing capabilities of PA are well proven and there is sufficient data accumulated from the previous tests involving agents to expect that any residual heels that may still be present in metal waste will be effectively destroyed.

4.3 Secondary Wastes

Secondary wastes are generated as a byproduct of primary waste destruction activities at both stockpile and non-stockpile sites and can be accumulated and processed after the primary wastes are destroyed. These wastes may or may not be contaminated with chemical warfare agents and other hazardous substances and include the following streams:

- Spent charcoal
- Discarded DPE and personal protective equipment (PPE) items
- Dunnage wood
- HEPA filters

- Laboratory wastes
- Spent lubricants and hydraulic fluids
- Contaminated rags
- Metal waste resulting from maintenance activities
- Plastic waste resulting from maintenance activities.

The approach to secondary waste management has already been defined at five incineration sites. The approach at two alternative technology sites and two ACWA sites are still being developed. No approach has yet been defined for management of the secondary waste from the non-stockpile demilitarization activities. Applicability of PA technology for secondary waste processing is addressed further in this document.

4.4 Closure Wastes

Closure wastes are generated by post-mission closure activities at both stockpile and non-stockpile chemical demilitarization facilities and can include the following streams:

- Contaminated concrete
- Contaminated soils
- Sandblast and CO_2 pellet blast residuals
- Contaminated wood
- Insulation
- Glass

- Metal waste (equipment pieces, piping, instruments, wiring, etc.)
- Plastic waste (gaskets, seals, panels, etc.)
- Discarded DPE and PPE items
- Spent decontamination solutions and spent rinsewater
- Tank sludge
- Spent lubricants and hydraulic fluids.

The current approach is to maximize the use of existing onsite equipment to process closure wastes and thus minimize the need for additional treatment systems. Closure activities were initiated at JACADS, the first site to be closed, after the completion of the agent demilitarization mission in late 2000. On other sites, closure activities are at various planning stages.

Table 4-1 summarizes current approaches to manage secondary and closure wastes at various CDP sites.

Section 5 provides discussion of how PA technology can be best applied to each category of wastes, except for the stockpile primary wastes. Where feasible, each of the wastes will be characterized in terms of its composition, and quantity; the PA process configuration described; and, characterized in terms of potential risks and unknowns.

Table 4-1. Current CDP Approach to Management of Agent-Contaminated Secondary and Closure Wastes[a]

	Baseline Incineration					Alt Tech Program		ACWA		NSCM Program
	ANCDF	PBCDF	TOCDF	UMCDF	JACADS	ABCDF	NECDF	PUCDF	BGCDF	PBNSF
Waste Description	Anniston AL	Pine Bluff AR	Tooele UT	Umatilla OR	Johnston Island	Aberdeen MD	Newport IN	Pueblo CO	Blue Grass KY	Pine Bluff AR
Secondary Wastes										
Spent charcoal	CMS/DFS	CMS/DFS	CMS/DFS	CMS/DFS	CMS/DFS	TSDF	TSDF	MPT	Note[b]	Note[c]
DPE/PPE waste	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Dunnage wood	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Miscellaneous wastes:						TSDF	TSDF	MPT	Note[b]	Note[c]
HEPA filters	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Laboratory wastes	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Spent lubricants and hydraulic fluids	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Contaminated rags	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Metal waste resulting from maintenance activities	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Plastic waste resulting from maintenance activities	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Closure Wastes										
Contaminated concrete	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Depainting residuals (sandblast grit, CO_2 pellet blast residuals)	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Contaminated wood	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Insulation	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Glass	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Metal waste (cut equipment, piping, instruments, wiring, etc.)	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Plastic waste (gaskets, seals, panels, etc.)	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
DPE/PPE waste	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Spent decontamination solutions and spent rinsewater	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Spent lubricants and hydraulic fluids	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]
Tank sludge										
Contaminated soils	MPF	MPF	MPF	MPF	MPF	TSDF	TSDF	MPT	Note[b]	Note[c]

Table 4-1. Current CDP Approach to Management of Agent-Contaminated Secondary and Closure Wastes[a]
(Continued)

Notes:

[a] Secondary and closure wastes that are not agent-contaminated will be sent offsite to a TSDF for disposal. Agent-contaminated wastes will be minimized by segregation, testing, and decontamination.
[b] Waste management technology is yet to be established for BGCDF. Competing alternatives include SCWO, GPCR, and Silver II
[c] Waste management technology has not been established. It is expected that secondary and closure wastes will be disposed offsite, which is the current disposal plan for the primary NSCMP wastes.

CMS/DFS	=	carbon micronization system coupled to the deactivation furnace system
DPE	=	demilitarization protective ensemble
HEPA	=	high efficiency particulate air
MPF	=	metal parts furnace
MPT	=	metal parts treater
PPE	=	personal protective equipment
TSDF	=	commercial treatment, storage, and disposal facility

SECTION 5
TECHNICAL EVALUATION OF PA PROCESSING OF SECONDARY AND CLOSURE WASTES

5.1 PA Processing of Secondary Wastes

Secondary wastes mainly consist of various auxiliary materials that are contaminated by agent or other hazardous compounds during primary waste destruction activities. These wastes can be classified as follows:

- Spent charcoal
- Discarded DPE and PPE items
- Dunnage wood
- Miscellaneous wastes:
  - HEPA filters
  - Laboratory wastes
  - Spent lubricants and hydraulic fluids
  - Contaminated rags
  - Metal and plastic waste resulting from maintenance activities.

Secondary wastes from five stockpile incineration sites (TOCDF, UMCDF, JACADS, PBCDF, and ANCDF) are to be managed as follows: agent-contaminated charcoal will be processed using a carbon micronization system (CMS) working in conjunction with

the existing deactivation furnace system (DFS); contaminated wood and other wastes that cannot be reliably decontaminated to the 3X condition will be processed through the metal parts furnace (MPF) system. The remaining agent-contaminated wastes will be chemically decontaminated to the 3X condition before disposal through a licensed TSDF. All agent non-contaminated wastes will also be disposed through a licensed TSDF.

At two alternative technology sites, ABCDF and NECDF, the current approach entails chemical decontamination followed by offsite disposal; low temperature thermal desorption for DPE and plastic wastes followed by land filling, and/or direct offsite disposal at a commercial TSDF.

For the remaining two ACWA sites (PUCDF and BGCDF), the general approach has been to seek a "total solution" that includes onsite disposal of agent-contaminated secondary wastes. At PUCDF, under the recently selected chemical neutralization and biotreatment main process concept, the wastes would be thermally decontaminated with superheated steam in the CST with the offgas routed through a catalytic oxidizer. At BGCDF, a number of technologies have been proposed and tested, and the process of selecting a technology is in progress. No secondary waste management strategy has yet been established for the PBNSF site.

Table 5-1 summarizes available estimated quantities of secondary and closure wastes generated by the baseline sites. The following paragraphs discuss PA application for main secondary waste stream processing and compare it briefly to the currently planned management methods.

5.1.1 Spent Charcoal. Originally, the Army designed a dunnage incinerator (DUN) system to dispose of all secondary wastes, including spent charcoal. After experiencing problems with DUN operations at JACADS, the Army investigated several alternatives, including CMS, a thermal desorption auger system, an improved DUN, burning of slurried material in the liquid incinerator (LIC), and burning charcoal in the MPF. The CMS was selected by the Army as the technology of choice to programmatically replace

Table 5-1. Estimates of Secondary Waste from Operations and Closure Wastes for Baseline Sites

Waste Type	Description	Total Waste Quantity (tons)												Comments
		ANCDF[a]			PBCDF[a]			TOCDF[a]			UMCDF			
		Operations	Closure	Total	Operations	Closure	Total	Operations	Closure	Total	Operations	Closure	Total	
Wood Dunnage	Wood munition pallets	2,806	0	2,806	1,329	0	1,329	3,743	0	3,743	1,647	0	1,647	Total wood dunnage estimated for each site.
1X Contaminated Wood Dunnage	Wood dunnage required to be treated onsite	140	0	140	1,329	0	1,329	187	0	187	1,647	0	1,647	Based on site-specific permit requirements. PBCDF and UMCDF cannot treat wood offsite. ANCDF and TOCDF can treat wood offsite. Approximately 5% of their total wood is estimated to be contaminated, thus requiring onsite treatment.
Agent-Contaminated Charcoal		233	103	336	163	103	266	160	77	237	621	103	724	Contaminated carbon estimated for each site.
Spent HEPA, Prefilter, Empty Charcoal Tray		60	58	118	41	58	99	36	57	93	84	69	153	Spent HEPA, prefilter, empty charcoal tray estimated for each site.
Agent-Contaminated 3X DPE		21	9	30	24	9	33	38	9	47	17	9	26	Operations estimates are based on TOCDF information of 20,769 lbs. 3X DPE/2 yrs. Closure estimates are the MDB size ratio[b] times the JACADS estimated closure amount.
Agent-Contaminated 1X DPE		18	6	24	20	6	26	24	6	30	15	6	21	TOCDF operations estimate is based on TOCDF information of about 12,806 lbs 1X DPE/2 yrs. Other sites are based on the JACADS operations estimate (more conservative). Closure estimates are based on JACADS estimate closure amounts.
Agent-Contaminated Hydraulic Fluid		1	1	2	1	1	2	1	1	2	1	1	2	Based on JACADS estimated lbs waste/month*1.5 and the ratio closure amount. Ratio 1.5 used because of the larger quantity of hydraulic equipment.

Table 5-1. Estimates of Secondary Waste from Operations and Closure Wastes for Baseline Sites (Continued)

Waste Type	Description	Total Waste Quantity (tons)												Comments
		ANCDF[a]			PBCDF[a]			TOCDF[a]			UMCDF			
		Operations	Closure	Total	Operations	Closure	Total	Operations	Closure	Total	Operations	Closure	Total	
Inert Bulk Solid Waste - Aluminum Waste		1	1	2	1	1	2	1	1	2	1	1	2	Based on the sum of MDB size ratio[b] times the JACADS estimated closure amount and (for UMCDF, ANCDF, TOCDF) the waste due to an additional LIC.
Spent Decontamination Solution	Used decontamination solution and contaminated water	1	1,420	1,421	1	1,420	1,421	1	1,420	1,421	1	1,420	1,421	Based on the sum of MDB size ratio[b] times the JACADS closure amount and (for UMCDF, ANCDF, TOCDF) the waste due to an additional LIC.
Inert Bulk Solid Waste-Metal	Nuts, bolts, munitions machinery equipment, valves, pipes, empty metal drums, metal instrumentation, HVAC ducts, charcoal filter train housing	6	1,154	1,160	6	1,154	1,160	10	1,154	1,164	5	1,154	1,159	Based on the sum of MDB size ratio[b] times the JACADS estimated closure amount and (for UMCDF, ANCDF, TOCDF) the waste due to an additional LIC.
Inert Bulk Solid Waste-Concrete	Complete removal of the ECR-A, ECR-B, MPB and TOX floors, and scabbling (1/4 inch) of all toxic category room (A, B, A/B, and C walls, floors, and ceilings)	0	803	803	0	803	803	0	803	803	0	803	803	Based on UMCDF MDB drawings (A, B, A/B, and C) assumes 20-foot ceiling height and 1/4-inch scabbled from all surfaces. ECR, TOX, and MPB floors are removed.
Other Bulk Solid Waste - Miscellaneous	Electronic hardware, electronic parts and conveyor parts	1	285	286	1	283	284	1	285	286	1	285	286	Based on the sum of MDB size ratio[b] times the JACADS estimated closure amount and (for UMCDF, ANCDF, TOCDF) the waste due to an additional LIC.

Table 5-1. Estimates of Secondary Waste from Operations and Closure Wastes for Baseline Sites (Continued)

Waste Type	Description	Total Waste Quantity (tons)												Comments
		ANCDF[a]			PBCDF[a]			TOCDF[a]			UMCDF			
		Operations	Closure	Total	Operations	Closure	Total	Operations	Closure	Total	Operations	Closure	Total	
Inert Bulk Solid Waste Greater Than 5% Plastic	2-inch sandwich wall panels, polypropylene-lined pipe, pipe fittings and valves, and doors	0	172	172	0	132	132	0	172	172	0	172	172	Based on the sum of MDB size ratio[b] times the JACADS estimated closure amount and (for UMCDF, ANCDF, TOCDF) the waste due to an additional LIC.
Halogenated Plastic and Rubber	Conduits, cable trays filled with wire, Teflon®-lined steel pipe, pipe fittings, and valves	6	127	133	7	125	132	11	127	138	5	127	132	Based on the sum of MDB size ratio[b] times the JACADS estimated closure amount and (for UMCDF, ANCDF, TOCDF) the waste due to an additional LIC.
Non-halogenated Plastics	Boots, plastic tools, plastic containers, rubber hoses, rubber gloves	3	2	5	3	2	5	26	2	28	2	2	4	Based on the sum of MDB size ratio[b] times the JACADS estimated closure amount and (for UMCDF, ANCDF, TOCDF) the waste due to an additional LIC.
Combustible Bulk Solid Waste	Paper, wood, absorbent pillows, cotton goods, non-halogenated synthetic fibers, polystyrene, and polyethylene waste	4	26	30	4	26	30	6	26	32	3	26	29	Based on the sum of MDB size ratio[b] times the JACADS estimated closure amount and (for UMCDF, ANCDF, TOCDF) the waste due to an additional LIC.
Sludge from Agent Collection System and Spent Decontamination Solution Tanks		1	1	2	1	1	2	1	1	2	1	1	2	Based on the sum of MDB size ratio[b] times the JACADS estimated closure amount and (for UMCDF, ANCDF, TOCDF) the waste due to an additional LIC.
Laboratory Solid Wastes[c]	Silver fluoride pads and other laboratory solid waste	2	0	2	2	0	2	5	0	5	1	0	1	Based on previous TOCDF operations waste estimate. Laboratory wastes are assumed not to be produced during closure.

Table 5-1. Estimates of Secondary Waste from Operations and Closure Wastes for Baseline Sites (Continued)

Waste Type	Description	Total Waste Quantity (tons)												Comments
		ANCDF[a]			PBCDF[a]			TOCDF[a]			UMCDF			
		Operations	Closure	Total	Operations	Closure	Total	Operations	Closure	Total	Operations	Closure	Total	
Laboratory Aqueous Waste[c]	Waste organic solvents, waste acid solution waste heavy metal solution, acidic, oxidizing	3	0	3	3	0	3	7	0	7	2	0	2	Based on previous TOCDF operations waste estimate. Laboratory wastes are assumed not to be produced during closure.
TOTAL for Onsite Disposal		501	4,168	4,669	1,607	4,124	5,731	515	4,141	4,656	2,407	4,179	6,586	
TOTAL for Offsite Disposal		3,166	4,168	7,334	1,607	4,124	5,731	4,071	4,141	8,212	2,407	4,179	6,586	

Notes:

[a] These facilities are similar in size and design to the UMCDF. Estimates for these facilities are based on the UMCDF concrete estimate and UMCDF (A, A/B, B, C) square footage.

[b] MDB size ratio= (square footage UMCDF A, A/B, B, C rooms) divided by the (square footage JACADS A, A/B, B, C rooms). This was used to scale up JACADS estimates for the larger CONUS sites.

[c] This waste category was not included in the JACADS estimate.

CONUS = continental United States
DPE = demilitarization protective ensemble
ECR = Explosive Containment Room
HEPA = high efficiency particulate air
HVAC = heating, ventilation, and air conditioning
LIC = liquid incinerator
MDB = Munitions Demilitarization Building
MPB = munitions processing bay
TOX = toxic cubicle

the DUN at five incineration sites. Spent charcoal is “micronized” (milled to a fine particle size) under negative pressure, and injected pneumatically as an air suspension into a special dual-fuel burner installed on the existing DFS rotary kiln retort. The system has several successful large scale analog industrial applications, including pulverized coal and coke combustion in power boilers and lime kilns. Designs have been prepared for TOCDF and JACADS and full-scale prototype testing has been successfully conducted by MicroEnergy Systems, the technology vendor. The CMS is currently being used at JACADS to process spent charcoal as part of the ongoing site closure activities.

Because the DFS will not be available for carbon processing during the agent campaigns, spent charcoal processing will be conducted at the end of each campaign before the turnaround and/or after all agent campaigns are complete. This may extend the overall schedule of operations, increasing the total operating cost. For this reason, it is important to minimize the amount of spent charcoal considered to be agent-contaminated. Specific state regulations differ considerably with respect to what charcoal is considered agent-contaminated. At UMCDF, the first three beds are considered contaminated in case of agent breakthrough; at other sites, only the first bed is considered contaminated.

Also, regulations differ from site to site with respect to restrictions on offsite disposal of contaminated charcoal and other waste. For example, Aberdeen Proving Ground-Edgewood Area has been allowed to ship all agent-contaminated secondary wastes to an offsite commercial incinerator, but such shipments will not be allowed at UMCDF and other sites. Since non-incineration technology will be employed at ABCDF and NECDF, these sites plan to rely on offsite disposal as the main management strategy for spent charcoal and other secondary wastes. At the ACWA sites (PUCDF, BGCDF), the current direction is to seek a “total solution” that encompasses onsite treatment of agent-contaminated secondary wastes. The systems under consideration for PUCDF include the CST where the wastes are contacted with superheated steam to achieve a 5X condition. This system uses a catalytic thermal oxidizer to treat the resulting offgas. The process has not yet been selected for BGCDF. One of the

promising approaches for use there is to hydropulp contaminated charcoal and other secondary waste and feed the resulting water slurry into a SCWO reactor. Another is to use GPCR technology where secondary wastes undergo direct hydrogenation at elevated temperatures or the AEA Technologies plc Silver II process where the wastes are electrochemically oxidized. All of these technologies were tested under the ACWA program.

The use of PA technology or any other technology or approach different from what has already been established as the secondary waste management approach at various CDP sites would have to offer specific schedule, cost, and/or technical advantages. One potential advantage of a stand-alone PA system (or other stand-alone system) over the CMS is that such a system can operate independently of and in parallel with the DFS (or MPF for processing other wastes) thereby increasing the availability of DFS and MPF incinerators for agent processing and thus shortening the schedule of overall operations.

Processing of spent carbon in a PA is problematic, as evidenced by excessive carbon carryover encountered during ATG's GASVIT™ operations in Richland, Washington, where spent charcoal and plastics that were fed too fast accumulated in piles on the hearth and glass bath with complete destruction of the piles occurring only 8 hours or more after all feed was stopped. Piling of carbon on top of the melt led to shorting of the arc electrodes and excessive carbon dust carryover out of the furnace. If a PA system was to be used to process spent charcoal, it should employ a thermal oxidizer followed by the gas cleanup train to maximize destruction of carbon before the offgas is scrubbed. Placing the thermal oxidizer after the scrubber would result in generation of carbon black dust and organics-contaminated scrubber blowdown streams that would require additional treatment either onsite or offsite. Extensive exploratory and demonstration testing would be required for this configuration with specific attention focused on establishing reliable scale-up relationship between the furnace size and maximum carbon feed rate. Based on the demonstrated success of the CMS approach, such testing and development costs do not appear to be justified for the baseline incineration sites.

At two alternative technology sites (ABCDF and NECDF), it is planned to send spent charcoal to an offsite commercial incineration or a regeneration facility (Saraiya, 2002). Offsite disposal of spent charcoal has been practiced for many years at Aberdeen Proving Ground-Edgewood Area. It is unlikely that PA technology (or any other onsite technology) could offer better technical and economic performance than this simple approach. PA technology does not provide any significant advantages over either CST or SCWO for processing spent charcoal treatment at the two ACWA sites.

5.1.2 Contaminated DPE and PPE Waste. These wastes include contaminated DPE, PPE, gas masks, booties, aprons, and gloves. Originally, they were to be processed in the DUN furnace system; however, the DUN experienced operational problems at JACADS while co-processing wood and charcoal. Additional concerns over the formation of dioxins and furans resulting from burning PVC wastes led to elimination of the DUN as the preferred method for disposing of these wastes. Subsequently, two alternative approaches were developed.

The initial approach was to use a low temperature desorption process where DPE and PPE items are decontaminated using hot air inside an oven-like chamber that discharges to the secondary combustion chamber of an existing incinerator. This approach was superseded by the use of the MPF at incineration sites.

The selected approach is to burn DPE and PPE items in the MPF system. This choice was made after successful tests conducted at JACADS verified that the rapid quench of the offgas from the secondary chamber effectively prevented the formation of dioxins and furans.

Processing of plastics inside the PA system at ATG's GASVIT™ facility and at the Hawaii Medical Vitrification facility resulted in significant carbon formation. IET designed and tested carbon recycle back to the reactor at the Hawaii Medical Vitrification facility, but this process change has not been implemented. Other approaches are also being investigated, including stabilizing temperature and O_2 feed in the thermal residence chamber. Unless carbon formation is completely eliminated,

carbon dust will have to be disposed of as a hazardous waste, probably in a commercial incinerator. For this reason, the previously discussed PA configuration incorporating a thermal oxidizer directly downstream of the reactor appears to have merit, but will require additional testing and development. In view of successful MPF performance, such testing and development appears unwarranted.

5.1.3 Contaminated Dunnage. Most of the wood waste is expected to be non-contaminated and, as such, suitable for offsite disposal. The remaining small quantities of agent-contaminated wood and other minor wastes (such as HEPA filters) unsuitable for offsite disposal were originally to be processed in the DUN system. After the DUN was abandoned due to operating problems at JACADS, tests to process contaminated dunnage wood waste in the MPF system were successfully conducted. These tests established the MPF as the management technology of choice for destroying these wastes at the baseline sites. The MPF system will not be fully available for dunnage waste processing during the agent campaigns; consequently it is likely that such processing would be performed after each agent campaign prior to the changeover and/or after all agent campaigns are complete. The overall schedule of operation for the MPF system and ancillary systems may be extended increasing the total operating cost. This strengthens the need to minimize the inventory of dunnage wood to be processed by the MPF by segregating uncontaminated wood and, with it, the development of a reliable analytical method to determine the extent of wood contamination.

A modification to the RCRA permit has been submitted at UMCDF, proposing sampling of wooden pallets to determine contamination, with the proposal that agent-contaminated wood would be incinerated and non-contaminated wood would be disposed offsite. Unless the tests confirm otherwise, a very large volume of wood will have to be processed onsite.

Cellulose-based materials, such as wood and rags, contain O_2 and generate less offgas and significantly less carbon black during PA processing than hydrocarbons; also the ash content of wood would be largely converted into slag. Hence, testing and

development requirements of the PA technology would likely be less demanding then for processing spent charcoal or plastic wastes. Overall, PA processing of dunnage wood can offer a potential alternative to the MPF if large quantities are categorized as agent-contaminated.

5.1.4 Miscellaneous Wastes. These wastes include HEPA filters, laboratory solid wastes, spent lubricants and hydraulic fluids, contaminated rags, and metal and plastic waste resulting from maintenance activities during systemization and operation periods. At the baseline sites, agent-contaminated miscellaneous wastes will be processed in the MPF and wastes not agent-contaminated would be disposed offsite. Although these wastes could be processed in a PAR, there are no apparent schedule, cost, or technical advantages in its use over the MPF, and offsite disposal.

5.2 PA Processing of Closure Wastes

Closure wastes are generated by post-mission decontamination and decommissioning of both stockpile and non-stockpile chemical demilitarization facilities. These wastes can be characterized as follows:

- Contaminated concrete
- Depainting residuals (sandblast grit, CO_2 pellet blast residuals)
- Contaminated wood
- Insulation
- Glass
- Metal waste (cut equipment, piping, instruments, wiring, etc.)
- Plastic waste (gaskets, seals, panels, etc.)

- Contaminated DPE and PPE items
- Spent decontamination solutions and spent rinsewater
- Spent lubricants and hydraulic fluids
- Tank sludge
- Contaminated soils.

In general, the effort will be made to segregate closure wastes according to agent contamination. That is, wastes that are potentially agent-contaminated from the closure of the Category A and B areas, and non-contaminated wastes from Category C, D, and E areas. All non-contaminated waste will be sent offsite for disposal. Potentially contaminated wastes will be further segregated into wastes that can be chemically decontaminated, such as metal wastes, and those adsorbent/porous materials that cannot be chemically treated, such as wood, sandblast residuals, scabbled concrete, and spent charcoal. Metal wastes will be chemically decontaminated to a 3X condition and either disposed of at an onsite landfill or shipped to the Army's Rock Island smelter facility. Potentially contaminated waste will be processed onsite using the MPF system at five baseline sites and the CST system at PUCDF. At BGCDF, a SCWO or the Silver II systems can be used to process plastic, wood, and spent charcoal. These systems are not practical for processing concrete, soils, or sandblast residues. Alternatively, a GPCR system, employing direct hydrogenation, could be used to process all of the contaminated closure waste at BGCDF.

PA processing of wood, plastic, charcoal, and miscellaneous secondary wastes has already been discussed in the paragraph 5.1. However, processing of concrete, sandblast residue, glass, insulation, tank sludge, and contaminated soils has not been previously covered. Based on the accumulated experience of commercial vitrification systems, PA is particularly well suited for processing of inorganic wastes with small amount of organic contaminants. In these applications, carbon formation is not a big

concern and demonstration testing will likely be either unnecessary or very limited. As such, contaminated concrete, sandblast residues, glass, insulation, tank sludge, and soils all appear to be a very good match with PA processing capabilities.

5.3 Evaluation of Potential Application of PA System

5.3.1 Introduction. There are eight continental United States (CONUS) sites for stockpile of chemical agents. Four of these sites, ANCDF, PBCDF, TOCDF, and UMCDF, have selected baseline incineration technology for disposal of their stockpile. Two sites, ABCDF and NECDF, with only bulk containers in their stockpile, have selected neutralization technology for disposal of their stockpile. PUCDF has selected neutralization process as primary treatment and immobilized cell bioreactors as secondary treatment for disposal of its stockpile. BGCDF has not finalized the selection of technology for its stockpile disposal.

As previously discussed, a considerable amount of secondary waste is generated during the processing of the stockpile. These include DPE, spent charcoal, contaminated dunnage wood and other miscellaneous wastes. Additional waste is generated during closure activities, including metal, concrete, plastic, and miscellaneous wastes. Moreover, each site has accumulated wastes from operations before the stockpile disposal operations. These wastes are designated as legacy wastes and will need to be disposed of either onsite or offsite.

This report includes a preliminary economic evaluation that is based on rough order of magnitude (ROM) estimates of capital and operating costs for the PA system. The selected options containing a PA system are compared to the baseline technology. The evaluation focuses on the disposal of the secondary and closure wastes including legacy wastes for the four CONUS sites using the baseline incineration technology. The baseline technology includes a CMS for processing spent charcoal in a DFS and an MPF for processing other wastes. Even though these sites have process equipment to dispose of all their wastes, the processing rates for some of these wastes may be too low and extend the total campaign duration (including closure time) too long to be cost

effective. The evaluation includes using PA technology in conjunction with the existing process equipment at the baseline incineration sites to determine if this would shorten the campaign duration in a cost effective manner.

5.3.2 Technical Overview. The basic strengths for PA technology are minimum feed preparation, smaller pollution abatement equipment, and the capability to encapsulate heavy metals in a non-leachable glass matrix. The major shortfalls are high electric energy consumption, low availability due to frequent changeout of refractories and electrodes and the need for development work to process wastes with high hydrocarbon content. The technology is mature and commercially available for applications to process metals and soil wastes. It may have some advantage over incineration for wastes containing larger amount of heavy metals because of its ability to tie up a large fraction of heavy metal into non-leachable slag.

5.3.3 PA Process Description. The conceptual PA system used for this comparison is comprised of a PAR, an SCC, and a wet pollution abatement system. The system will be capable of processing whole, unopened 55-gallon drums containing hazardous wastes. Drums will be processed at a rate of two to three drums per hour depending upon the type of waste with each drum containing about 400 pounds of waste material resulting in a processing rate of about 800 to 1,200 lb/hr. A process schematic for the PA system is shown in figure 1-1.

A drum conveyor and loading system will move the waste drums from storage and load them into the combination transfer chamber and airlock. The drums will then be transferred to the feed chamber where they will be ram fed in a slow, controlled fashion into the PAR.

The primary processing of the entire drum and its contents occurs in the PAR. Within the PAR, the organic constituents are volatilized, pyrolyzed and/or combusted while the nonvolatile metal and most of the inorganic materials are incorporated into a molten pool in the crucible. The molten pool consists of metallic and vitreous phases that may be removed separately. A simple hearth tilting mechanism will be used to pour molten

metal on one side and the molten slag on the other side. Both of them will be collected into waste containers.

The offgas from the plasma chamber will be ducted to an SCC where it will be mixed with excess air in the presence of a natural gas flame. While in the SCC, the combustible components in the offgas will be oxidized using at least a 2-second residence time and 1,090°C temperature.

After exiting the SCC, the offgas will be immediately quenched to below 93°C using recirculated caustic solution. The quenched gases will pass through a venturi scrubber and a packed bed scrubber to remove particulates and acid gases. Caustic will be added into the scrubber solution to maintain its pH above 7. An induced draft fan will provide a motive force for moving the gases through the system and maintaining a slight negative pressure in the PAR. The gases discharged from the induced draft fan will be exhausted through a stack.

5.3.4 PA Equipment Description. A conceptual design for the PA system is shown in figure 5-1. The plasma chamber will be a vertically oriented cylinder with a domed top. Its dimensions are approximately 10 feet outside diameter, with a height from the top of the hearth of 8 feet. The chamber will be refractory-lined and water-cooled, and equipped with a 1.2-MW transferred arc torch. The plasma torch assembly, including an electrode, will penetrate through the lid and will be oriented downward toward the hearth section. The torch electrode, will be hydraulically driven so that it may be remotely extended into or retracted from the chamber. The plasma chamber will have a second torch for preheating the chamber.

The hearth will be housed in the hearth chamber directly below the plasma chamber, but above the melt collection system. The plasma chamber and the hearth chamber will be connected together via flanges between the sections. The hearth will be refractory-lined and the hearth chamber will be water-cooled. A hearth cart will be used for removing and installing the hearth in the hearth chamber. Figure 5-2 shows details about the hearth cart lifting mechanism and the hearth tilting mechanism for pouring

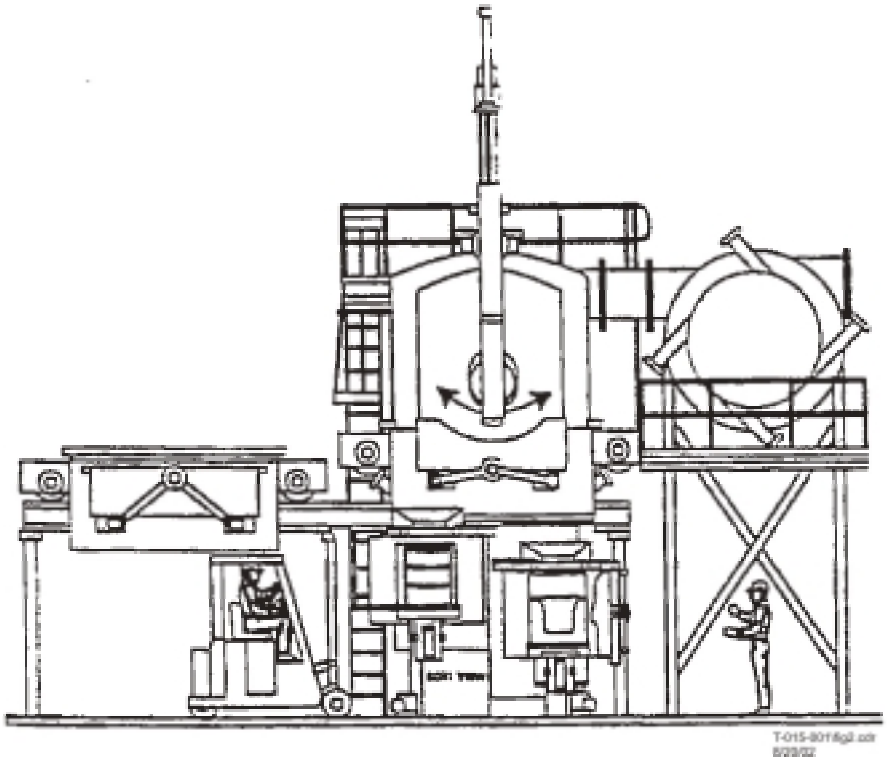


Figure 5-1. PA System Conceptual Design

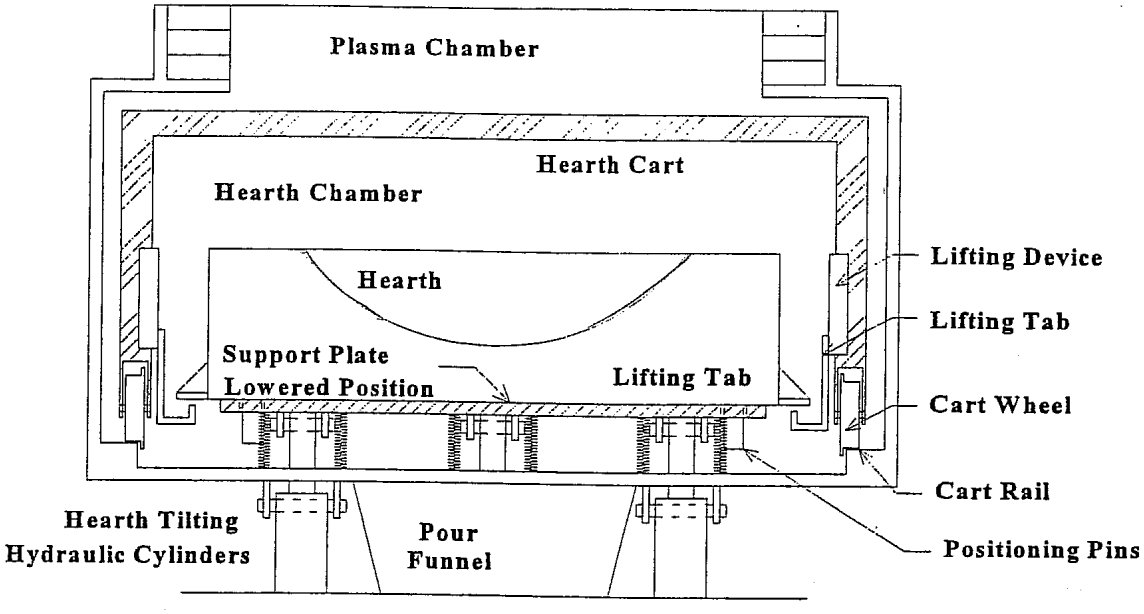


Figure 5-2. Plasma Hearth Cart

melt. There will be two melt collection chambers under the hearth chamber, one for collecting molten slag and the other for collecting molten metal.

The feed chamber will be a horizontal water-cooled chamber with a variable speed hydraulic drive for pushing the waste drums into the plasma chamber at a controlled rate. The waste drums will be first loaded into a transfer chamber. The transfer chamber will be a horizontal metal box with inner and outer isolation doors and will act as an airlock for loading drums into the feed chamber.

A preliminary equipment layout for the PAR, SCC, and the wet pollution abatement system is presented in figure 5-3. The facility area required for this system is approximately 7,600 square feet.

5.3.5 Qualitative Evaluation. As previously noted, the focus of this study is on the secondary and closure wastes. These wastes are categorized into the following seven major groups:

- Spent carbon
- DPE
- Halogenated and non-halogenated plastics
- Contaminated wood
- Metal
- Concrete
- Miscellaneous.

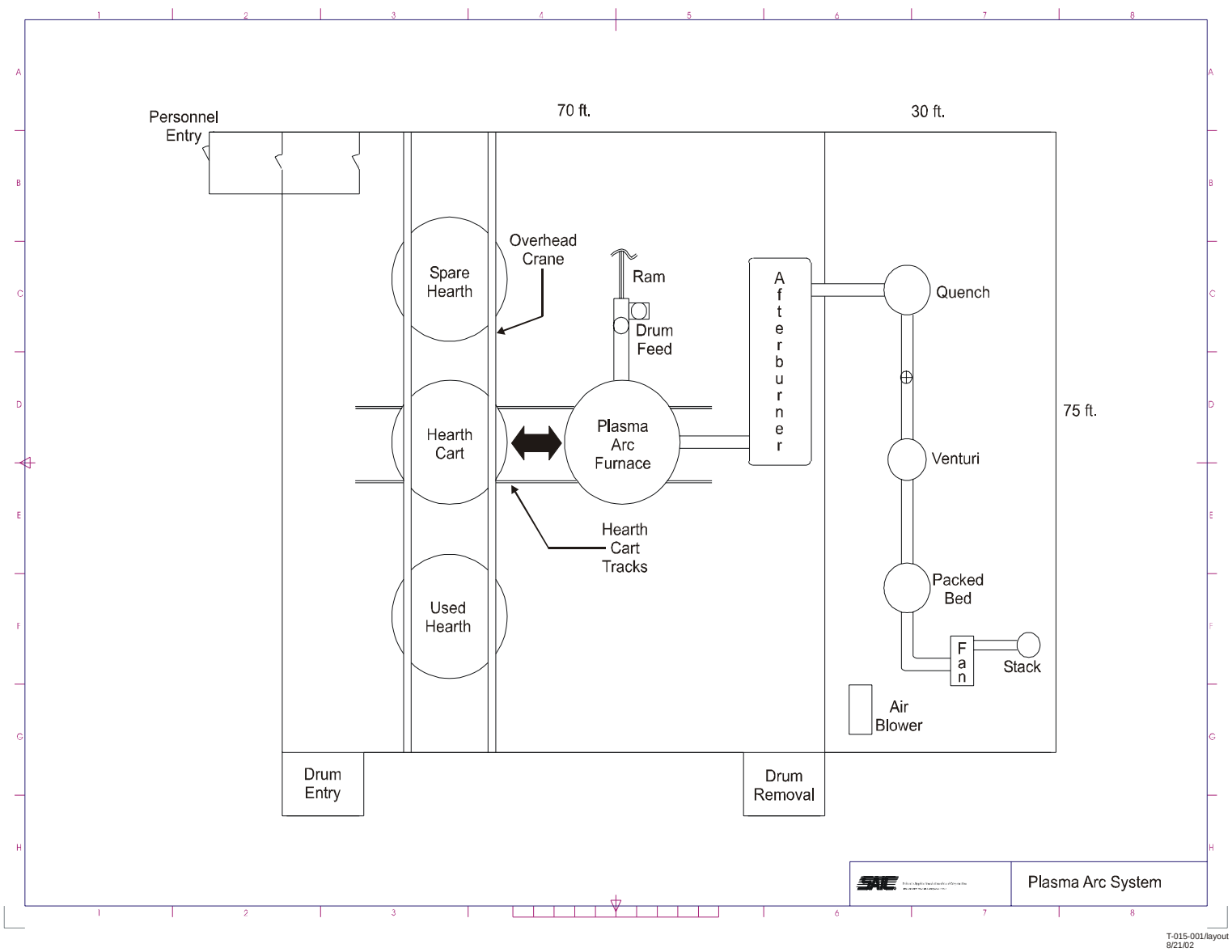


Figure 5-3. Equipment Layout

The PA technology and the baseline technology were qualitatively compared for each group of these wastes to determine suitability of the technology in relation to the group of wastes. These comparisons are summarized in tables 5-2 through 5-8 for these seven groups. A metal parts treater (MPT) is also included in this comparison, as it may be used at the alternative technology sites. However, complete information was not available for the MPT process. Three options were identified for comparison with baseline technology based on this qualitative analysis; one option with a PA system by itself, and two with a PA system in combination with existing baseline equipment. The four options, with the baseline option as Option 1 and PA options as Options 2 through 4, are as follows:

Option 1: MPF/CMS-DFS (Baseline)
Option 2: PA
Option 3: PA/MPF/CMS-DFS
Option 4: PA/MPF.

The processing rates and system to be used for each group of waste under each option are summarized in table 5-9. These tabulated processing rates are either actual data or estimates from JACADS experience. The need for development work is also identified for Options 2 and 4 in table 5-9.

5.3.6 Cost Analysis for Closure Wastes at Baseline Sites. Even though there are eight CONUS stockpile sites and two non-stockpile sites, this cost analysis is primarily focused on the four CONUS stockpile sites using baseline incineration technology. This is mostly due to the availability of detailed information on the volume of wastes in different categories at these sites and staffing requirements during different phases of closure. Offsite treatment and disposal is the most cost effective approach for processing of secondary and closure wastes for all stockpile and non-stockpile sites. However, this option may not be available due to public opposition. The cost analysis in this report mainly compares onsite options for secondary and closure wastes. A rough comparison for offsite and onsite costs is provided for the alternative technology stockpile sites using PA technology for the entire volume of expected wastes.

Table 5-2. Comparison for Concrete Waste

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Efficacy				
Processing Rate	1,000 lb/hr	Not applicable	1,200 lb/hr	Undefined
Auxiliary Systems	Afterburner and scrubber systems	Not applicable	Afterburner and scrubber systems	Catalytic oxidizer and scrubber systems
Need for Development	No	Not applicable	No	Pilot testing needed to obtain scale-up information
Commercial Availability	Yes	Not applicable	Yes	No integrated commercial unit in the market place
DRE	Can meet or exceed regulatory requirements	Not applicable	Can meet or exceed regulatory requirements	Can meet or exceed regulatory requirements
Materials of Construction	No testing required	Not applicable	No testing required	Testing required
Auxiliary Requirements	Natural gas as burner fuel and electric power	Not applicable	Natural gas, N_2, steam and electric power	Superheated steam and electric power
Availability/Reliability	70%	Not applicable	60%	60%
Operating Conditions	1,400° to 1,600°F in primary and 2,000°F in secondary chamber and slightly negative pressure	Not applicable	3,000°F in primary and 2,000°F in secondary chamber, slightly negative pressure	1,200°F in primary and 850°F in catalytic oxidizer, slightly negative pressure
Controls	Established	Not applicable	Established	May need development work to control reaction rate in primary chamber
Robustness	Very robust	Not applicable	Electrodes require frequent replacement	Catalyst poisoning may require catalyst replacement
Waste Weight Reduction	No weight reduction	Not applicable	No weight reduction	Small weight reduction from volatilization
Waste Volume Reduction	No volume reduction	Not applicable	Some volume reduction due to melting	Negligible volume reduction

Table 5-2. Comparison for Concrete Waste (Continued)

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Safety				
Worker Safety	Considerably safe with remote operation	Not applicable	Slag tapping will require proper procedures. Design improvements to eliminate pressurization from electrode cooling water leak.	Need for adequate measures to prevent fire hazard during discharging hot load
Public Safety	Adequate thermal inertia during abnormal shutdown	Not applicable	Adequate thermal inertia during abnormal shutdown	Inadequate thermal inertia during abnormal shutdown
Environment Safety	Low rate of concrete dust carry over to scrubber liquid	Not applicable	Low rate of concrete dust carry over to scrubber liquid	Low rate of concrete dust carry over to scrubber liquid
Schedule Impact	It will extend closure duration, as processing rate is lower than PA and other demands for MPF during closure.	Not applicable	Can help to reduce closure time, if MPF is over burdened. Need for permitting requirements may impact near term application of this technology.	Will depend upon the processing rate, volume of waste generated, and whether it is processed during operation or closure period
Cost Impact				
Capital Cost	No additional cost	Not applicable	Additional cost will depend upon the implemented option	Cost to be determined
Operating Cost	Higher operating cost due to longer time interval, if processed in MPF alone during closure	Not applicable	May lower operating cost, if used in conjunction with MPF during closure	Higher operating cost, if processed during closure

Table 5-2. Comparison for Concrete Waste (Continued)

Notes:

MPF has slightly lower processing rate for concrete waste than the selected 1,200 lb/hr PA unit for comparison. Thus PA can be cost effective for processing concrete waste when MPF is overburdened with other wastes.

CMS/DFS	=	carbon micronization system/deactivation furnace system
DRE	=	destruction removal efficiency
MPF	=	metal parts furnace
MPT	=	metal parts treater
PA	=	plasma arc

Table 5-3. Comparison for DPE

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Efficacy				
Processing Rate	350 lb/hr	Not applicable	800 lb/hr	Undefined
Auxiliary Systems	Afterburner and scrubber systems	Not applicable	Afterburner and scrubber systems	Catalytic oxidizer and scrubber systems
Need for Development	No	Not applicable	Pilot testing needed to resolve problem areas	Pilot testing needed to obtain scale-up information
Commercial Availability	Yes	Not applicable	Commercial units available for similar application, but none for this particular waste	No integrated commercial unit in the market place
DRE	Can meet or exceed regulatory requirements	Not applicable	Can meet or exceed regulatory requirements	Can meet or exceed regulatory requirements
Materials of Construction	No testing required	Not applicable	Testing may be necessary	Testing required
Auxiliary Requirements	Natural gas as burner fuel and electric power	Not applicable	Natural gas, N_2, steam and electric power	Superheated steam and electric power
Availability/Reliability	70%	Not applicable	60%	60%
Operating Conditions	1,400° to 1,600°F in primary and 2,000°F in secondary chamber and slightly negative pressure	Not applicable	3,000°F in primary and 2,000°F in secondary chamber, slightly negative pressure	1,200°F in primary and 850°F in catalytic oxidizer, slightly negative pressure
Controls	Established	Not applicable	May need development work to control reaction rate in primary chamber	May need development work to control reaction rate in primary chamber
Robustness	Very robust	Not applicable	Electrodes require frequent replacement	Catalyst poisoning may require catalyst replacement
Waste Weight Reduction	Significant weight reduction due to oxidation	Not applicable	Significant weight reduction due to steam reforming and partial oxidation	Small weight reduction from volatilization

Table 5-3. Comparison for DPE (Continued)

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Waste Volume Reduction	Significant volume reduction due to oxidation	Not applicable	Significant volume reduction due to reactions and melting	Negligible volume reduction
Process Safety				
Worker Safety	Considerably safe with remote operation	Not applicable	Slag tapping will require proper procedures. Design improvements to eliminate pressurization from electrode cooling water leak.	Need for adequate measures to prevent fire hazard during discharging hot load
Public Safety	Adequate thermal inertia during abnormal shutdown	Not applicable	Adequate thermal inertia during abnormal shutdown	Inadequate thermal inertia during abnormal shutdown
Environment Safety	Moderate rate of heavy metal volatilization and collection in scrubber liquid	Not applicable	High rate of heavy metal volatilization and carbon soot formation and collection in scrubber liquid	Low rate of heavy metal volatilization and collection in scrubber liquid
Schedule Impact	No impact, if processed during furnace idling time during operation. It will extend closure duration, if processed during closure.	Not applicable	Can significantly reduce closure time, if the waste is to be processed during closure due to higher processing rate. Need for development work and permitting requirements can seriously impact near term application of this technology.	Will depend upon the processing rate, volume of waste generated, and whether it is processed during operation or closure period
Cost Impact				
Capital Cost	No additional cost	Not applicable	Additional cost will depend upon the implemented option	Cost to be determined
Operating Cost	Higher operating cost, if processed during closure.	Not applicable	Lower operating cost, if processed during closure	Higher operating cost, if processed during closure

Table 5-3. Comparison for DPE (Continued)

Notes:

DPE generated during operation should be processed during idle time in MPF during operating period. Additional DPE generated during closure can also be processed in MPF during closure period, if the furnace schedule permits. Processing of DPE with PA will require some development work and may cause schedule delays associated with the requirement for development and permitting work. Using PA to process DPE is attractive at some baseline sites only when the MPF and PA are both used to minimize closure time.

CMS/DFS	=	carbon micronization system/deactivation furnace system
DPE	=	demilitarization protective ensemble
DRE	=	destruction removal efficiency
MPF	=	metal parts furnace
MPT	=	metal parts treater
PA	=	plasma arc

Table 5-4. Comparison for Halogenated and Non-halogenated Plastics Waste

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Efficacy				
Processing Rate	350 lb/hr	Not applicable	800 lb/hr	Undefined
Auxiliary Systems	Afterburner and scrubber systems	Not applicable	Afterburner and scrubber systems	Catalytic oxidizer and scrubber systems
Need for Development	No	Not applicable	Pilot testing needed to resolve problem areas	Pilot testing needed to obtain scale-up information
Commercial Availability	Yes	Not applicable	Commercial units available for similar application, but none for this particular waste	No integrated commercial unit in the market place
DRE	Can meet or exceed regulatory requirements	Not applicable	Can meet or exceed regulatory requirements	Can meet or exceed regulatory requirements
Materials of Construction	No testing required	Not applicable	Testing may be necessary	Testing required
Auxiliary Requirements	Natural gas as burner fuel and electric power	Not applicable	Natural gas, N_2, steam and electric power	Superheated steam and electric power
Availability/Reliability	70%	Not applicable	60%	60%
Operating Conditions	1,400° to 1,600°F in primary and 2,000°F in secondary chamber and slightly negative pressure.	Not applicable	3,000°F in primary and 2,000°F in secondary chamber, slightly negative pressure.	1,200°F in primary and 850°F in catalytic oxidizer, slightly negative pressure.
Controls	Established	Not applicable	May need development work to control reaction rate in primary chamber	May need development work to control reaction rate in primary chamber
Robustness	Very robust	Not applicable	Electrodes require frequent replacement	Catalyst poisoning may require catalyst replacement
Waste Weight Reduction	Significant weight reduction due to oxidation	Not applicable	Significant weight reduction due to steam reforming and partial oxidation	Small weight reduction from volatilization

Table 5-4. Comparison for Halogenated and Non-halogenated Plastics Waste (Continued)

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Waste Volume Reduction	Significant volume reduction due to oxidation	Not applicable	Significant volume reduction due to reactions and melting	Negligible volume reduction
Process Safety				
Worker Safety	Considerably safe with remote operation	Not applicable	Slag tapping will require proper procedures. Design improvements to eliminate pressurization from electrode cooling water leak.	Need for adequate measures to prevent fire hazard during discharging hot load
Public Safety	Adequate thermal inertia during abnormal shutdown	Not applicable	Adequate thermal inertia during abnormal shutdown	Inadequate thermal inertia during abnormal shutdown
Environment Safety	Moderate rate of heavy metal volatilization and collection in scrubber liquid	Not applicable	High rate of heavy metal volatilization and carbon soot formation and collection in scrubber liquid	Low rate of heavy metal volatilization and collection in scrubber liquid
Schedule Impact	No impact, if processed during furnace idling time during operation. It will extend closure duration, if processed during closure.	Not applicable	Can significantly reduce closure time, if the waste is to be processed during closure due to higher processing rate. Need for development work and permitting requirements can seriously impact near term application of this technology.	Will depend upon the processing rate, volume of waste generated, and whether it is processed during operation or closure period
Cost Impact				
Capital Cost	No additional cost	Not applicable	Additional cost will depend upon the implemented option	Cost to be determined
Operating Cost	Higher operating cost, if processed during closure	Not applicable	Lower operating cost, if processed during closure	Higher operating cost, if processed during closure

Table 5-4. Comparison for Halogenated and Non-halogenated Plastics Waste (Continued)

Notes:

Plastic waste generated during operation should be processed during idle time in the MPF during operating period. The additional plastic waste generated during closure can also be processed in the MPF during closure period, if the furnace schedule permits. Processing of plastic waste in the PA system will require some development work and may cause schedule delays associated with the requirement for development and permitting work. Processing of plastic waste in the PA system is attractive at some baseline sites only when MPF and PA are both used to minimize closure time.

CMS/DFS	=	carbon micronization system/deactivation furnace system
DRE	=	destruction removal efficiency
MPF	=	metal parts furnace
MPT	=	metal parts treater
PA	=	plasma arc

Table 5-5. Comparison for Metal Waste

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Efficacy				
Processing Rate	2,000 lb/hr	Not applicable	1,200 lb/hr	Undefined
Auxiliary Systems	Afterburner and scrubber systems	Not applicable	Afterburner and scrubber systems	Catalytic oxidizer and scrubber systems
Need for Development	No	Not applicable	No	Pilot testing needed to obtain scale-up information
Commercial Availability	Yes	Not applicable	Yes	No integrated commercial unit in the market place
DRE	Can meet or exceed regulatory requirements	Not applicable	Can meet or exceed regulatory requirements	Can meet or exceed regulatory requirements
Materials of Construction	No testing required	Not applicable	No testing required	Testing required
Auxiliary Requirements	Natural gas as burner fuel and electric power	Not applicable	Natural gas, N_2, steam and electric power	Superheated steam and electric power
Availability/Reliability	70%	Not applicable	60%	60%
Operating Conditions	1,400° to 1,600°F in primary and 2,000°F in secondary chamber and slightly negative pressure	Not applicable	3,000°F in primary and 2,000°F in secondary chamber, slightly negative pressure	1,200°F in primary and 850°F in catalytic oxidizer, slightly negative pressure
Controls	Established	Not applicable	Established	May need development work to control reaction rate in primary chamber
Robustness	Very robust	Not applicable	Electrodes require frequent replacement	Catalyst poisoning may require catalyst replacement
Waste Weight Reduction	No weight reduction	Not applicable	No weight reduction	Small weight reduction from volatilization
Waste Volume Reduction	No volume reduction	Not applicable	Some volume reduction due to melting	Negligible volume reduction

Table 5-5. Comparison for Metal Waste (Continued)

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Safety				
Worker Safety	Considerably safe with remote operation	Not applicable	Slag tapping will require proper procedures. Design improvements to eliminate pressurization from electrode cooling water leak.	Need for adequate measures to prevent fire hazard during discharging hot load
Public Safety	Adequate thermal inertia during abnormal shutdown	Not applicable	Adequate thermal inertia during abnormal shutdown	Inadequate thermal inertia during abnormal shutdown
Environment Safety	Moderate rate of heavy metal volatilization and collection in scrubber liquid	Not applicable	High rate of heavy metal volatilization and collection in scrubber liquid	Low rate of heavy metal volatilization and collection in scrubber liquid
Schedule Impact	No impact, if processed during furnace idling time during operation. It will extend closure duration, if processed during closure.	Not applicable	Can help to reduce closure time, if MPF is overburdened. Need for permitting requirements may impact near term application of this technology.	Will depend upon the processing rate, volume of waste generated, and whether it is processed during operation or closure period
Cost Impact				
Capital Cost	No additional cost	Not applicable	Additional cost will depend upon the implemented option	Cost to be determined
Operating Cost	Higher operating cost due to longer time interval, if processed in MPF alone during closure.	Not applicable	May lower operating cost, if used in conjunction with MPF during closure	Higher operating cost, if processed during closure

Notes:

The MPF has considerably higher processing rate for metal waste than the selected 1,200 lb/hr PA unit for comparison. Thus the PA unit is not cost effective for processing metal waste.

Table 5-5. Comparison for Metal Waste (Continued)

Notes: (Continued)

CMS/DFS	=	carbon micronization system/deactivation furnace system
DRE	=	destruction removal efficiency
MPF	=	metal parts furnace
MPT	=	metal parts treater
PA	=	plasma arc

Table 5-6. Comparison for Miscellaneous Waste

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Efficacy				
Processing Rate	2,000 lb/hr	Not applicable	1,200 lb/hr	Undefined
Auxiliary Systems	Afterburner and scrubber systems	Not applicable	Afterburner and scrubber systems	Catalytic oxidizer and scrubber systems
Need for Development	No	Not applicable	No	Pilot testing needed to obtain scale-up information
Commercial Availability	Yes	Not applicable	Yes	No integrated commercial unit in the market place
DRE	Can meet or exceed regulatory requirements	Not applicable	Can meet or exceed regulatory requirements	Can meet or exceed regulatory requirements
Materials of Construction	No testing required	Not applicable	No testing required	Testing required
Auxiliary Requirements	Natural gas as burner fuel and electric power	Not applicable	Natural gas, N_2, steam and electric power	Superheated steam and electric power
Availability/Reliability	70%	Not applicable	60%	60%
Operating Conditions	1,400° to 1,600°F in primary and 2,000°F in secondary chamber and slightly negative pressure	Not applicable	3,000°F in primary and 2,000°F in secondary chamber, slightly negative pressure	1,200°F in primary and 850°F in catalytic oxidizer, slightly negative pressure
Controls	Established	Not applicable	Established	May need development work to control reaction rate in primary chamber
Robustness	Very robust	Not applicable	Electrodes require frequent replacement	Catalyst poisoning may require catalyst replacement
Waste Weight Reduction	No weight reduction	Not applicable	No weight reduction	Small weight reduction from volatilization
Waste Volume Reduction	No volume reduction	Not applicable	Some volume reduction due to melting	Negligible volume reduction

Table 5-6. Comparison for Miscellaneous Waste (Continued)

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Safety				
Worker Safety	Considerably safe with remote operation	Not applicable	Slag tapping will require proper procedures. Design improvements to eliminate pressurization from electrode cooling water leak.	Need for adequate measures to prevent fire hazard during discharging hot load
Public Safety	Adequate thermal inertia during abnormal shutdown	Not applicable	Adequate thermal inertia during abnormal shutdown	Inadequate thermal inertia during abnormal shutdown
Environment Safety	Moderate rate of heavy metal volatilization and collection in scrubber liquid	Not applicable	High rate of heavy metal volatilization and collection in scrubber liquid	Low rate of heavy metal volatilization and collection in scrubber liquid
Schedule Impact	No impact, if processed during furnace idling time during operation. It will extend closure duration, if processed during closure.	Not applicable	Can help to reduce closure time, if MPF is overburdened. Need for permitting requirements may impact near term application of this technology.	Will depend upon the processing rate, volume of waste generated, and whether it is processed during operation or closure period
Cost Impact				
Capital Cost	No additional cost	Not applicable	Additional cost will depend upon the implemented option	Cost to be determined
Operating Cost	Higher operating cost due to longer time interval, if processed in MPF alone during closure.	Not applicable	May lower operating cost, if used in conjunction with MPF during closure	Higher operating cost, if processed during closure

Notes:

The MPF has considerably higher processing rate for miscellaneous waste than the selected 1,200 lb/hr PA unit for comparison. Thus the PA unit is not cost effective for processing miscellaneous waste.

Table 5-6. Comparison for Miscellaneous Waste (Continued)

Notes: (Continued)

CMS/DFS	=	carbon micronization system/deactivation furnace system
DRE	=	destruction removal efficiency
MPF	=	metal parts furnace
MPT	=	metal parts treater
PA	=	plasma arc

Table 5-7. Comparison for Spent Charcoal

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Efficacy:				
Processing Rate	100 lb/hr	400 lb/hr	800 lb/hr	Undefined
Auxiliary Systems	Afterburner and scrubber systems	Afterburner and scrubber systems	Afterburner and scrubber systems	Catalytic oxidizer and scrubber systems
Need for Development	No	No	Pilot testing needed to resolve problem areas	Pilot testing needed to obtain scale-up information
Commercial Availability	Yes	Yes	Commercial units available for similar application, but none for this particular waste	No integrated commercial unit in the market place
DRE	Can meet or exceed regulatory requirements	Can meet or exceed regulatory requirements	Can meet or exceed regulatory requirements	Can meet or exceed regulatory requirements
Materials of Construction	No testing required	No testing required	Testing may be necessary	Testing required
Auxiliary Requirements	Natural gas as burner fuel and electric power	Natural gas as burner fuel and electric power	Natural gas, N_2, steam and electric power	Superheated steam and electric power
Availability/Reliability	70%	70%	60%	60%
Operating Conditions	1,400° to 1,600°F in primary and 2,000°F in secondary chamber and slightly negative pressure	1,200° to 1,400°F in primary burner end and 2,000°F in secondary chamber, slightly negative pressure	3,000°F in primary and 2,000°F in secondary chamber, slightly negative pressure	1,200°F in primary and 850°F in catalytic oxidizer, slightly negative pressure
Controls	Established	Established	May need development work to control reaction rate in primary chamber	May need development work to control reaction rate in primary chamber
Robustness	Very robust	Very robust	Electrodes require frequent replacement	Catalyst poisoning may require catalyst replacement

Table 5-7. Comparison for Spent Charcoal (Continued)

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Waste Weight Reduction	Significant weight reduction due to oxidation	Significant weight reduction due to oxidation	Significant weight reduction due to steam reforming and partial oxidation	Small weight reduction from volatilization
Waste Volume Reduction	Significant volume reduction due to oxidation	Significant volume reduction due to oxidation	Significant volume reduction due to reactions and melting	Negligible volume reduction
Process Safety				
Worker Safety	Considerably safe with remote operation	Fire hazard with micronized carbon dust	Slag tapping will require proper procedures. Design improvements to eliminate pressurization from electrode cooling water leak.	Need for adequate measures to prevent fire hazard during discharging hot load
Public Safety	Adequate thermal inertia during abnormal shutdown	Adequate thermal inertia during abnormal shutdown	Adequate thermal inertia during abnormal shutdown	Inadequate thermal inertia during abnormal shutdown
Environment Safety	Moderate rate of fly ash carry over to scrubber system	High rate of fly ash carry over to scrubber system	High rate of fly ash/carbon soot carry over to scrubber system	Low rate of fly ash carryover to scrubber system
Schedule Impact	It will significantly extend closure duration, as it is processed during closure	It may moderately extend closure duration, if it is not processed simultaneously with other wastes in MPF	Can significantly reduce closure time in comparison to MPF, but no advantage against CMS, if it operates simultaneously with MPF. Need for development work and permitting requirements can seriously impact near term application of this technology.	Will depend upon the processing rate and volume of waste generated

Table 5-7. Comparison for Spent Charcoal (Continued)

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Cost Impact				
Capital Cost	No additional cost	Additional cost for CMS	Additional cost for equipment and facility will depend upon the implemented option	Cost to be determined
Operating Cost	Higher operating cost due to lower processing rate and processed during closure	Moderate operating cost	Lower operating cost due to higher processing rate	Higher operating cost due to lower processing rate and processed during closure

Notes:

The spent carbon at baseline facilities is planned to be processed through CMS/DFS system during closure and other wastes are planned to be processed through the MPF. The MPF/PA combination can significantly reduce the closure time. If this combination is economically attractive, then carbon could be processed in the PA rather than CMS/DFS.

CMS/DFS = carbon micronization system/deactivation furnace system
DRE = destruction removal efficiency
MPF = metal parts furnace
MPT = metal parts treater
PA = plasma arc

Table 5-8. Comparison for Wood Waste

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Process Efficacy				
Processing Rate	100 lb/hr	Not applicable	800 lb/hr	Undefined
Auxiliary Systems	Afterburner and scrubber systems	Not applicable	Afterburner and scrubber systems	Catalytic oxidizer and scrubber systems
Need for Development	no	Not applicable	Pilot testing needed to resolve problem areas	Pilot testing needed to obtain scale-up information
Commercial Availability	yes	Not applicable	Commercial units available for similar application, but none for this particular waste	No integrated commercial unit in the market place
DRE	Can meet or exceed regulatory requirements	Not applicable	Can meet or exceed regulatory requirements	Can meet or exceed regulatory requirements
Materials of Construction	No testing required	Not applicable	No testing required	No testing required
Auxiliary Requirements	Natural gas as burner fuel and electric power	Not applicable	Natural gas, N_2, steam and electric power	Superheated steam and electric power
Availability/Reliability	70%	Not applicable	60%	60%
Operating Conditions	1,400° to 1,600°F in primary and 2,000°F in secondary chamber and slightly negative pressure	Not applicable	3,000°F in primary and 2,000°F in secondary chamber, slightly negative pressure	1,200°F in primary and 850°F in catalytic oxidizer, slightly negative pressure
Controls	Established	Not applicable	May need development work to control reaction rate in primary chamber	May need development work to control reaction rate in primary chamber
Robustness	Very robust	Not applicable	Electrodes require frequent replacement	Catalyst poisoning may require catalyst replacement

Table 5-8. Comparison for Wood Waste (Continued)

Criteria	Technologies			
	MPF	CMS/DFS	PA	MPT
Waste Weight Reduction	Significant weight reduction due to oxidation	Not applicable	Significant weight reduction due to steam reforming and partial oxidation	Small weight reduction from volatilization
Waste Volume Reduction	Significant volume reduction due to oxidation	Not applicable	Significant volume reduction due to reactions and melting	Negligible volume reduction
Process Safety				
Worker Safety	Considerably safe with remote operation	Not applicable	Slag tapping will require proper procedures. Design improvements to eliminate pressurization from electrode cooling water leak.	Need for adequate measures to prevent fire hazard during discharging hot load
Public Safety	Adequate thermal inertia during abnormal shutdown	Not applicable	Adequate thermal inertia during abnormal shutdown	Inadequate thermal inertia during abnormal shutdown
Environment Safety	Moderate rate of fly ash carryover to scrubber system	Not applicable	High rate of carbon soot formation and collection in scrubber liquid	Low rate of fly ash carryover to scrubber system
Schedule Impact	No impact, if processed during furnace idling time during operation. It will extend closure duration, if processed during closure.	Not applicable	Can significantly reduce closure time, if the waste is to be processed during closure due to higher processing rate. Need for development work and permitting requirements can seriously impact near term application of this technology.	Will depend upon the processing rate, volume of waste generated and whether it is processed during operation or closure period
Cost Impact				
Capital Cost	No additional cost	Not applicable	Additional cost will depend upon the implemented option	Cost to be determined
Operating Cost	Higher operating cost, if processed during closure	Not applicable	Lower operating cost, if processed during closure	Higher operating cost, if processed during closure

Table 5-8. Comparison for Wood Waste (Continued)

Notes:

If the quantity of contaminated wood to be processed is too high for processing through the MPF during idling period of operation and considerable amount is expected to be left for processing during closure, then the PA system could be considered for this application.

CMS/DFS = carbon micronization system/deactivation furnace system
DRE = destruction removal efficiency
MPF = metal parts furnace
MPT = metal parts treater
PA = plasma arc

Table 5-9. Process Rates for Selected Options

Waste Group	Option 1 (MPF/CMS-DFS)		Option 2 (PA)		Option 3 (PA/MPF/CMS-DFS)		Option 4 (PA/MPF)	
	System	Rate (lb/hr)	System	Rate (lb/hr)	System	Rate (lb/hr)	System	Rate (lb/hr)
Concrete	MPF	1,000	PA	1,200	PA	1,200	PA/MPF	1,200/1,000
DPE	MPF	350	PA	800	MPF	350	PA	800
Halogenated and Non-halogenated Plastics	MPF	350	PA	800	MPF	350	PA	800
Metal	MPF	2,000	PA	1,200	MPF/PA	2,000/1,200	MPF	2,000
Miscellaneous Waste	MPF	2,000	PA	1,200	PA	1,200	MPF	2,000
Spent Charcoal	CMS-DFS	400	PA	800	CMS-DFS	400	PA	800
Wood	MPF	100	PA	800	MPF	100	PA	800
Need for PA Development	No	-	Yes	-	No		Yes	

Notes:

CMS/DFS = carbon micronization system/deactivation furnace system
DPE = demilitarization protective ensemble
lb/hr = pounds per hour
MPF = metal parts furnace
PA = plasma arc

5.3.6.1 Operating Cost. Staffing estimates at various phases of the closure activity were reported in table 10 of the draft report for CONUS Closure Estimate (March, 2001) for the baseline incinerator sites. These staffing estimates, which are summarized in table 5-10 of this report, were used to estimate the annual labor costs during the closure phase. Note that staffing levels decrease as each furnace is decommissioned. The DFS will be removed first, followed by the LIC, and finally the MPF. An average annual labor cost of $100,000 per person was assumed for the cost comparison. The annual labor cost for the baseline incinerator sites varies from between $61 million (for PBCDF) to $71.3 million (for UMCDF), with all furnaces operating, and reduces to between $53.1 million (for PBCDF) to $61.4 million (for UMCDF), with only the MPF in operation.

The utility cost is estimated at $1.5 million for the MPF and $3 million for the DFS. Miscellaneous cost for each furnace is approximated at $0.5 million. The total annual operating cost, which is the sum of the labor, utility and miscellaneous costs, is also summarized in table 5-10. It ranges from $66.5 million (for PBCDF) to $76.8 million (for UMCDF) with all furnaces operating and reduces to a range from $55.1 million (for PBCDF) to $63.4 million (for UMCDF), with only the MPF operating.

The annual operating cost data for labor, utility, and miscellaneous costs for the PA system were obtained from Gillens et al. (1998). These cost data are also summarized in table 5-10. The total annual operating cost for the PA system is estimated at $5.7 million for all sites.

Wastes generated at all sites are broadly categorized as operation wastes and closure wastes. Major operation wastes are wood and DPE. Even though carbon may be generated during operation, it will not be processed until the carbon micronization system is installed, which will most likely happen during closure. Therefore, spent charcoal is considered a closure waste rather than operation waste. Closure wastes include all major groups except wood. Volumes of operation and closure wastes in each major group of wastes are summarized in table 5-11 for the baseline incinerator sites. The operation waste volumes were extracted from table 5-1, and the closure waste data are from table 5-12, which is the most current information. This data

Table 5-10. Operating Cost Data

Item	TOCDF	ANCDF	UMCDF	PBCDF
Total Staffing Before Initiation of Closure	698	648	713	610
Staffing After Removal of DFS	643	601	660	565
Staffing After Removal of DFS and LIC	595	563	614	531
Average Annual Labor Cost ($M/person)	0.1	0.1	0.1	0.1
Annual Labor Cost Before Initiation of Closure ($M/yr)	69.8	64.8	71.3	61
Annual Labor Cost after Removal of DFS ($M/yr)	64.3	60.1	66	56.5
Annual Labor Cost After DFS and LIC Removal ($M/yr)	59.5	56.3	61.4	53.1
Labor Cost Savings with DFS Removal ($M/yr)	5.5	4.7	5.3	4.5
Labor Cost Savings with DFS and LIC Removal ($M/yr)	10.3	8.5	9.9	7.9
Labor Cost with Only MPF operating ($M/yr)	59.5	56.3	61.4	53.1
Utility Cost for MPF ($M/yr)	1.5	1.5	1.5	1.5
Miscellaneous Cost for MPF ($M/yr)	0.5	0.5	0.5	0.5
Total Operating Cost with Only MPF Operating ($M/yr)	61.5	58.3	63.4	55.1
Utility Cost for DFS ($M/yr)	3	3	3	3
Miscellaneous Cost for DFS ($M/yr)	0.5	0.5	0.5	0.5
Total Operating Cost with MPF and DFS Operating ($M/yr)	75.3	70.3	76.8	66.5
Staffing Required for PA System	35	35	35	35
Labor Cost for PA System ($M/yr)	3.5	3.5	3.5	3.5
Annual Utility Cost for PA System ($M/yr)	0.7	0.7	0.7	0.7
Annual Miscellaneous Cost ($M/yr)	1.5	1.5	1.5	1.5
Total Operating Cost for PA System ($M/yr)	5.7	5.7	5.7	5.7

Notes:

DFS = deactivation furnace system
LIC = liquid incinerator
MPF = metal parts furnace
PA = plasma arc
$M = millions of dollars
$M/yr = millions of dollars per year

Table 5-11. Waste Volumes, Processing Times, and Costs

	ANCDF		PBCDF		TOCDF		UMCDF	
	Operation	Closure	Operation	Closure	Operation	Closure	Operation	Closure
Major Secondary Wastes								
Non-contaminated Wood (tons)	2,616	0	1,263	0	3,556	0	1,565	0
Contaminated Wood (tons)	140	0	66	0	187	0	82.5	0
1X DPE (tons)	18	6	20	4.5	24	47.5	15	6
3X DPE (tons)	21	9	24	9	38	9	17	9
Major Closure Wastes								
Spent Carbon (tons)	0	175		175		220		275
Closure Metal Waste (tons)	0	851	0	703.5	0	877.5	0	877.5
Closure Concrete Waste (tons)	0	775	0	627	0	835	0	835
Closure Plastic and Combustible Solid Wastes (tons)	0	148	0	87	0	177	0	148
Closure Miscellaneous Waste (tons)	0	75.5	0	70.5	0	112.5	0	75.5
Process Time for Various Options								
Option 1: MPF/CMS								
Carbon Process Time Using CMS/DFS (hrs)	0	875	0	875	0	1,100	0	1,375
Availability for CMS/DFS or MPF	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Process Duration in CMS/DFS (months)		1.7		1.7		2.2		2.7
Waste (Excluding Carbon) Process Time in MPF (hrs)	3,023	3,408	1,571	2,602	4,094	3,994	1,833	3,554
Process Duration in MPF (months)	5.9	6.7	3.1	5.1	8.0	7.8	3.6	7.0
Option 2: PA System								
Process Time for all Wastes in PA (hrs)	448	3,681	275	3,024	623	4,175	286	4,075
Availability for PA System	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Process Duration in PA system (months)	1.0	8.4	0.6	6.9	1.4	9.5	0.7	9.3

Table 5-11. Waste Volumes, Processing Times, and Costs (Continued)

	ANCDF		PBCDF		TOCDF		UMCDF	
	Operation	Closure	Operation	Closure	Operation	Closure	Operation	Closure
Option 3: MPF/CMS/PA								
Process Time in PA (hrs)	0	1,488	0	1,163	0	1,799	0	1,532
Process Duration in PA (months)	0	3.4	0	2.7	0	4.1	0	3.5
Process Time in CMS/DFS (hrs)	0	875	0	875	0	1,100	0	1,375
Process Duration in CMS/DFS (months)	0	1.7	0	1.7	0	2.2	0	2.7
Process Time in MPF (hrs)	3,023	1,740	1,571	1,278	4,094	2,080	1,833	1,800
Process Duration in MPF (months)	5.9	3.4	3.1	2.5	8.0	4.1	3.6	3.5
Option 4: MPF/PA								
Process Time in MPF (hrs)	0	1,702	0	1,401	0	1,992	0	1,938
Process Duration in MPF (months)	0	3.3	0	2.7	0	3.9	0	3.8
Process Time in PA (hrs)	448	1,491	275	1,211	623	1,690	286	1,666
Process Duration in PA (months)	1.0	3.4	0.6	2.8	1.4	3.9	0.7	3.8
Capital and Operating Costs								
CMS Installed Cost ($M)		8.1		8.1		8.1		8.1
CMS Permitting and Trial Burn Cost ($M)		1.5		1.5		1.5		1.5
Capital Cost for Option 1-MPF/CMS ($M)		9.6		9.6		9.6		9.6
Operating Cost for Option 1-MPF/CMS ($M)		34.1		25.0		42.5		39.8
Total Cost for Option 1-MPF/CMS ($M)		43.7		34.6		52.2		49.4
Equipment Cost for PA System ($M)		4.5		4.5		4.5		4.5
Eng. Design [0.5 X Equip. Cost] ($M)		2.3		2.3		2.3		2.3
Development Cost for PA system ($M)		1.0		1.0		1.0		1.0
Installation Cost [0.75 X Equip. Cost] ($M)		3.4		3.4		3.4		3.4

Table 5-11. Waste Volumes, Processing Times, and Costs (Continued)

	ANCDF		PBCDF		TOCDF		UMCDF	
	Operation	Closure	Operation	Closure	Operation	Closure	Operation	Closure
Capital and Operating Costs (cont.)								
PA Permitting and Trial Burn Cost ($M)		1.5		1.5		1.5		1.5
PA System Facility Cost at $1,000/sq ft ($M)		7.6		7.6		7.6		7.6
Total Capital Cost for Option 2-PA System ($M)		20.2		20.2		20.2		20.2
Capital Cost for Option 3-MPF/CMS/PA ($M)		28.9		28.9		28.9		28.9
Operating Cost for Option 3-MPF/CMS/PA ($M)		19.9		14.4		25.3		23.3
Total Cost for Option 3-MPF/CMS/PA ($M)		48.7		43.2		54.1		52.1
Capital Cost for Option 4-MPF/PA		20.2		20.2		20.2		20.2
Operating Cost for Option 4-MPF/PA		17.8		13.9		21.8		21.9
Total Cost for Option 4-MPF/PA		38.0		34.1		42.0		42.1
Offsite Disposal Cost for Non-contaminated Wood ($M)	0.5	0	0.3	0	0.7	0	0.3	0
Offsite Disposal Cost for Other Wastes ($M)	0.2	2.0	0.1	1.7	0.3	2.3	0.1	2.2

Notes:

DPE and plastic waste process rate in MPF (lb/hr)	350
Carbon process rate in CMS/DFS (lb/hr)	400
Metal and miscellaneous waste process rate in MPF (lb/hr)	2,000
Concrete process rate in MPF	1,000
Carbon or wood process rate in MPF (lb/hr)	100
Metal, concrete, and miscellaneous wastes process rate in PA (lb/hr)	1,200
Wood, carbon, and plastic wastes process rate in PA (lb/hr)	800
Offsite disposal cost for non-contaminated wood ($/lb)	0.1
Offsite disposal cost for other wastes ($/lb)	0.50

Labor cost for each option is determined from the staffing needs at different phases of closure.

Table 5-11. Waste Volumes, Processing Times, and Costs (Continued)

Notes: (Continued)

For Option 3 (MPF/CMS/PA) carbon to be processed in the CMS/DFS, wood and plastic waste to be processed in the MPF and concrete and miscellaneous waste to be processed in the PA to eliminate any development requirement for the PA. Metal waste is to be optimally distributed between the MPF and PA to minimize total processing time.
For Option 4 (MPF/PA) carbon, plastic and wood is to be processed in the PA and metal and miscellaneous waste is to be processed in the MPF. Concrete waste is to be optimally distributed between the MPF and PA.
Capital cost for CMS includes equipment and installation costs. It is assumed that no facility cost will be involved, as it will be located inside existing facility.
Equipment cost for the PA reactor is $2.5 million and for the secondary combustion chamber with a scrubber system is $2 million. Installation cost is estimated as 75 percent of the equipment cost, facility square footage is 7,600. The DUN, DFS, or LIC secondary chamber with its associated scrubber system may be used to reduce PA system total cost.
The analysis is based on the assumption that waste generation rate during closure is much faster than it can be destroyed in an MPF.
The closure concrete waste quantity assumes removal of both 1/4-inch uniform scabbling and a 1-foot floor removal in category A contaminated areas.

CMS/DFS	=	carbon micronization system/deactivation furnace system
DPE	=	demilitarization protective ensemble
DUN	=	dunnage incinerator
hrs	=	hours
LIC	=	liquid incinerator
MPF	=	metal parts furnace
PA	=	plasma arc
$M	=	millions of dollars

Table 5-12. Waste To Be Processed During Closure

Waste	Furnace	JACADS[a] (tons)	ANCDF[a] (tons)	UMCDF[b] (tons)	TOCDF[a] (tons)	PBCDF (tons)
Agent-Contaminated Charcoal	CMS/DFS	139	175	275	220	175
Spent Decontamination Solution	LIC	1,325	1,349	1,370	1,370	964
Agent-Contaminated Spent Hydraulic Fluid	LIC	5.3	5.5	5.5	5.5	5.5
LIC Total		**1,330**	**1,354**	**1,376**	**1,376**	**969**
Non-halogenated Plastics	MPF	19.3	11.5	11.6	15.0	11.6
Sludge from Agent Collection System and Spent Decontamination Solution Tanks	MPF	13	0.5	1.3	1.7	0.5
Spent HEPA, Prefilters, and Charcoal Trays	MPF	76	15	15	18	15
Metal	MPF	960	851	878	878	703
Concrete (With Floor Removal)[c]	MPF	775	828	835	835	627
Concrete (Without Floor Removal)[d]	MPF	210	313	313	313	255
Solid Waste Greater than 5% Plastic	MPF	53	17	17	43	16
Combustible Bulk Solid Waste	MPF	33	21	21	21	20
Other Solid Waste Miscellaneous	MPF	107	75	75	112	70
Other Solid Waste Aluminum	MPF	0.45	0.09	0.09	0.09	0.09
Contaminated 1X DPE	MPF	60	6	6	48	5
Halogenated Plastic and Rubber	MPF	128	119	119	119	60
MPF Total (with floor)[c]		**2,213**	**1,945**	**1,979**	**2,090**	**1,528**
MPF Total (without floor)[d]		**1,648**	**1,430**	**1,457**	**1,568**	**1,156**

Notes:

[a] Includes legacy and pre-closure dismantlement waste.
[b] UMCDF legacy wastes are not defined at this time.
[c] Assumes removal of 1/4-inch uniform scabbling and 1-foot floor removal in category A contaminated areas.
[d] Assumes removal of 1/4-inch uniform scabbling.

Table 5-12. Waste to be Processed During Closure (Continued)

Notes: (continued)

CMS/DFS = carbon micronization system/deactivation furnace system
DPE = demilitarization protective ensemble
LIC = liquid incinerator
HEPA = high efficiency particulate air
MPF = metal parts furnace

included legacy wastes for all sites except UMCDF. Also, the closure concrete waste quantity in table 5-11 is based on both removal of 1/4-inch uniform scabbling and a 1-foot floor removal in category A contaminated areas.

Time to process these wastes was calculated for each option using the processing rates and equipment as described in table 5-9. Process availability factors were applied to convert the process time into processing duration. The amount of metal waste was optimally distributed between MPF and PA systems in Option 3 to equalize the process duration for both systems, in order to minimize the campaign duration. Similarly, the amount of concrete waste was distributed optimally between the PA system and MPF in Option 4 to equalize process duration for both systems. The process time and process durations for each system within an option are summarized in table 5-11. Note that in table 5-11, the time duration is approximately the same for the MPF and PA systems for Options 3 and 4.

The operating cost during closure for Options 3 and 4 is estimated by multiplying the annual operating cost and process duration in years. Option 2 has a longer operating duration for processing closure wastes than Option 1, and therefore offers no economic advantages over the baseline Option 1. Therefore, its operating cost was not evaluated in table 5-11. The operating costs decrease during the closure period as furnaces are decommissioned similar to the staffing decrease previously discussed. The total operating costs in table 5-11 reflect this changing operating cost.

5.3.6.2 Capital Costs. Installed cost data for the CMS was based on the information from JACADS (Tiller, 2001). The estimated cost at completion for the CMS at JACADS is $8.55 million. The ROM estimate for the CMS system of $8.13 million, as shown in table 5-11, is this $8.55 million cost less the $0.42 million cost of the ventilation filtration system. No facility cost for the CMS was included since the equipment was housed in the existing facility. A permitting and trial burn cost of $1.5 million was added to get the total capital cost of $9.6 million for the CMS.

The equipment cost data for the PA system was obtained from Gillins et al. (1998). The total equipment cost for the PAR, SCC, and the pollution abatement system was about $4.5 million. The development, engineering, installation, permitting, trial burns, and facility costs were added to the equipment cost to arrive at the total capital cost. Assumptions for this estimate include using 50 percent of the total equipment cost for the engineering costs and 75 percent of the total equipment cost was for the cost of installation. The assumed combined cost for permitting and trial burns for the PA system was $1.5 million, the same as used for the CMS. The development cost was assumed to be $1.0 million. The facility cost was estimated at $7.6 million, based on a facility area of 7,600 square feet, and a unit cost of $1,000 per square foot. The total capital cost, including the development cost, for the PA system was estimated to be $20.2 million as shown in table 5-11. As Option 3 does not require any significant development work for the PA system, the capital cost for the PA system for that option was estimated to be $19.2 million. The total capital cost for Option 3 includes $9.6 million for the CMS.

The economic evaluation was based on the total combined capital and operating cost for each option by site. Table 5-13 provides a summary of the total cost for the baseline option and the two competitive options at each of four baseline incineration sites. This summary indicates Option 3 is not economically attractive in comparison to Option 1. Option 4 appears economically attractive and can be implemented within the existing schedule for three sites (ANCDF, TOCDF, and UMCDF).

It is important to note that the error range of plus or minus 30 percent is typically assumed for a study estimate similar to this one (NRC, 2000). The potential cost savings (15 percent for ANCDF, 24 percent for TOCDF, and 17 percent for UMCDF) fall within the error range for total cost. A detailed cost and schedule study would be necessary to confirm the feasibility and value of implementing a PA system. Such a study should include the potential savings from more complex options, such as installing the PA system in an existing facility, having the PA system share the existing afterburner and pollution abatement equipment on one of the incinerators. Similarly, the potential costs and risks associated with constructing a new facility adjacent to an

Table 5-13. Total Cost Comparison for Different Options

(in $M)

	ANCDF	PBCDF	TOCDF	UMCDF
Annual Operating Cost for Baseline Facility ($M/yr)	70.3	66.5	75.3	76.8
Annual Operating Cost for PA Facility ($M/yr)	5.7	5.7	5.7	5.7
Operating Cost Differential ($M/yr)	64.6	60.8	69.6	71.1
Total Capital Cost for PA Facility ($M)	20.2	20.2	20.2	20.2
Minimum Campaign Time Reduction to Justify a PA System for Secondary Waste (months)	3.7	4.0	3.5	3.4
Estimated Campaign Time Reduction by Option 4 for Secondary Waste	4.9	2.4	6.6	2.9
Total Cost for Option 1: MPF/CMS	43.7	34.6	52.2	49.4
Total Cost for Option 2: PA System	Unattractive	Unattractive	Unattractive	Unattractive
Total Cost for Option 3: MPF/CMS/PA	48.7	43.2	54.1	52.1
Total Cost Option 4: MPF/PA	38.0	34.1	42.0	42.1

Notes:

Even though Option 4 appears economically attractive at three sites, there are several factors that need to be considered to ensure that the projected economic gains are feasible considering the closure activity schedule. If the waste generation rate during closure is not sufficiently high, then the MPF would not be a bottleneck. In this case reducing the process time by using a PA system does not reduce the total closure duration and the projected gains would not be realized. Additionally, the PA system implementation schedule cannot delay the site closure schedule.

CMS = carbon micronization system
MPF = metal parts furnace
PA = plasma arc
$M = millions of dollars
$M/yr = millions of dollars per year
yr = year

operating facility need to be reviewed. Finally, the MPF has a very low rate for processing wood. Any significant change in the current estimate that 5 percent of the wood is contaminated would also significantly change the operating time of the MPF.

5.3.7 Cost Analysis for Secondary Wastes at Baseline Sites. Table 5-11 lists the volumes of secondary wastes generated during operation. It is normally assumed that the MPF system has sufficient idle time available to process the secondary wastes generated during operation and processing secondary wastes in the MPF does not extend the campaign duration. As mentioned previously, the only apparent cost savings in using PA for processing secondary wastes is if it results in shortening the operating schedule. Therefore, this cost analysis only examines the situation where there is insufficient idle time in the MPF system to process all of the secondary wastes without extending the campaign duration.

The reduction in campaign schedule necessary to exactly offset the total capital and installation cost for a PA system was derived from the annual operating costs in table 5-13. These time durations, which vary from 3.4 months at UMCDF to 4.0 months at PBCDF, are tabulated in table 5-13. Similarly, table 5-11 provides the total schedule durations for processing secondary wastes for each option.

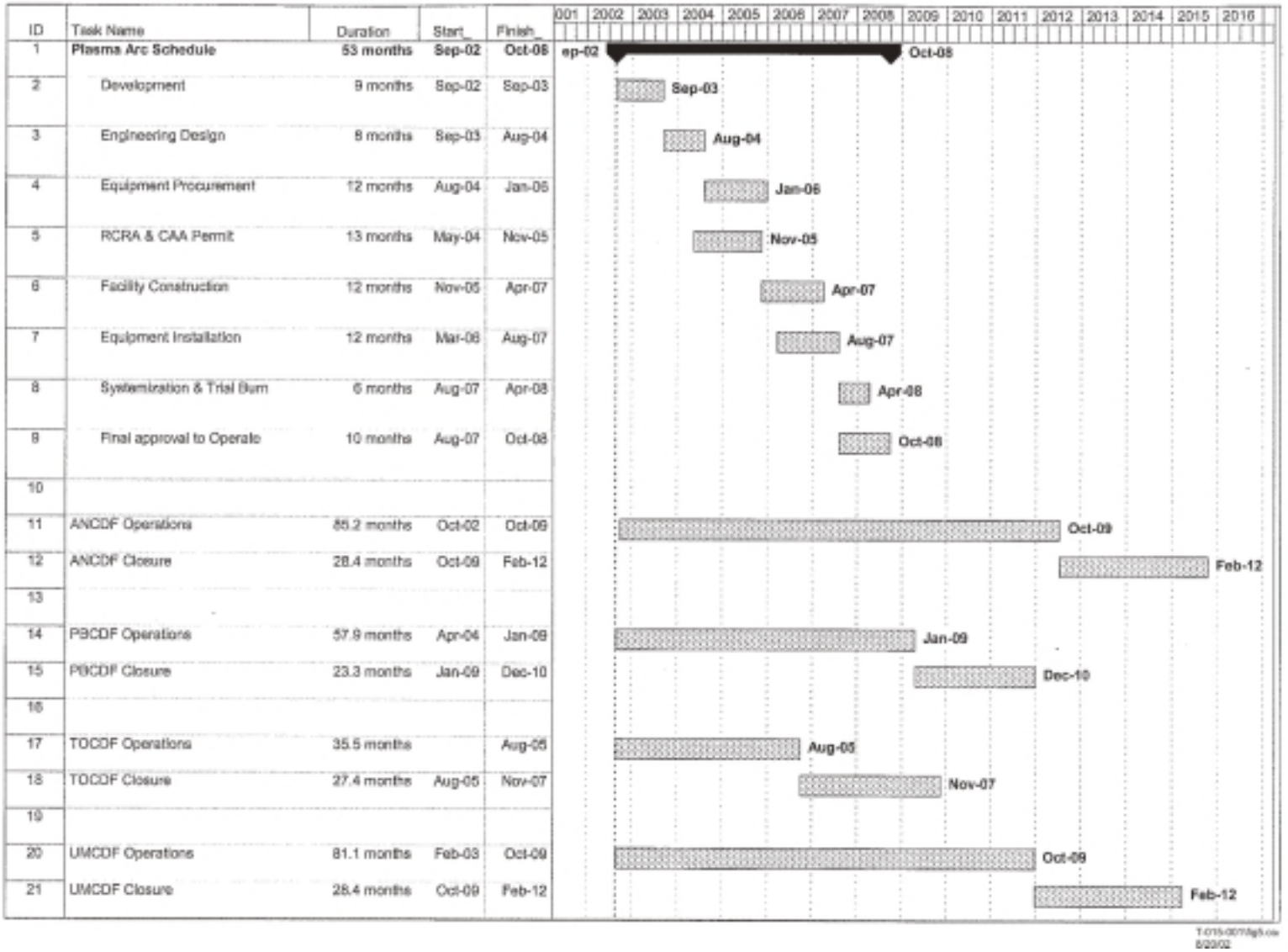
Although, under the assumptions of this analysis, it appears that using a PA system to process part of the secondary waste during the campaign schedule would result in a significant cost savings at ANCDF and TOCDF, the operating schedule compared to the PA system implementation schedule negates this assumption. TOCDF is already operating, and ANCDF is scheduled to begin operations this fall.

5.3.7.1 Cost Analysis Using Offsite Disposal. Estimates for offsite disposal costs vary from $0.08 to $0.50 per pound. Using a worst-case value of $0.50 per pound, the total disposal cost for closure wastes at baseline sites is estimated to be between $1.7 million for PBCDF to $2.3 million for TOCDF. Since these costs are a magnitude lower than the capital cost for a PA system, it is quite apparent that offsite disposal is superior to the onsite use of PA.

5.3.7.2 Cost Analysis for Alternative Technology Sites. The alternative technology sites use neutralization processes for their primary wastes. In these processes, hydrolysate comprises the large majority of total secondary waste. As these plants do not have any equipment for treatment and disposal of their secondary wastes, they plan to use offsite facilities for their disposal.

The details about secondary and closure wastes for all the alternative technology sites are not currently available. Some information for ACANF was gathered from Aberdeen Proving Ground in Maryland (see appendix D). The estimated cost for disposal of the secondary waste at a TSDF is $0.51 per pound. This cost is less than half of the estimated operating cost for a PA system of $1.08 per pound. Thus, the use of a PA system for processing secondary waste at ACANF is not economically attractive.

5.3.8 Schedule for PA System. A preliminary schedule for developing, designing, installing, and systemizing a PA system is shown in figure 5-4. As noted on this schedule, it will take about 4 years before starting the systemization process and almost 5 years to start full production with an operating permit. This schedule is key in determining the feasibility of using PA technology at the PMCD sites, since all of the cost savings is strictly in reducing the current operating schedules at these sites.



ID	Task Name	Duration	Start	Finish
1	**Plasma Arc Schedule**	**53 months**	**Sep-02**	**Oct-06**
2	Development	9 months	Sep-02	Sep-03
3	Engineering Design	8 months	Sep-03	Aug-04
4	Equipment Procurement	12 months	Aug-04	Jan-06
5	RCRA & CAA Permit	13 months	May-04	Nov-05
6	Facility Construction	12 months	Nov-05	Apr-07
7	Equipment Installation	12 months	Mar-06	Aug-07
8	Systemization & Trial Burn	6 months	Aug-07	Apr-08
9	Final approval to Operate	10 months	Aug-07	Oct-08
10				
11	ANCDF Operations	85.2 months	Oct-02	Oct-09
12	ANCDF Closure	28.4 months	Oct-09	Feb-12
13				
14	PBCDF Operations	57.9 months	Apr-04	Jan-09
15	PBCDF Closure	23.3 months	Jan-09	Dec-10
16				
17	TOCDF Operations	35.5 months		Aug-05
18	TOCDF Closure	27.4 months	Aug-05	Nov-07
19				
20	UMCDF Operations	81.1 months	Feb-03	Oct-09
21	UMCDF Closure	28.4 months	Oct-09	Feb-12

Figure 5-4. PA System Schedule

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SECTION 6
CONCLUSIONS AND FINDINGS

6.1 Findings

Key findings based on this review of PA technology and its potential for CDP waste processing applications are summarized as follows:

a. All of the stockpile sites except BGCDF have established the process for disposal of all secondary wastes. Based on current schedules and costs, there is no apparent benefit in using PA technology at any of these sites for processing secondary wastes.

b. Offsite disposal of non-contaminated secondary and closure wastes is significantly less expensive than any of the onsite options at baseline and alternative technology sites.

c. If offsite disposal cannot be accomplished, the use of PA technology for processing closure wastes in conjunction with the MPF shows some economic advantage at three sites (ANCDF, TOCDF, and UMCDF). A more detailed cost and schedule analysis is necessary to confirm these potential savings. Moreover, carbon deposition/formation problems experienced at some commercial facilities indicate the need for significant additional testing and development before selecting PA technology for processing charcoal. In contrast, PA technology is highly suited for processing contaminated concrete, sandblast grit, and soils, and there is significant commercial experience in using PA technology for processing inorganic materials with trace organic contamination.

d. The current offsite disposal path chosen by the alternative technology sites is more economical and should be pursued. If public opposition does

not permit it, then any alternate path chosen by these sites should be compared to the PA system.

6.2 Recommendations

There is no apparent economical advantage in using PA technology instead of the current processes that are to be used at the PMCD disposal sites.

This technology is given a rating of 2—it may be useful to PMCD. It is recommended to continue to periodically monitor the status of PA technology in relation to PMCD needs by application of the technical evaluation criteria.

It is also recommended to develop a conceptual design and cost estimate for a small PA system to treat the metal waste from the PBNSF to a 5X condition in the event that the planned chemical decontamination proves to be insufficient.

Any PA design effort should consider how the advances in torch life can possibly be incorporated into the design.

Finally, given the promise of significant cost savings indicated by the preliminary economic analysis presented in this report, it is recommended to perform a more detailed and definitive study of potential application of PA system to process closure wastes at ANCDF, TOCDF, and UMCDF.

APPENDIX A
ACRONYMS/ABBREVIATIONS

APPENDIX A
ACRONYMS/ABBREVIATIONS

ABCDF	Aberdeen Chemical Agent Disposal Facility
AC	alternating current
ACANF	Aberdeen Chemical Agent Neutralization Facility
ACWA	Assembled Chemical Weapons Assessment
ANCDF	Anniston Chemical Agent Disposal Facility
ATD	Advanced Technology Demonstration
ATG	Allied Technology Group, Incorporated
BGCDF	Blue Grass Chemical Agent Disposal Facility
CAIS	chemical agent identification set
CDP	Chemical Demilitarization Program
CMS	carbon micronization system
CO	carbon monoxide
CO_2	carbon dioxide
CONUS	continental United States
CRADA	Cooperative Research and Development Agreement
CST	continuous steam treater
DC	direct current
DF	methylphosphonic difluoride
DFS	deactivation furnace system
DMMP	dimethyl methylphosphonate
DPE	demilitarization protective ensemble
DRE	destruction removal efficiency
DUN	dunnage incinerator

GB	Sarin, (isopropyl methyl phosphonofluoridate)
GPCR	gas phase chemical reduction
GPS	gas polishing system
H_2	hydrogen
H_2O	water
HD	mustard agent (distilled), [bis(2-chloroethyl) sulfide]
HEPA	high efficiency particulate air
HF	hydrofluoric acid
HT&R	Hold, Test and Release/Rework
HWAD	Hawthorne Army Depot
IET	Integrated Environmental Technology LLC
in. w.c.	inches of water column
JACADS	Johnston Atoll Chemical Agent Disposal System
kW	kilowatt
LIC	liquid incinerator
MACT	maximum achievable control technology
MEA	monoethanolamine
mm	millimeter
MPF	metal parts furnace
MPT	metal parts treater
MSE	MSE Technology Applications, Incorporated
MW	megawatt
N_2	nitrogen
NECDF	Newport Chemical Agent Disposal Facility
ng	nanogram

NO_x	nitrogen oxides
NRC	National Research Council
NSCMP	Non-Stockpile Chemical Materiel Product
NSWCCD	Naval Surface Warfare Center, Carderock Division
PA	plasma arc
PAH	polycyclic aromatic hydrocarbon
PAR	plasma arc reactor
PBCDF	Pine Bluff Chemical Agent Disposal Facility
PBNSF	Pine Bluff Non-Stockpile Facility
PCG	plasma converter gas
PEAT	Plasma Energy Applied Technology
PFE	plasma-fired eductor
PIC	products of incomplete combustion
PMCD	Program Manager for Chemical Demilitarization
PODS	Plasma Ordnance Demilitarization System
PPE	personnel protective equipment
ppm	parts per million
PS	plasma system
PUCDF	Pueblo Chemical Agent Disposal Facility
PVC	polyvinyl chloride
QL	O, O'-ethyl diisopropylaminoethyl methyl phosphonite
RCRA	Resource Conservation and Recovery Act
RCWM	recovered chemical warfare materiel
ROM	rough order of magnitude
RRS	Rapid Response System
SCC	secondary combustion chamber
SCWO	supercritical water oxidation
SO_2	sulfur dioxide

TC	toxicity characteristic
TCLP	Toxicity Characteristics Leaching Procedure
TEQ/m^3	toxicity equivalent quotient per cubic meter
THC	total hydrocarbons
TOC	total organic carbon
TOCDF	Tooele Chemical Agent Disposal Facility
TRC	thermal residence chamber
TSDF	treatment, storage, and disposal facility
UMCDF	Umatilla Chemical Agent Disposal Facility
USEPA	United States Environmental Protection Agency
VRI	Vanguard Research Institute
VX	nerve agent, O-ethyl S-(2-diisopropylaminoethyl)methylphosphonothioate
WESP	wet electrostatic precipitator

APPENDIX B
REFERENCES

APPENDIX B
REFERENCES

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APPENDIX C
PLASMA ARC PROCESSING OF PRIMARY NON-STOCKPILE CHEMICAL MATERIEL PRODUCT WASTES

APPENDIX C
PLASMA ARC PROCESSING OF PRIMARY NON-STOCKPILE CHEMICAL MATERIEL PRODUCT WASTES

A preliminary design for the Pine Bluff Non-Stockpile Facility (PBNSF) initially incorporated plasma arc reactors (PARs) to process both primary and secondary wastes. In this design, agents were drained and chemically neutralized using the Munitions Management Device, Version 2 system. Resulting neutralents, corresponding aqueous wastes, and metal wastes were to be processed in a dedicated PAR. Binary precursors methylphosphonic difluoride (DF) and O, O'-ethyl diisopropylaminoethyl methyl phosphonite (QL) were to be processed neat in a separate dedicated PAR.

The Non-Stockpile Chemical Materiel Product (NSCMP) primary wastes include liquid streams (agent neutralents, binary precursors, spent decontamination solutions, spent rinse water, and scrubber blowdown), and solid streams (metal shrapnel with soot from detonation chamber, cut non-explosively configured munitions, glass fragments from chemical agent identification sets (CAIS)/chemical samples items, DF canisters, QL drums). Table C-1 provides a summary of expected quantities for the primary NSCMP wastes originating from the activities of an integrated PBNSF that were destined to be processed in the PARs. Preliminary design of the entire facility was carried out and is the basis for the discussion that follows. It is noted that since the preliminary design was completed, the process configuration was drastically altered and PARs were eliminated in favor of offsite disposal.

Under the envisioned scheme, the PBNSF would consist of two separate plants, Plant A processing recovered chemical warfare materiel (RCWM), CAIS, and chemical samples, and Plant B processing binary precursors DF and QL. In Plant A, the RCWM would be drilled to drain the agents, and CAIS bottles would be manually emptied inside a glovebox. Drained agents would be reacted with monoethanolamine (MEA) or sodium hydroxide reagent and the resulting neutralents processed in PAR System A. The

Table C-1. Estimates of Waste Resulting from Demilitarization of Non-Stockpile Chemical Materiel Inventory at Pine Bluff Arsenal

Campaign	Waste Stream Generated	Mass,lbs	Comments
H-MEA Neutralent	H Neutralent	226,928	Based on 1:36.5641 mass ratio of HD to reagent (91%MEA+9%H2O)
	Spent Rinsewater and Spent Decontamination Solution	738,755	
	Metal (incl. consumable cradles and pails)	14,354	
	Soot fm Detonation Chamber	145	
	Glass	1,073	
	OVERALL	981,254	
H-DCDMH Neutralent	H-DCDMH Neutralent	5,657	Based on 1:30.18 mass ratio of H to DCDMH reagent mix
	Spent Rinsewater and Spent Decontamination Solution	incl.	
	Metal	0	
	Glass	incl.	
	OVERALL	5,657	
HD/CHCl3-DCDMH Neutralent	HD/CHCl3-DCDMH Neutralent	3,694	Based on 1:43.67 mass ratio of HD/CHCl3 to DCDMH reagent mix
	Spent Rinsewater and Spent Decontamination Solution	incl.	
	Metal	0	
	Soot fm Detonation Chamber	incl.	
	Glass	incl.	
	OVERALL	3,695	
Nitrogen Mustard	HN3 Neutralent	23,612	Based on1:41.02 mass ratio of HN3 to reagent
	Spent Rinsewater and Spent Decontamination Solution	122,920	
	Metal (incl. consumable cradles and pails)	5,433	
	Soot fm Detonation Chamber	50	
	Glass	0	
	OVERALL	152,015	

Table C-1. Estimates of Waste Resulting from Demilitarization of Non-Stockpile Chemical Materiel Inventory at Pine Bluff Arsenal (Continued)

Campaign	Waste Stream Generated	Mass,lbs	Comments
CG	CG Neutralent	683	Based on1: 24.68 wt. ratio of CG to 20%NaOH reagent
	Spent Rinsewater and Spent Decontamination Solution	34,683	
	Metal	334	
	Soot fm Detonation Chamber	6	
	Glass	0	
	OVERALL	35,706	
GB	GB Neutralent	10,357	Based on 1:12.7 mass ratio of GB to reagent (5%NaOH)
	Spent Rinsewater and Spent Decontamination Solution	44,423	
	Metal	144	
	Soot fm Detonation Chamber	0	
	Glass	15	
	OVERALL	54,939	
VX	VX Neutralent	671	Based on 1:18.49 mass ratio of HL to reagent (18%NaOH)
	Spent Rinsewater and Spent Decontamination Solution	17,904	
	Metal	1	
	Soot fm Detonation Chamber	0	
	Glass	1	
	OVERALL	18,577	
Arsenicals	Arsenical Neutralent (20%NaOH based)	43,340	Based on 1:20 mass ratio of agent to reagent
	Arsenical Neutralent (DCDMH based)	349	Based on 1:20 mass ratio of agent to reagent
	Spent Rinsewater and Spent Decontamination Solution	300,516	
	Metal (incl. consumable cradles and pails)	13,074	
	Soot (carbon)	179	
	Glass	71	
	OVERALL	314,188	

Table C-1. Estimates of Waste Resulting from Demilitarization of Non-Stockpile Chemical Materiel Inventory at Pine Bluff Arsenal (Continued)

Campaign	Waste Stream Generated	Mass,lbs	Comments
DF	Neat DF	352,349	Processed directly without prior neutralization
	Spent Rinsewater and Spent Decontamination Solution	360,348	
	Metal	269,546	
	HDPE	63,276	
	OVERALL	1,045,519	
QL	Neat QL	98,166	Processed directly without prior neutralization
	Spent Rinsewater and Spent Decontamination Solution	227,427	
	Metal (crushed drums to PAR-A)	30,474	
	HDPE	0	
	OVERALL	356,068	
ALL CAMPAIGNS	TOTAL WASTE	2,967,618	

CAIS/chemical sample vials and ampules would be processed in small reactors capable of breaking small glass containers in the presence of a strong oxidizing reagent (1,3-dichloro-5,5-dimethylhydantoin solution). The resulting neutralents would also be processed in the PAR along with the separated glass fragments. Drilled, drained, and rinsed energetic RCWM would be deactivated in the detonation chamber. Non-energetic RCWM would be cut using a saw. Shrapnel and metal fragments would undergo additional size reduction in a shredder followed by decontamination in the rotary wash drum filled with decontamination solution, then fed into the PA. Spent decontamination solutions would be commingled with rinsewaters and vent scrubber blowdown and later processed as aqueous waste in the PAR. Operations would be conducted in subsequent agent campaigns separated by turnaround periods.

Binary precursors would be processed in Plant B. DF canisters would be unpacked, then punched and drained under an inert atmosphere inside a special enclosure. Drained DF would be injected directly into the PAR System B along with drained (but not rinsed) canisters. Following the DF campaign, QL would be drained from the drums and injected directly into the PAR. Rinsed QL drums would be recycled, or alternatively crushed, shredded, and fed to the PAR.

A PA system was selected for this application based in part on its “omnivore” characteristics, that is, the ability to process a wide range of feeds, including liquids and solids, with little or no feed conditioning. Other systems were considered for the final treatment of neutralents and the associated wastes, including supercritical water oxidation, gas phase chemical reduction, biodegradation, and conventional incineration. Several PAR configuration and component options were considered before selecting the current design; these included non-transferred plasma torch, water-cooled electrodes, oxidizing and inert atmosphere, electric arc furnace, etc.

The PAR chosen for both plants was Integrated Environment Technology’s (IET’s) vertical stationary transferred arc furnace with two direct current (DC) graphite electrodes for plasma generation and three alternating current (AC) graphite electrodes for joule heating of the melt. This design was chosen because graphite electrode failure

would not cause the release of cooling water into the melt, thus eliminating the potential for steam explosions. The reactor would operate in the steam-reforming mode and would be equipped with spray lances for liquid injection, a containerized feed system for introduction of containerized waste, and a bulk feed system for introduction of granular materials, such as glass and slag additives. Steam reforming mode was chosen to allow co-processing of aqueous wastes along with neutralents. The reactor was a refractory-lined carbon steel vessel with an air-cooled outer vertical surface and water-cooled bottom surface. The process chamber consisted of two zones: the melt crucible that contains the molten slag, and the plenum or vapor space above the melt. In addition to the electrode ports, plenum nozzles were provided for the waste feed, offgas exit, and viewports.

The vessel lining was composed of several different types of refractory and insulating materials. These materials served to reduce energy losses and contain the molten glass and metal phases in the crucible. The plenum area of the process vessel was lined with both insulating materials and coated with corrosion barrier material to protect the carbon steel shell from corrosive feed, decomposition gases, and vapors. The shell is maintained above the gas dew point. The plenum volume was sized to provide a 2-second residence time to complete steam-reforming reactions.

Energy input into the PAR is required to evaporate injected liquids, to heat and react the resulting vapors (steam reforming and pyrolysis reactions are endothermic), to melt the metal and flux additives, and to compensate for heat losses. The energy for the PAR was provided by two DC graphite electrodes generating PA, and three AC graphite electrodes providing joule-heating of the slag layer. The AC electrodes allow the PAR to idle whenever it is desired to stop processing for a few hours or days while still maintaining glass and metal in molten state. The system maintains the molten bath temperature automatically and requires no operator presence once the PAR system is put into idle mode.

The power inputs to DC PA and AC joule heating electrodes are controlled by the operating staff and vary depending on the type of feed processed. Feeds that contain a

high percentage of organic material require more power from the DC PA, while feeds that contain a high fraction of inorganic material will require more power delivered through joule-heating. The refractory temperature and the plenum temperature also affect the power drawn from each source.

Neutralent waste would be introduced into the plenum as a pressure-dispersed spray using an injection lance. A part of spent rinsewater and spent decontamination solution aqueous waste would also be injected into the reactor as spray using a separate injection lance to satisfy steam reforming reaction requirements. If the available spent rinsewater and spent decontamination solution waste quantities are insufficient, supplemental water would be introduced to satisfy the requirements for the steam reforming reactions. Liquids would vaporize instantaneously, and organic constituents would undergo simultaneous pyrolysis and steam-reforming reactions, producing a variety of compounds including carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), and hydrogen halides. Most inorganic constituents and metals would become a part of the molten slag and metal pool.

The depths of molten slag and metal layer would be monitored periodically by slowly inserting a spare electrode towards the melt while simultaneously monitoring the depth of insertion and the electrical resistance of the circuit formed between the electrode and the ground. When the electrode touches the slag, the resistance would drop and the position of liquid level would be noted. When the electrode reaches molten metal, the resistance would drop further indicating that the slag/metal interface was reached. The molten slag and metal would be poured separately into melt containers consisting of 30-gallon steel drums set in sand-filled 55-gallon steel drums and allowed to cool and solidify under ambient conditions. Thermal valves would be used to stop the flow of slag, however, the entire molten metal pool would empty upon hot tapping of the bottom discharge port.

The PAR would be maintained at a negative pressure (-10 inches of water column [in. w.c.]) to prevent gas leaks to the outside. A small amount of air would infiltrate into the reactor because of the negative pressure. Gas residence time in the PAR would be

2 seconds. The offgas containing mainly CO_2, CO, H_2, water, hydrogen halides, along with carryover ash and carbon particles, would leave the reactor at 2,000°F.

Modeling the PAR as a Gibbs free energy equilibrium reactor indicated a possibility of formation of hydrogen cyanide, carbon, and polycyclic aromatic hydrocarbons (PAHs). Subsequently, the process configuration chosen for this application proposed routing PAR offgas directly into the oxidizing chamber to assure complete oxidation of any soot particles and organic products of pyrolysis and steam-reforming reactions. An alternative to thermal oxidation of the PAR offgas was to conduct partial oxidation in the temperature conditioning chamber downstream of the PAR in order to minimize concentrations of soot and unoxidized species, then remove acidic impurities and particulates and use cleaned gas as a fuel in an internal combustion engine driving a power generator. This alternative was not pursued given uncertainties regarding composition of the PAR offgas, potential formation of elemental carbon and other solids with the corresponding hazardous waste generation, uncertainties in the configuration of the gas cleanup train, a probable need for recycling of organic-contaminated scrubber blowdown back to PAR, a need to co-process spent rinsewater and spent decontamination solution not used in PAR, and potentially unfavorable economics. Analysis of applicable regulations and subsequent permitting strategy definition efforts revealed no schedule advantages between Resource Conservation and Recovery Act (RCRA) Subpart O and RCRA Subpart X permitting pathways.

The oxidizing chamber, designed as a vertical cyclonic combustor with a slag/ash bottom hopper, would provide approximately 3-second gas residence time and would operate at a temperature of approximately 1,800°F (2,200°F maximum). Excess air would be introduced into the chamber to provide required O_2 to the oxidation process. The chamber would be equipped with injection ports for excess aqueous waste that was not fed into the PAR and natural gas burners used for startup and for maintaining stable temperature during the operation. The offgas would exit horizontally at the bottom of the chamber and would be routed to the gas cleanup train.

The gas cleanup train would consist of a thermal DENOX ammonia injection system, wet quench, venturi scrubber, packed tower scrubber, wet electrostatic precipitator (WESP), gas reheater, high efficiency particulate air/charcoal filter bank, induced draft fans, and a stack. This configuration was very similar to the one used successfully in baseline incineration systems. Key differences included the addition of the thermal DENOX section and replacement of the candle demister with a more efficient and state-of-the-art WESP for aerosol removal.[1]

The preliminary design revealed the following areas of uncertainties and technical risk involving the PAR:

a. *PAR Offgas Composition.* The PAR offgas composition was determined theoretically using the Gibbs free energy reactor model and has not been experimentally confirmed. The Gibbs model predicts the presence of hydrogen cyanide. Also, there is a potential for formation of elemental phosphorus and carbon soot that could form deposits in the PAR and in the duct leading to the oxidizing chamber. For this reason it may be necessary to introduce air directly into the PAR and/or conduct controlled periodic burnout of such deposits during operation and before every shutdown of the PAR for maintenance or inspection. It was recommended that such provisions be included, such as an airline with flow controls to the injectors or to the airlock on the solids feed chute.

b. *Element Partition.* The energy and material balance assumed that all compounds containing sodium, arsenic, halogens, sulfur, and phosphorus are carried overhead from the PAR into the oxidizing chamber and pollution abatement system as volatile or aerosolized compounds. In reality, some of the sodium, arsenic, phosphorus, sulfur, chlorine, and fluorine may likely be retained in the slag or in the metal melt in the PAR. Experimental data is needed to determine the distribution of these

[1] Since arsenicals were to be processed at PBNSF, a more efficient device than a candle demister was required for aerosol removal.

elements between slag, metal melt, and vapor phases. Such data was partially provided by the previously discussed DF simulant tests with IET's Plasma Enhanced Meter (PEM™) system (see paragraph 3.3 in main document); however, that test system was configured differently than the PBNSF PA system.

c. *Fly Ash Load.* The assumption of 15 percent of iron input converted into ferric oxide and carried out as fly ash was made to obtain a conservative fly ash load estimate. The assumption should be verified experimentally during pilot tests.

d. *Carbon Electrode Consumption Rate.* Carbon electrode consumption was taken as 3 percent of the total waste load to PAR and should be verified experimentally during pilot tests.

e. *Slag Additives.* Specific composition and dosage of the slag/flux additive was not established with certainty and should be determined experimentally. Such additives can be silicate glass, silica sand, calcium carbonate, or mixture of these and other materials. The potential exists for significant capture of phosphorus, sulfur, chlorine, fluorine, and arsenic in the slag. (The slag will likely contain trivalent arsenic compounds that may make it difficult to landfill.)

f. *Molten Metal Accumulation.* Current design was based on the premise that molten metal will not accumulate beyond a 30-gallon limit in the PAR. If the metal accumulated beyond this limit, it would be impossible to avoid overfilling a 30-gallon receptacle container, subsequently spilling molten metal on the floor of the PAR room. It would be prudent to redesign the system such that multiple 30-gallon containers joined by a removable spill guard, would be staged side by side on a roller conveyer, and positioned under the pour port one-by-one using remote controls.

g. *Excessive Nitrogen Oxide (NO_x) Formation.* The PAR offgas may contain considerable concentrations of nitrogen compounds, such as hydrogen cyanide. To avoid excessive NO_x formation in the oxidizing chamber due to chemically bound nitrogen, it may be prudent to design capability for staged combustion, such that the first stage operates under oxygen (O_2)-starved conditions leading to oxidation of nitrogen compounds to N_2, while the second stage operates with O_2 excess. The current design incorporated a more conventional and readily available single stage combustor with an auxiliary natural gas burner. Pilot testing should provide a definitive answer as to the composition of the PAR offgas. It was recommended that the pilot test combustor be two-stage designed with the ability to reconfigure and operate it in a single stage mode.

h. *Refractory Materials.* Refractory materials for the PAR, oxidizing chamber, thermal DENOX chamber, and the interconnecting ducting were selected using an uncertain composition of the slag and, to a lesser degree, of the process gas. Pilot tests must verify that the choices made are indeed suitable for the application, such that the refractory repair/replacement frequency is not excessive.

i. *Metal Materials of Construction.* In the current design of refractory-lined equipment (PAR, oxidizing chamber, thermal DENOX chamber and interconnecting ducting), carbon steel was chosen as shell construction material. The steel shell would be maintained safely above the dew point temperature to prevent acidic corrosion. This design needs experimental verification given that certain parts of the PAR are externally cooled using air or water. It was recommended to evaluate a high temperature corrosion barrier between the steel and refractory, such as epoxy mastic.

j. *Thermal DENOX Chamber.* The thermal DENOX chamber was designed to provide a minimum 1-second residence time to promote reactions between NO_x and ammonia (NH_3) independent of layout. It is

recommended to evaluate deletion of the thermal DENOX chamber and instead use a long (56 feet or more) duct of proper diameter between the oxidizing chamber and the wet quench to provide sufficient residence time and turbulence. The NH_3 injection point would have to be moved to a point directly downstream of the oxidizing chamber gas exit nozzle. Consultation with Exxon Mobil Corporation (the technology licensor for the thermal DENOX) was recommended.

k. *Emergency Quench.* In the event that power was lost, there would be a short period of time (maybe a few minutes) before the backup power became available. During this period, it would be imperative that the fiber reinforced plastic (FRP) scrubbers downstream of the quench towers for both pollution abatement systems be protected from the over-temperature caused by a temporary interruption of the quench water supply. The design called for a separate emergency quench water line to be activated by a temperature switch high on the quench offgas line. This emergency quench water line originated directly from the pressurized water main delivering potable water to PBNSF. The reliability of this pressurized water source needs to be ascertained. If necessary, other means of providing emergency quench water need to be evaluated or implemented.

l. *Extent of Scrubbing Reactions.* It was recommended for the pilot tests to determine the extent of scrubbing reactions (for example between hydrochloric acid, hydrofluoric acid [HF], nitrogen dioxide, or sulfur dioxide) and removal of fly ash and formed particulates occurring in the quench, venturi, and packed scrubber. The energy and material balances assumed that wet quench would remove 50 to 70 percent of the acidics and 20 to 100 percent of the particulates with the remainder removed in the venturi/packed scrubber/WESP system.

m. *Low Energy Venturi.* A medium energy (25-in. w.c. pressure drop) variable throat venturi was provided to remove 99 percent of particulates over 1 micron diameter. It is possible that with a highly efficient WESP, a low energy fixed-throat venturi would be sufficient. Use of a low, fixed-throat venturi would save capital and power costs. Pilot testing should include operating the venturi at low-pressure drops.

n. *Air vs. Water Cooling.* The heat from cooling the oxidizing chamber offgas is dissipated through the clean liquor coolers into the cooling tower. A competing scheme would be to use air for cooling—one option would be to use conventional fin-fan coolers (as in the current baseline chemical disposal facility design), another would be to use this waste heat (approximately 3-million British thermal units [Mbtu] per hour on the average from both PAR System A and PAR System B) for space heating of the building in the winter or to run absorption type chillers for AC in the summer. Note that the temperature of the brine leaving the coolers would have to be raised up from 100°F to provide adequate temperature differential for air cooling. This would decrease the amount of heat to be recovered and also raise the scrubber blowdown temperature.

o. *Safer Electrode Changeout Operations.* Consider stacking two (or more) electrodes in the vertical queue to minimize frequency of personnel access to the high operating platform and the associated hazard. Ensure the overhead crane is disabled during electrode changing operations to prevent the crane from hitting the energized electrode.

p. *Hot Spot Monitoring.* Hot spots may develop due to cracks or due to an increase in thermal conductivity caused by volatile salt or metal condensation inside the refractory pores. An infrared camera was provided for monitoring of all refractory-lined equipment or ducting for periodic hot spots.

Overall, significant testing and design development work were deemed necessary to fully qualify PA technology for intended use at PBNSF. The main objective of such tests would be to demonstrate that selected process configuration would work as designed and achieve sustained and stable operation over a sufficiently long period. Other objectives would include obtaining more data on promising materials of construction, reactor offgas composition, and partition of elements between slag and offgas, and demonstrating the feasibility of feeding whole DF canisters directly into reactor.

APPENDIX D

ABERDEEN CHEMICAL AGENT NEUTRALIZATION FACILITY WASTE MATRIX

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ABERDEEN CHEMICAL AGENT NEUTRALIZATION FACILITY WASTE MATRIX

Table 1 - Cost Summary ($)

This workbook provides estimates for ACANF hazardous and industrial wastes as follows:

Pages 1-2: Time-phased summary tables of waste stream quantities (by cost, by weight, by assumed disposal technology, and by container types).

Page 3: Phase 1 Agent-Related Waste Details,

Page 4: Phase 1 Non-Agent Related Waste Details,

Page 5: Phase 2 Agent-Related Waste Details,

Page 6: Phase 2 Non-Agent Related Wastes,

Page 7: Closure wastes. Construction wastes are not included in this analysis.

The POC for this workbook is Kevin Rankin (410-436-9636)

Item	Cost
Phase 1 Ops: Agent Related Waste	$24,337,829
Phase 1 Ops: Non-Agent Related Waste	$82,019
Phase 2 Ops: Agent Related Waste	$10,287,340
Phase 2 Ops: Non-Agent Related Waste	$164,387
Closure Related Waste	$481,288
Total Waste Mgt. Cost (T&D), Incl. Hyrolysate =	$35,352,863
Less ACANF Managed	$32,802,051
Total T&D managed via APG-DSHE Contract	$2,550,812

ACANF Schedule Assumptions.

Phase 1: Agent Neutralization Operations: 1 Jul 2002 - 20 Dec 2002

Phase 2: TC Cleanout Operations: 20 Jan 2003 - 20 Jan 2004

Closure: 21 Jan 2004 - 21 Oct 2004

Source: Saraiya, fax to Jay Shah, 8 August 2002, 10:50 a.m.

Table 2 - Waste Quantity Table (In pounds) - Grouped by Disposal Technology

			Phase 1 - Agent Neutralization			Phase 2 - Ton Containers Cleanout			Closure	Grand Total
Cat.	Assumed Disposal Technology	Assumed Cost ($)	Agent Related (lbs)	Non-Agent Related (lbs)	Phase 1 Total (lbs)	Agent Related (lbs)	Non-Agent Related (lbs)	Phase 2 Total (lbs)	Closure Total (lbs)	Grand Total (lbs)
ID	Incin Drum	0.008/lb	38,175	28,578	66,753	84,632	57,628	142,460	211,310	420,523
IB	Incin Bulk	0.008/lb	0	0	0	0	0	0	132,000	132,000
LD	Landfill Drum	0.008/lb	40,788	0	40,788	159,192	0	159,192	67,820	267,800
LB	Landfill Bulk	0.008/lb	0	0	0	0	0	0	3,600,000	3,600,000
LD-S	Landfill Drum + Stabilization	0.16/lb	0	19,800	19,800	0	39,600	39,600	41,250	100,650
LB-S	Landfill Bulk + Stabilization	0.16/lb	0	396,000	396,000	0	792,000	792,000	0	1,188,000
BIO	Bio/Deepwell	0.06/lb	0	0	0	0	0	0	44,000	44,000
FD	Fuels Blending Drum	0.10/lb	0	6,300	6,300	0	12,600	12,600	1,650	20,550
A	ACANF Managed (Hydrolysate & Related)	0.52/lb	46,759,067	0	46,759,067	16,277,800	0	16,277,800	44,000	63,080,867
				Total (lbs)	47,288,708			17,423,652	4,142,030	68,854,390
			Less ACANF Managed (lbs)		48,759,067			16,277,800	44,000	63,080,867
			Total to be managed under APG-DSHE Contract (lbs)		529,641			1,145,852	4,098,030	5,773,523

Note: TC Half transportation and disposal cost estimated at $477/half. TC halves are not included in the quantity table because disposal cost is not driven by TC weight. TC Halves only generated during Phase 2 Operations. Estimate 302.5 TC halves/month during Phase 2, for a total of 3703 halves during Phase 2. (The extra volume is due to plugs, valves, tubes, etc.). Estimate excludes - 800 empty protective TCs currently in CASY.

ACANF Offsite Waste 01.18.02 Rollup

Source: Saraiya, fax to Jay Shah, 8 August 2002, 10:50 a.m.