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EVALUATION OF AFBC CO-FIRING OF COAL AND HOSPITAL WASTES

Technical Report For The Period January, 1989 - August, 1990

February, 1991

Work Performed Under Contract No. DE-FG21-88MC25033

For

U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By

Good Samaritan Hospital
Lebanon, Pennsylvania

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PROJECT ABSTRACT

The purpose of this program is to expand the use of coal by utilizing CFB (circulating fluidized bed) technology to provide an environmentally safe method for disposing of waste materials. Hospitals are currently experiencing a waste management crisis. In many instances, they are no longer permitted to burn pathological and infectious wastes in incinerators. Older hospital incinerators are not capable of maintaining the stable temperatures and residence times necessary in order to completely destroy toxic substances before release into the atmosphere. In addition, the number of available landfills which can safely handle these substances is decreasing each year. The purpose of this project is to conduct necessary research investigating whether the combustion of the hospital wastes in a coal-fired circulating fluidized bed boiler will effectively destroy dioxins and other hazardous substances before release into the atmosphere. If this is proven feasible, in light of the quantity of hospital wastes generated each year, it would create a new market for coal -- possibly 50 million tons/year.

The first tasks of the program have evaluated the potential for hospital waste destruction (using non-hazardous surrogate materials) in a coal-burning circulating fluidized bed combustor concurrent with required design modifications to DONLEE Technologies' existing 10 MM BTU/hr. CFB demonstration facility. Destroying hospital waste in a coal-fired circulating fluidized bed combustor has been determined to be a promising alternative technology for the destruction of hospital wastes. Based on thermodynamic calculations, adequate chlorine capture within the bed is possible. Pursuant to these conclusions, a conceptual design of a waste handling system has been developed for use in modifying DONLEE's CFB demonstration unit.

Following these tasks, various combustion/incineration tests were performed accompanied by both air quality monitoring and ash leachate tests. The combustion tests were performed using both bituminous and anthracite coal. Evaluation of the test data has confirmed the environmental advantages of the CFB for the destruction of waste materials. Analyses of ash samples indicate that the material is suitable for disposal in a permitted landfill. The stack gas sample analyses showed dioxin, furan, and hydrocarbon concentrations well below levels recorded at existing incinerators as well as coal-fired power plants. Substantial capture of chlorine in the fluidized bed was demonstrated at feed rates equivalent to one part coal to one part polyvinyl chloride.

Based on the positive findings from the modelling and combustion tests, a host site was targeted for installation of a proof-of-concept unit. The candidate site is the VA Medical Facility in Lebanon, Pennsylvania. Conceptual designs and cost estimates were developed for a full scale facility sized to accommodate steam and waste disposal needs at this hospital. Economic analyses showed that a 15 MM BTU/hr. CFB unit provided distinct economic advantages compared to alternative means for disposal of hospital wastes.

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The purpose of this program is to expand the use of coal by utilizing CFB (circulating fluidized bed) technology to provide an environmentally safe method for disposing of waste materials. Hospitals are currently experiencing a waste management crisis. In many instances, they are no longer permitted to burn pathological and infectious wastes in incinerators. Older hospital incinerators are not capable of maintaining the stable temperatures and residence times necessary in order to completely destroy toxic substances before release into the atmosphere. In addition, the number of available landfills which can safely handle these substances is decreasing each year. The purpose of this project is to conduct necessary research to investigate whether the combustion of the hospital wastes in a coal-fired circulating fluidized bed boiler will effectively destroy dioxins and other hazardous substances before release into the atmosphere. Phase 1 activities were performed under five (5) separate tasks. This research has formed the basis for installation and monitoring of a full-scale proof-of-concept unit.

The first task of the program evaluated the potential for hospital waste destruction in a coal-burning circulating fluidized bed combustor. This involved characterizing hospital waste as to the content of the products found in the waste in the forms of paper, plastic, moisture, and other components. The ultimate analyses of the plastic types is also a part of this characterization. The survey of possible components of the waste stream included a listing of chlorine containing drugs and a listing of recommended compounds to model these drugs based on the five different ways in which chlorine is chemically incorporated in the structure. Fluorine and bromine will not be captured and are not permitted to be combusted in Pennsylvania. A review of existing technology used for hospital waste disposal shows that there are advantages and disadvantages for this equipment. These existing technologies include excess air incineration, controlled air incineration, rotary kiln incineration, and autoclaving.

Initial task efforts found that combusting wastes in a coal-fired fluidized bed unit appears to be a promising alternative technology for the destruction of hazardous wastes; and it appears that parallel conclusions for hospital wastes can be drawn. Research indicated that circulating fluidized bed combustors can meet the stringent permit regulations of the Environmental Protection Agency for hazardous waste incineration which is 99.99% destruction of hazardous chemicals and 99% retention of acid gases. It was also established

that these standards can be met with a coal-fired fluidized bed combustor cofiring small quantities of hospital wastes, however, pilot-scale testing was necessary to confirm this position.

Circulating fluidized bed combustors have been shown to operate cleanly, efficiently, and economically. Their simple design uses high turbulence in the reaction zone to eliminate afterburners and scrubbers and allows for operating temperatures as low as 1450°F. Proven benefits seen with CFB's used on industrial wastes show combustion efficiencies greater than 99.99%, HCl capture greater than 99%, very high boiler efficiencies, and low NO_x and CO emissions.

Research efforts included a descriptive summary of pollutant forming mechanisms in the air emissions from hospital incinerators. These pollutants take the forms of acid gases, particulate emissions, trace metals, polycyclic organic matter, low weight organic compounds, and carbon monoxide. The coal-fired circulating fluidized bed as discussed in the first task section shows the potential of dealing with the hospital waste stream and the air emissions problems associated with combustion of hospital wastes. This potential is due to the CFB's high turbulence, cyclone capture of particulate matter, use of limestone as a sorbent for acid gas, and highly controlled staged combustion.

Capture of the chlorine from plastics and drugs was studied further with thermodynamic models to show that chlorine capture with the CFB is capable of meeting the HCl limits of four pounds per hour with available coals. Potential for acceptable sulfur capture with the limestone sorbent is also discussed and demonstrated. The theoretical approach used in this task is to give a rough approximation of possible emission levels of hydrogen chloride and sulfur dioxide. Overall, the initial results suggested that adequate chlorine capture within the bed is possible along with controlling sulfur emissions. The variables which should be of concern are the coal character, operating temperature, the percentage of the feedstock which is waste, and the waste composition.

The second task of this program was to develop a waste handling system that can be used to render the hospital waste materials suitable for injection into the combustion unit. This system must be able to properly handle the waste without creating contamination and posing health risks to combustion plant personnel. Also, the methods for handling the ash residue had to be addressed.

The first step required to fulfill this task involved investigation of the solid waste handling, storage, and transport regulations of the Environmental Protection Agency and the

Pennsylvania Department of Environmental Resources. These regulations along with the operating requirements of the AFBC system provided the parameters upon which the handling system concept was developed.

An evaluation of existing hospital waste management techniques was then performed. Actual field review of waste handling systems of hospitals and private waste management companies, and also review of available literature was conducted. During this task, advantages and disadvantages of the various available technologies were identified.

Using the information assembled during the initial investigative steps, a conceptual design of the waste handling system was developed. This design is compatible with the physical needs of the combustor, while it also provides safe and efficient handling of hospital waste.

Unlike most traditional incinerator designs, the AFBC requires that the waste stream consist of small particles preferably no larger in size than two-inch-minus. For this reason, some type of size reduction unit must be incorporated for processing the waste prior to feeding the material into the combustion chamber. To avoid regulatory problems, the size reduction unit was designed integrated with the combustor and incorporating sterilization.

To meet this size reduction requirement, an industrial heavy-duty shredder with stainless steel components was chosen for the conceptual design. This shredder must have the proper in-feed opening, cutter diameter, cutter thickness, and horsepower to process the 10,000 pounds of infectious and general waste per week anticipated, and also to produce the desired discharge particle size.

Under this conceptual design, the material size reduction unit and AFBC are built as one unit so as to prevent contamination of the atmosphere. All doors and connections between individual components of the system are sealed. Disinfectant atomizers are positioned in compartments above the CFB and also in the discharge chute. These atomizers emit a misting spray, chemical in nature, to sterilize the system prior to any access into the compartments for maintenance and for any other reason access may be required.

The Bottom ash disposal is accomplished by gravity flow from beneath the combustor while fly ash is collected by baghouse. Cooling of the ash is needed before storage in bins. The bins would be the loadout point for trucks hauling to a suitable landfill disposal. Pennsylvania regulations require monitoring of pathogens in the ash and chemical analyses of the ash on a regular basis.

Task 3 involved the bench scale combustor design using the DONLEE CFB technology. The goal was to perform testing at stable operating conditions for pilot plant testing.

Task 4 involved CFB pilot plant testing based on parameters established under the third task. In total, 22 test runs were completed to examine the effects of velocities, temperatures, Ca/S ratio, excess air levels, main bed pressure drops, main bed stoichometric ratio, and lead levels. The tests used one anthracite and two bituminous coals and a limestone from Pennsylvania. Surrogate hospital waste material was employed in the testing consisting of PVC to represent the plastics and selected chemical compounds to represent the drugs. Gas analyzers continuously monitored O_2, CO, CO_2, SO_2, and NO_x. Calculated Loss of Ignition values indicate that combustion efficiency is not sensitive to upper combustion velocity. There was also a positive trend for increased combustion efficiency with increased combustor operating temperature. The limestone sorbent was selected on the basis of proximity to the test location rather than optimum reactivity. The testing provided sufficient data for evaluation of the CFB.

Results of the combustion test program confirmed the environmental advantages of using the CFB unit for combustion of waste materials. Also, the ability to maintain stable operation at 20% of full load heat input will accommodate extreme variations in steam demand associated with hospitals. Operating at 1600°F gave high combustion efficiency (> 97%), good sulfur capture (> 85%), and low NO_x emissions (< 150 ppm). Dioxin and furan emission levels were two to three orders of magnitude less than levels recorded for medical waste incinerators without scrubbers. Analyses of ash indicated that the material can be disposed of in permitted municipal waste landfills.

An average of 50% of the infeed chlorine was captured in the combustion system. This lower than expected capture rate will necessitate installation of a stack gas scrubber system.

Task 5 involved a conceptual design and cost estimate for a full scale hospital waste disposal facility. The site selected for analysis was the Veterans Administration Hospital in Lebanon, Pennsylvania where sufficient space is available adjacent to the existing boiler house.

Under Task 5, a cost/benefit analysis was performed using two scenarios that are available to the Lebanon VA Hospital. Scenario 1 assumes that the hospital will dispose of hospital wastes through an outside contractor who will remove the wastes from the facility.

Scenario 2 evaluates the cost to purchase permit and operate a new gas incinerator. Both scenarios are as compared to the installation of the CFB unit. In each case, the operating costs for the CFB unit are incorporated as annual expenditures which are offset against the benefits of avoided costs (savings) of the alternatives.

Based upon the discounted cash flow analyses, the circulating fluidized bed combustor approach offers the Lebanon VA Hospital a substantial cost savings under both scenarios evaluated. Scenario 1 will result in a payback of the initial $1.6 million in nine years with a $1.48 million in additional benefits during the next 15 years. Under Scenario 2, the incremental capital of $0.6 million has a three year payback with more than $2.33 million return on investment over the 15 year period.

Results of Phase 1 research show that co-firing coal and hospital wastes in a CFB is a viable alternative technology that can be used without generating other environmental problems with air emissions. The CFB is not only technically viable, but is economically suitable even under conservative cost estimates.

Extended Phase 1 activities are being conducted in preparation for the proof-of-concept test program. More detailed designs are being developed along with preliminary work pertaining to permitting the proposed installation. Finally, the feed system will be procured and tested at the pilot plant prior to installation at the host hospital.

INTRODUCTION

This report contains the results of investigations to evaluate the technical potential for disposal of hospital waste material in a coal-burning, fluidized bed combustor as compared to other technologies. It represents an effort to gather currently available data to assess the viability of using a circulating fluidized bed combustor as a hospital waste disposal system and to confirm the potential through combustion testing with surrogate wastes.

Hospital waste consists of infectious and noninfectious wastes. In the past, most hospitals disposed of their infectious waste by incineration and the remaining solid waste was landfilled. More recently, the cost of landfilling and the reluctance of landfills to accept infectious waste has led to on-site incineration for the following reasons (Tessitore and Cross, 1988): (1) landfilling reluctance to accept any hospital waste due to regulatory criteria or public pressure; (2) liability considerations due to possible transmission of AIDS or viral diseases; and (3) significant cost increase for the transportation and handling of these wastes for off-site disposal. In addition, regulatory agencies have proposed and/or adopted more comprehensive and stringent combustion and emission requirements for on-site hospital incinerators. These new considerations require that on-site incineration of infectious waste be evaluated against current criteria rather than previous historical experience. For these reasons, improvements to existing incineration methods as well as new incineration technologies are necessary to remedy the hospital waste disposal problem.

The U.S. Department of Energy is addressing the hospital waste problems listed above and has initiated a circulating fluidized bed combustion program with the Good Samaritan Hospital located at Lebanon, Pennsylvania.

The initial project phase is divided into five tasks. A description of each task and its objectives as detailed in the statement of work from the Department of Energy follows.

Task 1 - Evaluate AFBC Incineration Technology

- Evaluate, based upon published literature, the technical potential for disposal of hospital waste material in a coal-burning, fluidized bed combustor as compared to other technologies.

- Determine the optimum design (e.g., residence time, temperature, and excess air) and the potential advantages of destroying hospital waste in an atmospheric fluidized bed combustor (AFBC).

- Identify the principal organic hazardous constituents (POHC) in hospital waste streams. Select environmentally acceptable model

compounds to simulate the behavior of POHC's in the AFBC for testing in Task 4, Pilot Plant Testing. Based on the identification of the POHC's, determine the optimum operating conditions (time, temperature, heat extraction, excess air, coal feed rate, etc.) for the destruction of the POHC's in an AFBC within the constraints of the allowable operating parameters.

- Evaluate the likely interaction of the bed material with chlorine (hydrogen chloride) produced from the combustion of the hospital waste and the interaction of potential emission species with the coal mineral matter (ash) so as to maintain acceptable emissions during the combustion of hospital waste in a coal-fired, fluidized bed combustor.

- The results of this task will be considered in establishing a test plan required for Task 3, Bench-Scale Combustor Design.

Task 2 - Develop Waste Handling System

- Investigate all Federal, state, and local regulations applicable to handling, storage, and transportation of hospital waste and establish an appropriate waste handling approach.

- Evaluate existing hazardous waste handling systems to determine problems associated with feeding hospital waste into a fluidized bed system.

- Create a conceptual design for the handling system.

Task 3 - Bench-Scale Combustor Design

- Design a combustor that will burn coal and waste and will operate in a non-adiabatic mode with coal as the base-load fuel.

- Include the necessary mechanics and instrumentation to allow pretesting of surrogate hospital waste materials with regard to handling and metering.

- Prepare a test plan to conduct combustion test.

Task 4 - Pilot Plant Testing

- Develop a combustor which meets the design from Task 3.
- Run a series of 10 combustion tests using bituminous and anthracite coals as the primary fuel and surrogate hospital waste to simulate the principal organic hazardous constituents (POHC) and other components of hospital waste.
- Monitor stack gases and analyze ash material to document the destruction and removal efficiencies of POHC's and the suitability of ash residue for disposal in permitted landfills.

Task 5 - Conceptual Design and Cost Estimates of Full-Scale, Proof-of-Concept Facility

- Develop a conceptual design for a full-scale facility incorporating the conceptual feed and boiler design including a complete layout of coal storage and handling equipment, waste delivery and storage systems, ash removal system, sorbent storage, and the boiler room structure.
- Prepare cost estimates for the design, construction, and operation of the system. Operating costs were to include all labor, equipment operating and maintenance expenses, coal purchases, sorbent purchases, ash disposal, and permitting costs.

Following report sections describe the investigative procedures and findings within each of the Phase 1 tasks. Results form the basis for Phase 2 activities which are underway to install a Full-Scale proof-of-concept facility at the VA Medical Facility in Lebanon, Pennsylvania.

PURPOSE

The purpose of this program is to expand the use of coal by utilizing Circulating Fluidized Bed (CFB) technology to provide an environmentally safe method for disposing of waste materials. Hospitals are currently experiencing a near crisis situation related to waste management. In many instances, they are no longer permitted to burn pathological and infectious wastes in incinerators. Older hospital incinerators have not demonstrated the capability to maintain the stable temperatures and residence times necessary in order to completely destroy potentially toxic substances before release into the atmosphere. In addition, the number of available landfills which can safely handle these substances are limited.

The objective of this project was to determine the impact of destroying relatively small quantities of infectious and pathological hospital wastes in a coal-fired circulating fluidized bed boiler. Utilizing coal as the primary fuel source in the fluidized bed creates a stable operating environment in which to burn the wastes. Aside from demonstrating the ability to create a stable temperature, research efforts were aimed at determining the resultant destruction potential of toxic gases and the reduction of chlorine in flue gas. Phase 1 investigations were also to establish the basis for installation and monitoring of a full-scale proof-of-concept unit. The ultimate success of these endeavors will expand the use of coal and help resolve a major waste problem.

RESULTS AND DISCUSSION

The project was structured to provide a thorough investigation of factors that have presented existing incinerator operators with difficulties in complying with regulatory authorities. Under the initial task, research was conducted to define the characteristics of hospital wastes and to assess background data pertaining to existing methodologies for rendering these materials innocuous. This research was then utilized to ascertain the advantages that a CFB combustion unit offers and to establish model compounds to simulate medical wastes during subsequent combustion testing.

Although the research identified shortcomings with existing incineration technologies and the operating characteristics of a CFB that should result in enhanced emissions, it was necessary to examine regulations pertaining to the packaging, handling, storage, and disposal of infectious wastes prior to beginning the combustion test program. The regulatory review established the standards by which CFB combustion will be judged during the permitting review process. Of particular concern was the ability to adapt waste material size reduction and feed requirements for efficient combustion/incineration to comply with regulatory restrictions. The regulatory review and conceptual feed system design were addressed under the second task. Findings from the first two project tasks were incorporated into the combustion test program. In addition to establishing CFB operating parameters and surrogate waste materials, these initial studies helped finalize the gas and ash sampling/testing requirements.

The following discussions present the results of each project task leading to the test program. Details are provided for the actual tests along with evaluation of results relative to the planned proof-of-concept installation. Conceptual designs and cost analyses are also presented for installation of the proof-of-concept unit at the Lebanon VA Medical Facility.

TASK 1 - EVALUATE AFBC INCINERATION TECHNOLOGY

As previously indicated, the first step in the evaluation of incineration technologies consisted of defining the characteristics of typical hospital wastes. The following sections discuss findings from this study along with a survey of industrial boilers and the prospects for chlorine capture.

Characterization of Hospital Waste

Few data are available on the composition of hospital waste, although it is characteristically heterogeneous in nature. The mix of materials includes general refuse (e.g., office paper, food waste, noninfectious patient waste), infectious wastes (e.g., pathological wastes, human blood and blood products, contaminated sharps, anatomical wastes, isolation wastes), hazardous wastes (e.g., waste pharmaceuticals, cytotoxic agents used in chemotherapy, mercury or other heavy metals), and radioactive wastes.

It is estimated that about 85% of a hospital's waste stream is noninfectious while the remaining 15% is contaminated with infectious agents. Radioactive wastes and hazardous wastes are generally small-quantity wastes which require special treatment that are subject to severe permit restrictions (Marks, 1988).

Particular components of the hospital waste stream of special concern when this waste is incinerated include the relatively high plastic content of hospital waste. About 30% of the hospital wastestream is estimated to be plastics. Table 1 contains a general breakdown of the composition of typical hospital waste. The percentages in Table 1 do not necessarily add up to 100% since they are approximations.

The types of plastics most commonly encountered include polyethylene, polypropylene, and polyvinyl chloride. Ultimate analyses for four common plastics are shown in Table 2.

TABLE 1
HOSPITAL WASTE CHARACTERIZATION

PRODUCT	APPROXIMATE WEIGHT PERCENT
Paper	65
Plastic	20-30
Moisture	10
Other	5

TABLE 2
ULTIMATE ANALYSES OF FOUR PLASTICS
(Weight Percent)

	POLYETHYLENE	POLYSTYRENE	POLYURETHANE	POLYVINYL CHLORIDE
Moisture	0.20	0.20	0.20	0.20
Carbon	84.38	86.91	63.14	45.04
Hydrogen	14.14	8.42	6.25	5.60
Oxygen	0.00	3.96	17.61	1.56
Nitrogen	0.06	0.21	5.98	0.08
Sulfur	0.03	0.02	0.02	0.14
Chlorine	trace	trace	2.42	45.32
Ash	1.19	0.45	4.38	2.06
Higher heating value, Btu/lb	19,687	16,419	11,203	9,754

Hospital waste may contain potentially toxic components. Such chemicals include waste pharmaceuticals, cytotoxic agents used in chemotherapy, and anti-neoplastic agents. Heavy metals may also be air emission concerns if they enter the combustor along with other hospital wastes.

Survey Of Chlorine-containing Drugs And Possible Model Compounds For Combustion

A survey of chlorine containing drugs and possible model compounds for combustion was conducted to identify compounds for Task 4, Pilot Plant Testing, and was reported in the progress report submitted to the Department of Energy from the Good Samaritan Hospital (November, 1988). Seventy-one drugs or related medicinal materials were surveyed to determine whether the molecules contained chlorine, and, if so, also to determine the manner in which the chlorine was chemically bonded to the remainder of the molecule. The list of drugs was taken from documentation which originated with the Good Samaritan Hospital. Information on composition and structure was obtained from the ninth edition of The Merck Index (Windholz, et. al., 1976). The complete list of drugs and related materials surveyed is given in Table 3.

TABLE 3
LIST OF MATERIALS SURVEYED FOR CHLORINE CONTENT

Acetazolamide
Acetic Acid
Acetylcysteine
Acyclovir
Adriamycin
Albumin
Ampicillin
Antihemophilic factor
Balanced salt solution
Benzocaine
Bleomycin
BCNU
Calcium gluconate
Chlorpromazine hydrochloride
Codeine phosphate
Cytosar
Cytoxan
Dacarbazine
Daunorubicin
Dactinomycin
Dexamethasone
Dilantin
Diptheria and tetanus toxoids
Erythromycin lactobionate
Etoposide
Fluorouracil
FUDR
Fluphenazine decanoate
Heparin sodium
Insulin
Insulin isophane
Insulin zinc suspension
Insulin humulin
Lasix
Lidocaine
Magnesium sulfate
Mannitol
Mefoxin
Methicillin sodium
Methotextrate
Methotextrate sodium
Medrol
Mitomycin C
Mithramycin
Morphine
Nafcillin
Nitrogen mustard
Naprosyn
Narcan
Nebcin
Nubain
Penicillin G sodium
Penicillin potassium
Penicillin S potassium
Penicillin-152 potassium
Phenobarbital sodium
Piperacillin
Plasma protein fraction
Planitol
Potassium chloride
Prolixin decanoate
Promethazine hydrochloride
Ranitidine
Streptozocin
Terbataline sulfate
Tetracycline hydrochloride
Thio-TEPA
Tolazoline
Tuberculin ptotein
Velban
Vincristine

Of these seventy-one substances, structural or compositional data could not be located for the following drugs: acyclovir; etoposide; nubain; piperacillin; planitol; and ranitidine. As will be discussed below, the number of ways in which chlorine is incorporated into drugs is relatively limited, and therefore it is likely that even if any of these six drugs contain chlorine, the chemical bonding of the chlorine is probably not different from other

chlorine-containing drugs for which the structure is known. In addition, no structural or compositional data was found for the following materials: albumin; antihemophilic factor; diphtheria and tetanus toxoids; the various insulin derivatives; plasma protein; and tuberculin protein. Since all of these substances seem to be proteins or protein-like materials, and no naturally occurring amino acids contain chlorine, it was presumed that chlorine was not present in this latter group.

Based on the composition or structural data found in the literature, the following substances from Table 3 were found to definitely contain chlorine.

TABLE 4
CHLORINE-CONTAINING DRUGS

BCNU	Penicillin S potassium
Chloropromazine hydrochloride	Potassium chloride
Cytoxan	Promethazine hydrochloride
Lasix	Tetracycline hydrochloride
Nitrogen mustard	

However, from this list of quite diverse compounds, there are only five different ways in which the chlorine is chemically incorporated into the structure as listed in Table 5.

TABLE 5
CHLORINE BONDING SITES IN DRUGS

1° Aliphatic carbon
Amine hydrochloride
Aromatic carbon
Ionic
Vinylic carbon

Consequently, it should be possible to model the combustion behavior of all of the chlorine-containing drugs with just five model compounds. The model compounds recommended for future experimental work were chosen on the basis of three criteria: most importantly, they should contain chlorine with the same kinds of bonding as noted in Table 5; they should be reasonably inexpensive and readily available from laboratory supply houses; and they should pose no special handling problems (i.e., be solids or high-boiling

liquids) or safety hazard when used. The recommended model compounds are shown in Table 6.

TABLE 6

RECOMMENDED COMPOUNDS TO MODEL CHLORINE-CONTAINING DRUGS

STRUCTURAL TYPE	RECOMMENDED MODEL COMPOUND
1° Aliphatic carbon	(2-Chloroethyl) benzene
Amine hydrochloride	Benzyltriethylammonium chloride
Aromatic carbon	2-Chlorobenzoic acid
Ionic	Potassium chloride
Vinylic carbon	1-Chloro-2-methylpropene[a]

[a] This compound is a safety hazard, although it meets the other two criteria of similar bonding and availability.

Two additional sources of chlorine remain to be considered. The first is the plastics used for a variety of instruments, appliances, and containers. Most likely the predominant chlorine-containing polymer would be polyvinyl chloride. Since polyvinyl chloride is widely available, it could be used as its own model compound in any experimental work. The other source of chlorine would be pathological wastes. Presumably the major chlorine form in the human body would be as chloride ion in body fluids; ionic chloride is covered in the model compounds in Table 6.

The principal focus of this work has been the presence of chlorine in hospital wastes and the potential for chlorine capture during combustion. In the course of the investigation so far, other halogen-containing compounds were found that might be present in the wastes. For completeness, some comments are offered on these other materials.

Fluorine is present in several drugs, specifically dexamethasone, fluorouracil, fluphenazine decanoate, and FUDR. Bromine may derive from two general sources. The first, and more probable, is bromine-containing compounds used in flame retardants on hospital gowns and other clothing. The second is that one naturally occurring amino acid, 3,5-dibromotyrosine, contains bromine and may possibly occur in small amounts in proteins or protein-derived materials. Similarly, iodine occurs in two amino acids, 3,5-dibromotyrosine and thyroxine. The elements in question are noncombustible (as with chlorine). Therefore, fluorine and/or bromine will not be destroyed during combustion.

Additionally, flourine and/or bromine probably will not be captured in the bed material. These elements are not allowed to be incinerated in Pennsylvania by law.

Survey Of The Disposal Of Hazardous Wastes In Industrial Boilers

The purpose of this section is to: review existing disposal technologies and their advantages and disadvantages; discuss air emissions; and evaluate the potential for using a fluidized bed combustor to destroy hospital waste.

Existing Disposal Technology Review

Incineration

The primary objectives of hospital waste incinerators are to render waste innocuous and reduce the size and mass of the waste. Some of the problems associated with hospital wastes which must be considered in designing and operating incineration equipment follow.

- The fuel is nonhomogeneous and of variable composition. This poses a problem in feeding, flame stability, particle entrainment, and emissions control.
- The fuel contains variable ash content which can lead to clinker formation, slagging, and fouling.
- Hospital wastes often have low heating value and high moisture content leading to flame stability problems.
- Hospital wastes contain varying amounts of corrosive materials such as chlorine and fluorine.

The advantages of incineration of hospital wastes include significant volume reduction while requiring little processing of the wastes before treatment. Disadvantages include high costs and potential pollution risks associated with incineration processes.

The three types of incinerators used most frequently in the United States are: excess air; controlled air; and rotary kiln models (Radian Corporation, 1988). All three types use primary and secondary combustion chambers to ensure maximum combustion of the waste.

Excess Air Incinerators

Most incineration systems constructed before the early 1960s were of the excess air type (sometimes referred to as pyrolitic and multiple chamber incinerators). Combustion of the waste begins in the primary, or ignition, chamber (Radian Corporation, 1988). The waste is dried, ignited, and combusted by heat provided by a primary chamber as well as by hot chamber walls heated by flue gases. Moisture and volatile components in the waste feed are vaporized and pass, along with the combustion gases, out of the primary chamber. Secondary air is mixed with the volatile components in the secondary chamber. Burners are also fitted to the secondary chamber to maintain adequate temperatures for combustion of the volatile gases. Incinerators designed to burn general hospital waste operate at total excess air levels of up to 300% whereas if only pathological wastes are combusted, excess air levels near 100% are more common.

Excess air incinerators require scrubbers to remove particulate matter to meet air pollution control standards because they operate with such high excess air levels. Few excess air incinerators are being installed today, instead, older units are used primarily for noninfectious wastes.

Controlled Air Incinerators

Most of the incinerators built for medical waste treatment in the last 15 to 20 years have been controlled air incinerators (sometimes called starved air, two stage, and modular incinerators). These burn waste in two or more chambers under conditions of both low and excess stoichiometric oxygen requirements.

In the primary chamber, waste is dried, heated, and pyrolyzed, thereby releasing moisture and volatile components. The nonvolatile combustible portion of the waste is burned to release heat while the noncombustible portion accumulates as ash. Auxiliary burners may provide additional heat to maintain the desired temperatures depending on the heating value and moisture content of the waste. Approximately 40 to 80% of the stoichiometric air is added in this chamber.

Moisture, volatiles, and combustion gases from the primary chamber are mixed with air and burned in the second chamber. If the primary chamber gases are sufficiently hot, they will self ignite when mixed with air. A second burner located near the entrance to the second chamber provides additional heat for ignition of the combustible gases and to maintain a flame in the chamber at all times of operation. The air injection rate in the second

chamber is generally between 100 and 150% of total stoichiometric requirements. Thus, the total air added to both chambers can vary between 140 and 230% of stoichiometric requirements (i.e., between 40 and 130% excess air).

The secondary chamber burner is located near the entrance to this chamber to maximize the residence time of gases at high temperatures in this chamber. Bulk average gas residence times in the secondary chamber typically range from 0.25 to 2.0 seconds. Design exit gas temperatures generally range from 1400° to 2000°F.

One advantage of using low levels of air in the primary chamber is that there is very little entrainment of particulate matter in the flue gas. For example, excess air incinerators have average particulate emission factors of 7 pounds per ton of waste compared with 1.4 pounds per ton of waste for controlled air units (Office of Technology Assessment, 1988). Available data indicate that many controlled air incinerators can be operated to meet existing particulate standards that are at or below 0.08 grains per dry standard cubic foot (gr/dscf) corrected to 12% carbon dioxide. Many States, however, are adopting lower standards (e.g., 0.015 gr/dscf) for incinerators, which probably would require additional control technologies. Additional controls may raise capital costs and require expansion space; however, additional controls would capture finer particulates and possibly some other pollutants.

Advantages of the controlled air system include high thermal efficiency as a result of lower stoichiometric air use, higher combustion efficiencies, and low capital costs (which may increase as more controls are required). As will all types of incinerators, disadvantages include potential incomplete combustion under poor operating conditions and problems associated with achieving proper operating temperatures during startup of a batch unit (Office of Technology Assessment, 1988).

Rotary Kiln Incinerators

A small number of rotary kiln incinerators are currently operating. In this unit, the primary chamber consists of a horizontal, rotating kiln. The kiln is inclined slightly so that the waste material migrates from the charging end to the ash discharge end as the kiln rotates. The waste migration, or throughput, rate is controlled by the rate of rotation (typically between 1 and 3 rpm) and angle of incline of the kiln. Air is injected into the primary chamber and mixes with the waste as it rotates through the kiln. A primary chamber burner is generally present for heat-up purposes and to maintain desired temperatures.

Volatiles and combustion gases from the primary chamber pass to the secondary chamber where combustion is completed by the injection of additional air. High temperatures

are maintained in the secondary chamber with a second burner. The primary chamber is operated at substoichiometric conditions and the secondary chamber greater than stoichiometric conditions.

The kiln rotation provides excellent mixing (i.e., turbulence). Yet, the rotary kiln systems tend to be costly to operate and maintain and usually require shredding (i.e., some size reduction of wastes). Due to the turbulent motion of the waste, particle entrainment is higher for kiln incinerators than for controlled air or excess air incinerators. As a result, rotary kiln incinerators generally require emissions control.

Autoclaving

Autoclaving, or steam sterilization, is a process to sterilize medical infectious wastes prior to disposal in a landfill. Some wastes (e.g., pathological tissue, chemotherapy waste, sharps) may not be adequately treated by some sterilization operations however, and thus require incineration.

Autoclaves do provide some advantages over incinerators, which may increase their attractiveness as a disposal option, particularly if incineration regulations become more stringent and thereby increase incineration costs. For example, operation and testing of autoclaves is less complex and difficult than that for incinerators. In addition, environmental releases from autoclaves probably contain a smaller range of constituents (e.g., dioxins, heavy metals) than incinerators. Autoclaves are also less costly to purchase and operate and require less space. These cost advantages, however, may be lessened if incineration is also required.

Several problems have lead to some hospitals to abandon autoclaving. For example, problematic operating conditions can lead to incomplete sterilization. In addition, landfill and off-site incinerator operators are increasingly refusing to receive such wastes, questioning whether the waste has actually been treated. This, along with other difficulties associated with autoclaving, such as ensuring the proper operation of the autoclaving process (e.g., sufficient residence time to ensure pathogen destruction), the more limited capacity of most autoclaves, and the time-consuming process for autoclaving compared with incineration, make it a less common waste treatment method for most facilities.

Air Emissions

This section contains brief descriptions of formation mechanisms for pollutants from hospital incinerators, presents hazardous compound destructibility, and discusses measured emission levels from conventional hospital incinerators (Radian Corporation, 1988; Office of Technology Assessment, 1988). Where applicable, information on formation mechanisms for some compounds has been borrowed from the municipal solid waste literature. Table 7 contains a list of measured pollutants from hospital waste incinerators (Radian Corporation, 1988).

TABLE 7
MEASURED/TESTED HOSPITAL WASTE POLLUTANTS

TRACE METALS	POLYCYCLIC ORGANIC MATTER	LOW MOLECULAR WEIGHT ORGANIC COMPOUNDS	ACID GASES	OTHERS
Arsenic	Dioxins[a]	Ethane	Hydrochloric acid	Particulates
Cadmium	Furans[b]	Ethylene	Sulfur dioxide	Carbon
Chromium	Propane	Nitrogen oxides	monoxide	
Iron		Propylene		Pathogens
Manganese		Trichorotrifluoroethane		Viruses
Nickel		Trichlorethylene		
Lead		Tetrachlorethylene		

[a]polychlorinated dibenzodioxin
[b]polychlorinated dibenzofuran

Pollutant Formation Mechanisms

Acid Gases

The acid gases produced in hospital waste incineration are hydrogen chloride, sulfur dioxide, and nitrogen oxides. Based on thermodynamic considerations, chlorine which is chemically bound within the hospital waste will be predominantly converted to hydrogen chloride (HCl), assuming there is hydrogen available to react with the chlorine.

Sulfur, which is chemically bound within the materials making up the hospital waste, is oxidized during the combustion process to form sulfur dioxide (SO_2) (as is the sulfur present in the coal in a coal-fired coincineration scheme). The rate of SO_2 emissions is directly

proportional to the sulfur content of the waste. HCl is a stronger acid than SO_2 and will react more quickly with available alkaline compounds than SO_2. If there is a limited quantity of alkaline compounds present, the HCl will tie up the alkaline compounds before they can react with SO_2.

Nitrogen oxides, which are predominantly NO with a small amount of NO_2 in a combustion system, are produced from thermal fixation (reaction between molecular nitrogen and oxygen in the combustion air) and fuel nitrogen oxidation. It as widely accepted that the thermal fixation in the combustion zone is described by the Zeldovich model (Wark and Warner, 1981). The mechanisms by which nitrogen compounds (primarily organic) contained in liquid and solid fuels evolve and react to form NO are much more complex and the empirical data are less conclusive.

Particulate Emissions

Particulate matter is emitted as a result of incomplete combustion and by the entrainment of noncombustibles in the flue gas stream. Particulate matter may exist as a solid or an aerosol, and may contain heavy metals or polycyclic organics. There are three general sources of particulate matter:

- inorganic substances contained in the waste feed that are carried into the flue gas from the combustion process;
- organometallic substances formed by the reactions of precursors in the waste feed; and
- uncombusted fuel molecules.

Inorganic matter is not destroyed during combustion and most of this material leaves the incinerator as ash. Some becomes entrained in the stack gas as particulate matter.

Organometallic compounds present in the waste stream can be volatilized and oxidized under the high temperatures and oxidizing conditions in the incinerator. As a result, inorganic oxides or salts of metals can be formed from the metallic portion.

The fuel molecules themselves can also contribute significantly to particulate matter formation. Pyrolitic reactions can lead to the formation of large organic molecules.

In general, good combustion conditions lead to lower particulate emissions. As residence time, temperature, and turbulence increase, the mass of the particulate matter tend to decrease.

Trace Metals

The amount of trace metals in the flue gas is directly related to the quantity of trace metal contained in the incinerator waste. Some of the metal sources in the waste include surgical blades, foil wrappers, plastics, and printing inks. Plastic objects made of polyvinyl chloride contain cadmium heat stabilizing compounds. In addition, cadmium, chromium, and lead may also be found in inks and paints.

Some metals are selectively deposited on the smaller particles which are emitted. There are three general factors affecting fine particle enrichment. They are particle size, number of particles, and flue gas temperature. The influence of particle size on trace metal enrichment of fine particles is thought to be due to specific surface area effects. Particles with large specific surface areas are expected to show enrichment since there is more surface area for condensation per unit mass of particulate matter. The influence of the number of particles is due to the increased probability of contact associated with higher particle population. Higher temperatures are thought to lead to increased activity levels which in turn makes the metals less likely to condense and bond with particulate matter.

Many of the volatile metals of concern tend to selectively deposit on the smaller ash particles. The distribution of volatile metals among the different size fractions of ash is influenced by the amount of ultrafine particles produced during combustion. The trace metals tend to concentrate on the surface of fine particles rather than uniformly distribute throughout the particle size range because refractory oxides (e.g., SiO_2, MgO, CaO, Fe_2O_3) which are vaporized in the flame are the first species to condense and would become the nuclei for the fine particulate matter. As the combustion gases cool, volatile trace species would be expected to condense on the outer surface of these particles. In summary, the ultrafine particles present a very high specific surface area and thus receive a disproportionate share of the condensing elements.

Polycyclic Organic Matter

Many factors are believed to be involved in the formation of chlorinated isomers of dibenzodioxin (commonly referred to as dioxin or PCDD) and dibenzofuran (referred to as furan or PCDF). The best supported theories are illustrated in Figure 1 (Radian Corporation, 1988). The first theory shown involves the breakthrough of unburned dioxin/furan present in the feed. The second mechanism involves the plausible combination of precursor species which have structures similar to the dioxins and furans to form these compounds. These precursors can be produced in oxygen-starved zones. The third mechanism involves the synthesis of dioxin/furan from a variety of organics and a chlorine donor. The final mechanism presented in Figure 1 involves catalyzed reactions on flyash particles at low temperatures.

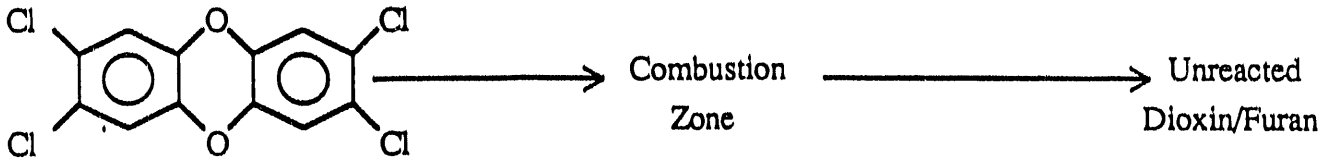
Available data from municipal solid waste and hazardous waste incineration indicate that the polycyclic organic matter emission rate is closely related to efficiency of the combustion process. Generally, when the flame temperature and combustion are increased, the products of incomplete combustion (PICs) emission rates decrease. PICs are defined as any hazardous organic constituent detected in the stack gas but not present in the waste feed at a concentration of 100 g/g or higher (Trenholm, et. al., 1988). Studies involving hazardous waste incineration have resulted in emissions of PICs and unburned principal organic hazardous constituents (POHCs) being the highest when the excess air level was the highest (Staley, 1988; Huffman and Staley, 1988). Excess air leads to lower combustion temperatures which favor in situ chlorine formation over HCl. The additional presence of chlorine is then believed to promote the formation of dioxins and furans, as well as other chlorine containing compounds.

Dioxins and furans may exist in both the vapor phase and as fine particulate in hospital waste incinerator emissions with as much as 80% in the vapor phase. At temperatures below 300°F, they condense onto the fine particulate.

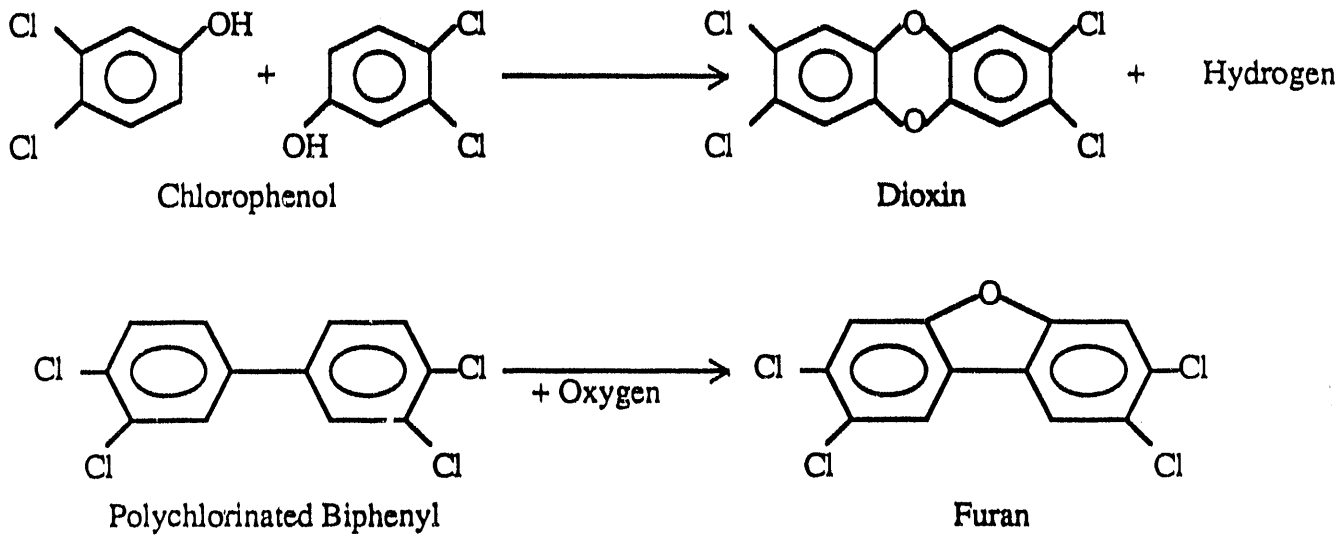
Low Molecular Weight Organic Compounds

Low molecular weight organic compounds are a product of incomplete combustion of the waste. They may be present due to some of the mechanisms previously discussed above for dioxins and furans (i.e., they may be compounds which were present in the fuel, combinations of precursors, or the dioxin and furan precursors themselves).

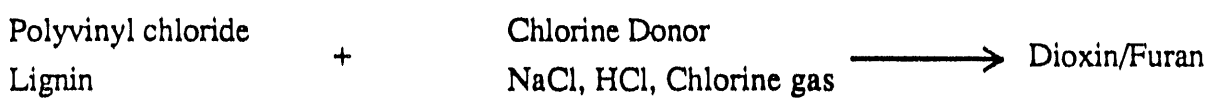
I. DIOXIN IN REFUSE



II. FORMATION FROM RELATED CHLORINATED PRECURSORS



III. FORMATION FROM ORGANICS AND CHLORINE DONOR



IV. SOLID PHASE FLYASH REACTION

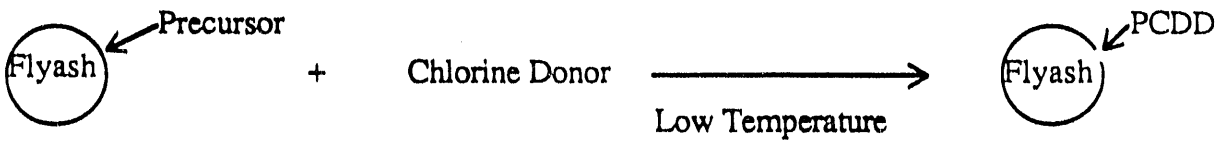


FIGURE 1

HYPOTHETICAL MECHANISMS OF POLYCHLORINATED DIBENZO-DIOXIN AND POLYCHLORINATED DIBENZOFURAN FORMATION CHEMISTRY

Carbon Monoxide

Carbon monoxide is also a product of incomplete combustion. Carbon monoxide is not considered as a hazardous PIC per the previous definition of PIC (Olexsey, et. al., 1988).

Compound Destructibility and EmissionConcentrations

Castaldini, et. al., (1986) reviewed the disposal of hazardous wastes in industrial boilers and furnaces. Their conclusions as related to the objective of this proposal follow.

- Cofiring of hazardous wastes at a small percentage of the base fuel (about 5 to 10%) appears to be a viable method of disposing of most hazardous organic material.
- Cofiring many wastes may produce lower levels of criteria pollutant and trace element emissions than either traditional coal or oil combustion.
- The conditions found in many types of watertube boilers appear to be sufficient to achieve at least 99.99% destruction of most hazardous organic compounds.
- The conditions found in firetube boilers do not appear to be sufficient to destroy all hazardous organic materials. There is too great a likelihood that cold tube-wall quenching of the waste degradation reactions is possible before destruction can occur.
- Watertube boilers whose furnace exit temperatures are greater than 1500°F and whose furnace mean residence times are greater than one second appear to be best candidates for the destruction of simple hazardous organic waste streams.
- Complex organic waste streams are likely to require approximately 360°F higher temperatures (refering to boilers in general, not including fluidized beds).

Each of these points supports the premise of the original proposal.

The relative destructibility of several organic compounds is given in Table 8 (Castaldini, et. al., 1986). Table 8 lists the order of increasing destructibility by temperature required for 99.99% destruction at one second residence time.

TABLE 8
ORDER OF DESTRUCTIBILITY

ORDER	COMPOUND	TEMPERATURE (^{o}F) NEEDED AT ONE SECOND
1	Methyl Chloride	1550
2	Methane	1535
3	Phenol	1484
4	Methylene chloride	1466
5	Pyridine	1455
6	Chlorobenzene	1413
7	Dichlorbenzene	1408
8	Hexachlorobenzene	1405
9	Ethane	1401
10	Vinyl chloride	1373
11	Ethyl chloride	1358
12	Benzene	1358
13	Cresol	1331
14	Ethylene	1329
15	Toluene	1327
16	Nitrobenzene	1327
17	Hexachlorobutadiene	1325
18	Trichlorobenzene	1320
19	Vinylidene chloride	1313
20	Acetophenol	1310
21	Propane	1305
22	1,2,2-trichloro-1,1,2-trifluoroethane	1277
23	Dichloropropane	1266
24	Trichloropropane	1260
25	Phthalic anhydride	1240
26	Isobutanol	1229
27	Trichloroethylene	1222
28	Napthalene	1221
29	Methyl ethyl ketone	1213
30	Dichloroethane	1212
31	Epichlorohydrin	1143
32	Maleic anhydride	1123
33	Bis(2-chloroethyl)ether	1115
34	Methyl isobutyl ketone	1109
35	Trichloropropane	1060
36	Benzotrichloride	982
37	Carbon disulfide	751

Table 9 lists the worst case compounds for destruction by structural class and indicates that a broad range of compounds can be replaced by several judiciously chosen ones in terms of thermal destructibility (Castaldini, et. al., 1986).

TABLE 9
DEFINITION OF WORST CASE COMPOUNDS FOR DESTRUCTION

COMPOUND	LIMITING COMPOUND FOR DESTRUCTION
Methyl chloride	Methane
Methylene chloride	Methane
Chloroform	Methane
Carbon tetrachloride	Methane
Carbon disulfide	Dichloropropane
Ethyl chloride	Vinyl chloride
Dichloroethanes	Dichloroethanes
Trichloroethanes	Propane
Tetrachloroethanes	Propane
Pentachloroethanes	Propane
Hexachloroethanes	Propane
Trichlorotrifluorethane	Propane
Ethylene	Ethylene
Vinyl chloride	Vinyl chloride
Vinylidine chlorine	Vinyl chloride
Trichloroethylene	Propane
Perchloroethylene	Propane
Bis(chloromethyl)ether	Dichloroethanes
Chloropropane	Propane
Dichloropropane	Propane
Trichloropropane	Dichloroethanes
Dichloropropanols	Propane
Epichlorohydrin	Dichloroethanes
Isobutanol	Propane
Chlorobutadiene	Toluene
Hexachlorobutadiene	Toluene

TABLE 9
(CONTINUED)

COMPOUND	LIMITING COMPOUND FOR DESTRUCTION
Maleic Anhydride	Dichloroethanes
Bis(2-chloroethyl)ether	Dichloroethanes
Methyl ethyl ketone	Dichloroethanes
Methyl isobutyl ketone	Dichloroethanes
Benzene	Benzene
Chlorobenzene	Benzene
Dichlorobenzene	Benzene
Trichlorobenzene	Hexachlorobenzene
Tetrachlorobenzene	Hexachlorobenzene
Pentachlorobenzene	Hexachlorobenzene
Hexachlorobenzene	Hexachlorobenzene
Pyridine	Methane
Nitrobenzene	Toluene
Phenol	Methane
Chlorophenol	Methane
Dichlorophenol	Methane
Trichlorophenol	Methane
Tetrachlorophenol	Methane
Pentachlorophenol	Methane
Nitrophenols	Methane
Toluene	Toluene
Benzachloride	Toluene
Benzotrichloride	Toluene
Cresols	Benzene
Cresylic acid	Benzene
Nitrocresols	Benzene
Dinitrocresols	Benzene
Acetophenone	Toluene
Phthalic anhydride	Propane
Dimethyl phenols	Methane
Cumyl phenol	Methane
Napthalene	Propane
Napthoquinone	Propane

The indication from Tables 8 and 9 is that the operating conditions in a coal-fired fluidized bed combustor should provide the appropriate reaction environment for destruction of organic hospital wastes (the next report section contains details of fluidized bed combustion of hazardous/hospital wastes). Tables 8 and 9 also indicate that the reaction environment is appropriate for the model compounds recommended in Table 6 for Task 4.

The reported range of concentrations of constituents in hospital incinerator emissions are reported in Table 10 (Radian Corporation, 1988; Office of Technology Assessment, 1988).

Table 10 gives the emissions for trace metals, polycyclic organic matter, and acid gases. Table 11 contains emissions factors for the low molecular weight organics for which emission results were identified in the study by the Radian Corporation (1988).

TABLE 10
CONCENTRATIONS OF CONSTITUENTS IN EMISSIONS FROM HOSPITAL INCINERATORS WITHOUT PARTICULATE CONTROL DEVICES

CONSTITUENT	RANGE OF EMISSIONS[a]
Arsenic	1-5.99 gr/dscf
Cadmium	24.7-140 gr/dscf
Chromium	2.15-30.9 gr/dscf
Lead	532-1190 gr/dscf
Nickel	2.22-8.0 gr/dscf
Total dioxins	51.8-450 ng/Nm^3
Total furans	18.9-79.8 ng/Nm^3
HCl	41-2095 ppmv
SO_2	19-50 ppmv
NO_x	55-270 ppmv

[a]Abbreviations: gr/dscf = grains per dry standard cubic foot; ng/Nm^3 = nanograms per standard cubic meter; ppmv = parts per million volume

TABLE 11
EMISSION FACTORS FOR SELECTED LOW MOLECULAR WEIGHT ORGANICS FROM HOSPITAL WASTE INCINERATORS

	EMISSIONS FACTOR (LB/TON FEED)
Ethane	< 0.003
Ethylene	< 0.02
Propane	< 0.024
Propylene	< 0.022
Trichlorotrifluoroethane	8.25×10^{-5}
Tetrachloromethane	9.91×10^{-5}
Trichloroethylene	2.39×10^{-5}
Tetrachloroethylene	2.49×10^{-4}

The following table shows that, for both dioxins and furans, hospital emissions are on the average one to two orders of magnitude higher per gram of waste burned than emissions from municipal incinerators (Office of Technology Assessment, 1988).

TABLE 12
DIOXIN AND FURAN EMISSION CONCENTRATIONS (in ng/Nm^3)

FACILITIES	TOTAL DIOXINS	TOTAL FURANS
Hospitals:		
A	160-260	386-700
B	290-450	700-785
C	117-197	52-84
Municipalities:		
Hampton, NY	243-10,700	400-37,500
North Andover, Mass.	225	323
Marion Co., Oregon	1.13	--
Prince Edward Island, Canada	60-125	100-160
Tulsa, Oklahoma	18.9	15.5
Wurzburg	22.1	27.9
Akron, Ohio	258	679

Possible reasons for higher emission levels of dioxins and furans, as indicated by the Office of Technology Assessment (1988) are:

1) the frequent startups and shutdowns these incinerators undergo;
2) less stringent emission controls;
3) poorer combustion control (e.g., waste mixing and oxygen controls); and
4) differences in the waste feed composition as compared with municipal solid waste.

Points 1-3 are not a concern in the proposed fluidized bed combustor. No supporting evidence for point 4 has been found.

Studies, as reported by the Office of Technology Assessment (1988), have shown that dioxins and furans can be formed after leaving the furnace by the catalysis at low temperatures of precursors such as chlorophenol and benzene and chlorine atoms on flyash particles. Disagreement exists whether pyrolysis of polyvinyl chloride can produce chlorobenzene (a potential dioxin precursor). During waste charging, which is either batch or semicontinuous, hospital incinerators often experience high carbon monoxide (as well as other products of incomplete combustion) emissions indicating poor combustion. Poor combustion, which can occur at temperatures below 1500°F, results in substantial increases in dioxin and furan formation in the furnace.

Almost all hospital incinerators are operated on an intermittent basis. Frequent startups and shutdowns of medical waste incinerators may lead to increased dioxin formation and may volatilize certain waste components, including pathogens. During cold starts without auxiliary fuel, dioxin and furan emissions can be at least 10 times higher than under normal operation. Dioxins can be formed in cool sections of the incinerator at temperatures between 400° and 800°F. Higher emissions of dioxins and furans are not generated in the proposed fluidized bed combustor because the cofiring concept adds to the stability of the combustion process by eliminating startup problems.

Laboratory studies have found that pyrolysis of various plastics produces chlorinated aromatic hydrocarbons. For example, pyrolysis of polyvinyl chloride has resulted in the formation of benzene, 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene. It is conceivable that pyrolysis of plastics may occur in the primary combustion chamber of controlled air units, causing the formation of dioxin and furan precursors. To reduce formation of these precursors, increased turbulence, retention time, and temperature are required.

The concentrations of hydrogen chloride also appear to be continuously higher, on average, compared with municipal waste combustors. One reason for this may be higher levels of polyvinyl chloride in medical waste.

As stated previously, particulate matter exiting the furnace consists of both inorganic material entrained in the combustion gases and organic materials which were not completely burned. Inorganic particulate matter can consist of both volatile and nonvolatile material. The organic compounds associated with emitted particulate matter are generally heavy hydrocarbons such as soot, PICs, or unburned POHCs.

Circulating Fluidized Bed Hospital Waste Incinerator

Coburning hospital wastes in a coal-fired circulating fluidized bed combustor is an alternative technology under study for medical waste disposal. Presently, circulating fluidized bed combustors are an emerging technology for the destruction of hazardous wastes and it appears that parallel conclusions for hospital wastes can be drawn.

This new generation system uses high air velocity and circulating solids to create a highly turbulent combustion zone. Because of the high air velocity, solids are entrained and combustion occurs along the entire height of the combustion section. Solids are separated from offgases by a cyclone and returned to the combustor through a nonmechanical seal. Temperatures are uniform within 50°F throughout this loop. This uniform temperature and high solids turbulence avoid the ash slagging encountered in other types of incinerators. NO_x and CO emissions are well controlled by the good mixing, relatively low temperatures (1450° to 1600°F), and staged combustion achieved by injecting secondary air at higher locations in the combustor.

With the pollution control features described above, the circulating fluidized bed combustor can meet the stringent permit regulations of the Environmental Protection Agency (EPA) for hazardous waste incineration which is 99.99% destruction of hazardous chemicals and 99% retention of acid gases (Rickman, et. al., 1985). There is no reason to believe that these standards can not be met with a coal-fired fluidized bed combustor cofiring small quantities of hospital wastes. Pollution control involves: efficient combustion/destruction of POHCs; efficient retention of halogens, phosphates, and sulfur; and collection of particulates.

Circulating fluidized bed combustion burns wastes in the presence of dry limestone to control acid gases without costly scrubbing systems. Test data from circulating fluidized bed pilot plants confirm greater than 99.999% efficiency in destroying and removing a variety of POHCs in the temperature range of 1450° to 1600°F (Rickman, et. al., 1985; Chang, et.

al., 1987; Chang and Sorbo, 1988). Effluent from the circulating fluidized bed combustor consists of dry stabilized ash.

A popular rule of thumb is that to destroy 99.99% of industrial waste, an incinerator must operate at 2000°F with a two second residence time. Conventional incinerator designs, as discussed in Section 3.1.1, are built with this rule in mind. However, an important variable, turbulence, can be increased to allow reduced time or temperature in the combustion zone (Rickman, 1985). Circulating fluidized bed combustor operation is an order of magnitude more turbulent than conventional incinerators, allowing operations as low as 1450°F, while still meeting the requirement of 99.99% waste destruction.

Conventional incinerator systems use wet caustic scrubbers to remove acid gases such as HCl and SO_2. This results in large volumes of fine, wet, scrubber sludge which causes difficult materials handling. Circulating fluidized bed combustors operate at temperatures low enough to allow dry lime scrubbing of these acid gases in the combustion chamber. These acid gases are removed where they are formed, in the highly turbulent combustion chamber.

Emissions of NO_x can be a concern in conventional incinerators because NO_x levels are strongly influenced by the temperature of the combustion zone. NO_x levels in circulating fluidized bed incinerators are kept very low (<100 ppmv) by minimizing the temperature, maintaining good mixing in the combustion zone, and introducing a portion of the combustion air above the main distributor.

Pilot-scale circulating fluidized bed combustion tests have been performed using surrogate waste mixtures (representative of hazardous waste POHCs) to evaluate destruction and removal efficiencies (DRE) in hazardous waste incinerators (Chang, et. al., 1987; Chang and Sorbo, 1988). Results of those tests indicated that greater than 99.99% DRE was observed even during periods where the bed temperature decreased to 1300°F. Operation at 1300°F was not an optimum condition as CO and total hydrocarbon emissions increased substantially. At bed temperatures below 1300°F, DRE decreased sharply. Formation of chlorinated PICs appeared to be correlated with CO and total hydrocarbon emissions.

Circulating fluidized bed waste combustors operate cleanly, efficiently, and economically. Their simple design uses high turbulence in the reaction zone to eliminate afterburners and scrubbers. Proven performance on industrial wastes includes the following benefits:

- Combustion efficiency > 99.999%;
- HCl capture > 99%;
- No scrubbers or wet sludge product;
- No afterburners or auxiliary fuel;
- Waste volume reduction up to 40:1;
- Highest boiler efficiency in the industry; and
- NO_x and CO emissions < 100 ppmv.

The discussion presented above involved the incineration of hazardous wastes such as those produced in an industrial process. The wastes were either solid or aqueous mixtures of organo-chlorine fuels. There is no reason to believe the proposed scenario at the Good Samaritan Hospital would be different. In fact, the emissions may even be less of a concern than those from a hazardous waste incinerator. The fuel in the proposed cofired hospital waste incinerator would be a combination of coal and hospital waste (~99% coal and ~1% waste) instead of solely hazardous waste.

An area that may be a concern in a coal-fired circulating fluidized bed combustor is bed agglomeration. Although the bed temperature is such that slagging would not necessarily be a concern, agglomeration may occur depending on the coal's ash content and composition and quantity of calcium added for HCl and SO_2 capture. More detail on this is given in the following section.

Prospects For Chlorine Capture

An important aspect of determining the feasibility of hospital waste incineration in a circulating fluidized bed combustor is the fate of the chlorine supplied to the system by plastic s and chlorine-containing drugs described in previous sections of this report. Of particular interest is the interaction of the bed material (coal inorganic material and sorbent) with chlorine during the combustion of hospital wastes and the interaction of potential emission species with the coal mineral matter and ash.

Chlorine is liberated primarily as hydrogen chloride in the combustion gas (Keairns, et. al., 1978). The hydrogen chloride can then react with metal oxides in the ash forming new solid or liquid species or remain as hydrogen chloride in the flue gas. If the hydrogen chloride remains in the flue gas, corrosion problems can occur. In addition, hydrogen chloride in emissions is environmentally unacceptable and would require downstream cleanup of the flue gas prior to release into the atmosphere. Therefore, it is desirable to determine if sufficient capture of chlorine by the inorganics in the system is feasible, avoiding the expense of downstream flue gas cleanup.

The most likely candidates for reacting with hydrogen chloride are the metal oxides. An initial screening was conducted to determine the thermodynamic feasibility of the reaction of hydrogen chloride with various metal oxides at temperatures from 1340°F (1000 K) to 2060°F (1400 K) (Good Samaritan Hospital, 1988). The reactions considered were the following:

$$SiO_2 + 4\,HCl = SiCl_4 + 2\,H_2O$$
$$Al_2O_3 + 6\,HCl = 2\,AlCl_3 + 3\,H_2O$$
$$FeO + 2\,HCl = FeCl_2 + H_2O$$
$$TiO_2 + 4\,HCl = TiCl_4 + 2\,H_2O$$
$$MgO + 2\,HCl = MgCl_2 + H_2O$$
$$CaO + 2\,HCl = CaCl_2 + H_2O$$
$$Na_2Si_2O_5 + 2\,HCl = 2\,NaCl + 2\,SiO_2 + H_2O$$

The standard Gibbs free energy change was calculated by assuming that all reactants and products were in their standard states. Thermodynamic data were obtained from the JANAF (Joint Army, Navy, Air Force) tables. JANAF Thermochemical Tables are published by the American Chemical Society, the American Institute of Physics, and the National Bureau of Standards. Using this procedure only two reactions are thermodynamically feasible in the temperature range 1340°F (1000 K) to 2060°F (1400 K): the reactions of calcium oxide and sodium silicate with hydrogen chloride.

Based on this preliminary work, it is assumed that given ample quantities of calcium compounds present in the bed to aid in sulfur capture, there should be no difficulty in chlorine capture. While the capture of chlorine by calcium oxide is feasible, the product, calcium chloride, has a relatively low melting point of 1421°F (1030 K). The importance of this information is that the presence of a liquid phase in the bed could result in agglomeration rendering the bed nonoperational. Therefore, it is necessary to determine what phase particular species are present in the bed at a given temperature. In addition, it is recognized that many of the metal chlorides would be undesirable products and would vaporize at these temperatures. In particular, the chlorides of silicon, aluminum, and titanium would all vaporize well below the lowest likely bed temperature. The result would be that chlorine would once again be released into the gas stream.

The literature which deals specifically with mechanisms of chlorine capture in fluidized beds is very limited. Most papers deal with chlorine as it occurs naturally in coal. As a result, the levels of chlorine in these studies are substantially lower than what one would encounter in a hospital waste incineration facility. A paper by Keairns, et. al. (1978) includes chlorine in their discussion of corrosion and deposition in fluidized bed combustion power

plant systems. For the purposes of this project, the paper is worth noting in that they determine the various phases, including hydrogen chloride, present at various temperatures based on thermodynamic calculations. The factors which affect release of alkalies and thereby affect chlorine capture are the feedstock composition and operating temperature.

These results are adequate for a first approximation of the types of chlorides that might be present in the bed. The following discussion is based on expanding the initial thermodynamic calculations to include the relative amounts and phases of different species commonly found or anticipated in a coal-fired system. In order to determine the chlorine capturing capabilities of a system, the effect of having multiphase components on the thermodynamic equilibrium concentrations of the various chloride species (i.e. solid, liquid, and gas) were studied. In addition, the effect of chlorine concentration, limestone addition, and coal ash composition on chlorine and sulfur capture and the formation of a liquid phase was examined.

Approach

Thermodynamic Calculations and Input Parameters

To evaluate the amount of various species in the solid, liquid, and gas phases during combustion of a feedstock consisting of coal and hospital waste, a computer program, SOLGASMIX, was utilized. The program determines the equilibrium concentrations of various species at different temperatures based on thermodynamic data taken from the JANAF tables and calculated for 2060°F (1400 K) and 1 atm. The program input includes molar composition of the fuel and temperature.

The database was set up to include sixty different species including: twenty-one gas phases; twenty-one liquid phases; and eighteen solid phases. The species chosen to make up the database were based on their importance to the system in terms of sulfur and chlorine capture and their abundance in coal ash. Important gas phases include sulfur dioxide and hydrogen chloride. Liquid and solid phases include sulfates, oxides, and chlorides. A total of ten elements was used including: carbon; hydrogen; sulfur; oxygen; sodium; calcium; potassium; chlorine; silicon; and aluminum. A complete listing of the database is given in Appendix A.

The input parameters which were varied in using the SOLGASMIX program include coal composition, temperature, and limestone addition for sulfur capture. Two coals were evaluated to determine the effect of using a compliance versus a noncompliance coal. The

two coals used were a Elk Creek bituminous coal and a Darmac bituminous roof coal, respectively. The compositions of the two coals are given in Table 13.

TABLE 13
PROXIMATE, ULTIMATE, AND PARTIAL COAL INORGANIC ANALYSES OF STUDY COALS
(As Received)

	ELK CREEK BITUMINOUS	DARMAC ROOF COAL
Proximate		
Moisture	1.21	5.30
Ash	4.22	28.55
Volatile Matter	36.03	26.81
Fixed Carbon	58.54	39.34
Ultimate		
Hydrogen	5.13	4.25
Carbon	80.15	52.81
Nitrogen	1.17	0.85
Sulfur	0.80	2.13
Oxygen	7.33	11.41
Heating Value (Btu/lb)	13,550	9714
Inorganics in Coal		
Silicon Dioxide	2.03	15.77
Aluminum Oxide	1.47	7.15
Calcium Oxide	0.10	0.19
Sodium Oxide	0.04	0.11
Sulfur Trioxide	0.09	0.24
Potassium Oxide	0.41	0.93
Remaining Oxides[a]	0.08	4.16

[a]Includes iron, phosphorous, titanium, magnesium and manganese oxides

The Elk Creek represents a compliance coal with little sulfur while the Darmac roof coal represents a noncompliance coal containing significant amounts of sulfur. The purpose for including two such coals is to determine the effect of coal character on chlorine and sulfur capture. While the cost of the Darmac roof coal is significantly lower than a compliance

coal, it may not be the most economical if it is ineffective in chlorine capture thereby limiting the rate of waste destruction or requiring downstream hydrogen chloride cleanup.

Each coal was evaluated at temperatures from 1340°F (1000 K) to 2060°F (1400 K) at 180°F (100 K) intervals. At each temperature the molar amounts of each species were determined as well as the molar fraction of each species within each gas, liquid, and solid phase. The amounts of each species as it changed with temperature was used to determine the theoretically optimum operating temperature for each coal.

Limestone was added to the Elk Creek and Darmac coals such that a molar ratio of calcium oxide to sulfur of 2:1 was established. The limestone was considered to be approximately forty percent efficient in sulfur capture. The Elk Creek coal was run with and without limestone addition to determine the effect of limestone on sulfur and chlorine capture. One concern is that the chlorine will compete with sulfur to react with calcium oxide provided by the limestone. The possible result would be reduced sulfur capture possibly requiring additional limestone or reduced amounts of chlorine in the system.

Operational Parameters Assumed for the System

In order to evaluate the interaction of chlorine with the other inorganics in the system, certain assumptions had to be made regarding the character of the feedstock, feed rates, and firing rates. The feedstock composition was based on the following:

- 90% coal; and
- 10% waste composed of 65% paper, 30% plastic, and 5% moisture. This is roughly equivalent to Type O trash (Radian Corporation, 1988). The 30% plastic was assumed to be composed entirely of polyvinyl chloride thereby representing a worst case scenario.

The composition of the polyvinyl chlride and paper on a per pound basis was added to the coal composition assuming 90% coal and 10% waste stream. The composition of the waste is given in Table 14.

TABLE 14
ULTIMATE ANALYSES OF WASTE STREAM COMPONENTS (Weight Percent)

	POLYVINYL CHLORIDE[a]	PAPER[b]
Moisture	0.20	25.0
Carbon	45.04	35.0
Hydrogen	5.60	5.0
Oxygen	1.56	24.3
Nitrogen	0.08	0.3
Sulfur	0.14	0.4
Chlorine	45.32	0.0
Btu/lb[c]	9754	6343

[a]Source: Radian Corporation, 1988
[b]Source: Singer, 1981
[c]Heat content of paper based on Dulong Formula

Each coal sample had the same relative percentage of waste added to the feed stream. A total feedstock composition was determined. The stoichiometric oxygen required for combustion was determined and an additional fifteen percent excess oxygen was added.

In order to determine the rate of emissions, it was necessary to calculate feed rates based on an assumed firing rate of 50 million Btu per hour. The flow rates in Table 15 were based on this assumption and the known heat content of the feedstock.

TABLE 15
CALCULATED FEED RATES REQUIRED OF STUDY COALS TO GENERATE 50 MILLION BTU PER HOUR
(Pounds Per Hour)

	COAL FEED	WASTE FEED	TOTAL FEED
Elk Creek Coal	3124	347	3471
Darmac Roof Coal	4260	473	4733

Results of Thermodynamic Model

Hydrogen Chloride Capture and Emissions

To date there is no set EPA limit on hydrogen chloride emissions from facilities of this sort. A limit of four pounds of hydrogen chloride per hour has been quoted in the literature (Gorman et. al., 1988). Other sources have reported a 99% removal of hydrogen chloride prior to emission (Rickman et. al., 1985). The calculated hydrogen chloride emissions for the Elk Creek coal with and without limestone addition is shown in Table 16.

TABLE 16
CALCULATED HYDROGEN CHLORIDE EMISSION LEVELS FOR THE ELK CREEK COAL WITH AND WITHOUT LIMESTONE ADDITION CONTAINING TEN PERCENT WASTE IN THE FEEDSTREAM

	ELK CREEK COAL	ELK CREEK COAL WITH LIMESTONE
Theoretical maximum HCl emissions (lb/h)[a]	53.5	53.5
HCl emissions at given temperatures (lb/h)		
1340°F (1000 K)	2.2	1.74
1520°F (1100K)	9.2	7.57
Percent reduction in HCl emissions from theoretical maximum	95.9	96.7

[a]Assumes no chlorine capture

Calculations were based on firing rate and feed composition assumptions previously outlined. An increase of 180°F (100 K) in both samples results in an increase in HCl emissions over 400%. Therefore, a maximum operating temperature between 1340° and 1520°F is suggested. The limestone addition accounts for a reduction in HCl emissions of 20%. The greatest reduction in HCl due to limestone addition occurs at lower temperatures and decreases with increasing temperature. The 95.9 and 96.7% chlorine capture are not quite the 99% reduction levels reported elsewhere, however, the chlorine levels considered here

are substantially higher. Theoretical calculations using the Darmac roof coal show the HCl emission level of hydrogen chloride to be unacceptable at any temperature even with the limestone addition.

The calculated HCl emissions for the Darmac coal was beyond the acceptable level of 4 pounds per hour even with limestone addition. The Darmac coal would not be an acceptable coal given the conditions considered here. The calculated emission levels are based on the operational assumptions previously made.

In general, both Elk Creek coals meet HCl limits of 4 pounds per hour at temperatures below 1520°F (1100K) using a coal/waste ratio of 5/1. Limestone addition accounts for reducing the HCl emissions by 20% and also allows increased operational temperatures producing the same levels of HCl in the gas phase. The effectiveness of limestone in reducing HCl emissions is greatest at lower temperature and decreases with increasing temperature. The concentration of HCl increases with increasing temperature. Figure 2 shows the moles of HCl produced by each coal as a function of temperature. The Darmac coal proved not to be very effective in capturing HCl. The higher feed rate required due to the lower heating value of the coal results in more chlorine being supplied to the system during a given period of time and might explain some of the high HCl levels.

Sulfur Dioxide Capture and Emissions

Hospital waste incinerators are not currently a source category subject to New Source Performance Standards (NSPS). However, they would be subject to NSPS for industrial, commercial, and institutional steam generating units (i.e., boilers) if units have a heat input capacity above 100 million Btu per hour and recover heat to generate steam or heat water (or other heat transfer media). EPA is currently evaluating NSPS for smaller boilers with capacities below 100 million Btu per hour. In general, the sulfur dioxide present in the gas stream increases with increasing temperature at a greater rate than hydrogen chloride (Figures 2 and 3). Assuming no sulfur capture by the inorganic material, the Elk Creek coal, which contains 0.8% sulfur in the coal, would theoretically produce approximately 1.2 pounds of sulfur dioxide per million Btu. The Darmac roof coal has 2.13% sulfur in the coal and would produce 4.4 pounds of sulfur dioxide per million Btu. Again, these emission levels are based on the operational assumptions made earlier. The Elk Creek coal meets current emission standards for coal-fired boilers with a firing rate greater than 100 million Btu per hour without requiring any limestone addition to enhance sulfur capture. At temperatures up to 2060°F (1400 K), the Elk Creek coal only produced 0.02 pounds of sulfur dioxide per million

FIGURE 2
MOLES OF HCl IN GAS PHASE

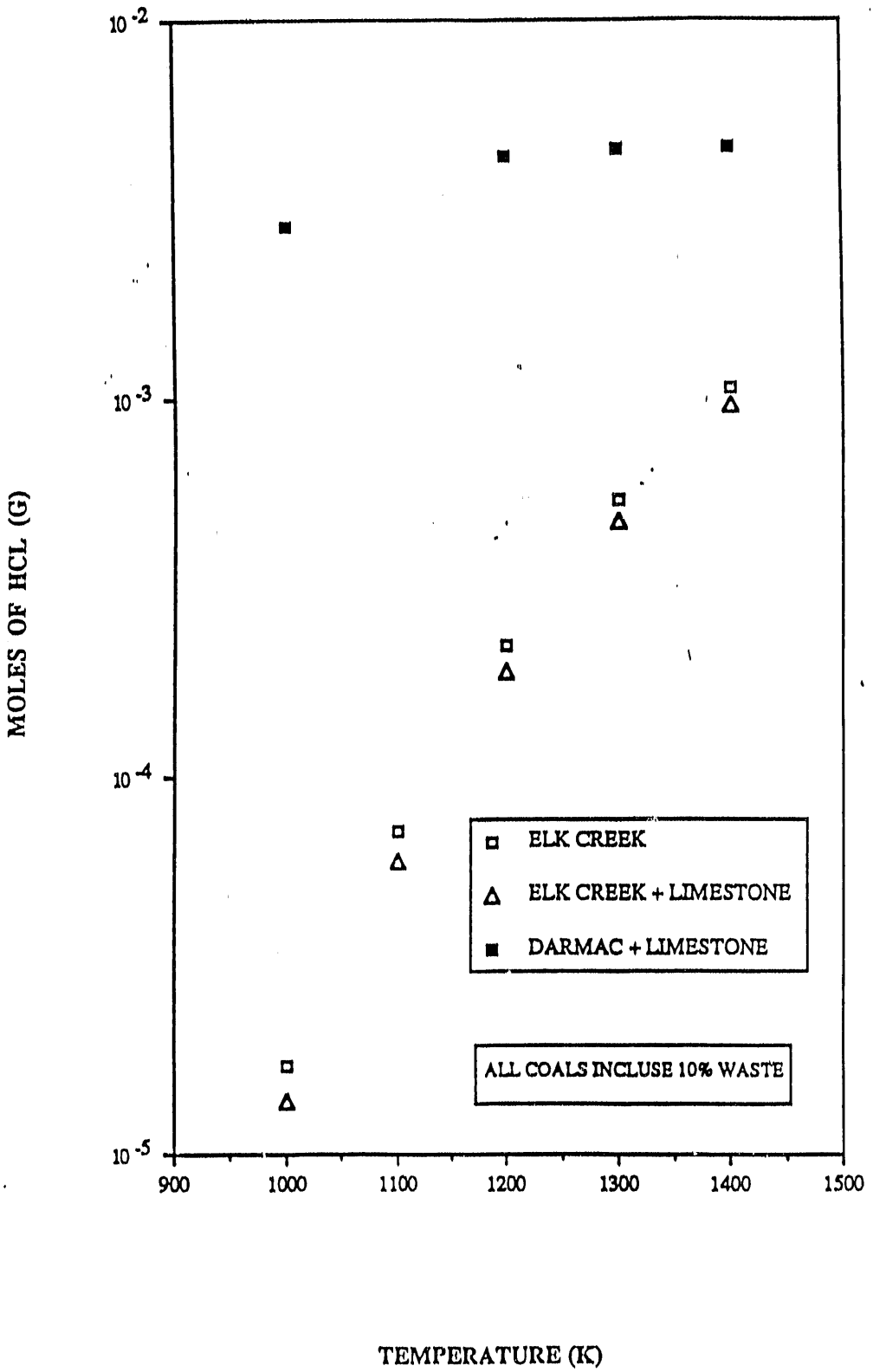
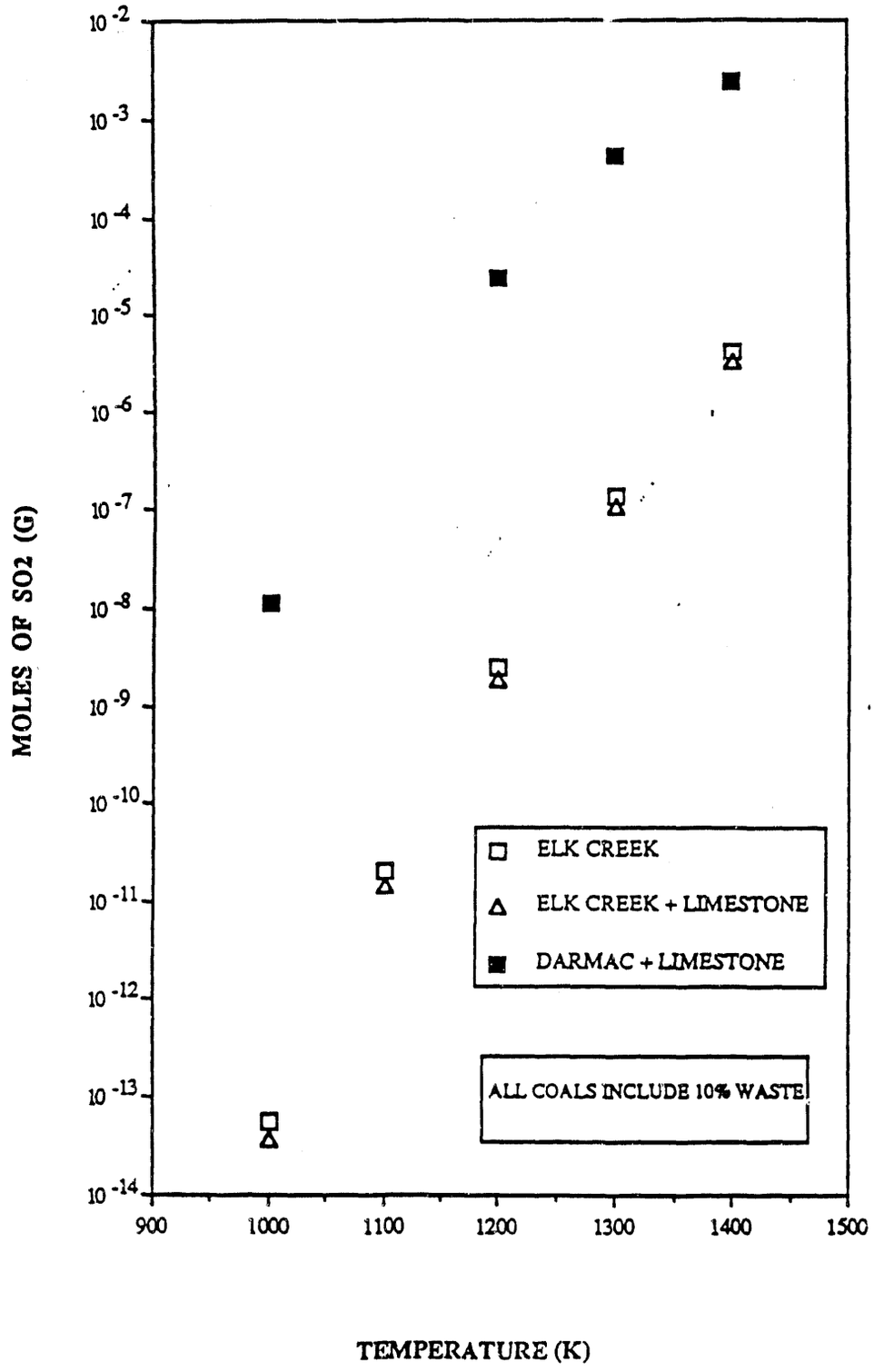


FIGURE 3

MOLES OF SULFUR DIOXIDE IN GAS PHASE



Btu suggesting efficient sulfur capture by the bed material. The Darmac roof coal requires some manner of sulfur retention in the bed or flue gas cleanup due to the high initial sulfur in the coal. Thermodynamic calculations for the Darmac coal at 1700°F (1200 K) showed sulfur dioxide levels of 0.16 pounds per million Btu. At 1880°F (1300 K), the sulfur dioxide level increases to 2.85 pounds per million Btu. Therefore, in terms of sulfur dioxide emissions, the maximum operating temperature for the system using the Darmac coal would be between 1700 and 1880°F.

The effect of limestone addition on the weight percent of sulfur dioxide in the gas stream was evident in the Elk Creek coal. With limestone addition, a reduction of 17.5 to 33% in the weight percent of sulfur dioxide in the gas phase occurred. The greatest reduction in the weight percent of sulfur dioxide due to limestone addition occurred at 1340°F (1000K). With increasing temperature, the effective weight reduction in sulfur dioxide in the gas phase due to limestone addition decreased.

Relation of Hydrogen Chloride and Sulfur Dioxide in the Gas Phase to Calcium Sulfate and Calcium Chloride in the Solid Phase

Calcium sulfate and calcium chloride are the two most likely species which form when solid calcium oxide reacts with gaseous hydrogen chloride and sulfur dioxide. The formation of either of these two species results in the removal of chlorine and sulfur species from the gas phase. Chlorine and sulfur compete for the calcium oxide. The resulting chemistry depends on the concentration of the reactants, their proximity to one another, temperature, and other factors which affect the thermodynamics and kinetics of the reactions involved. In Figures 4 through 6, the mole concentrations for these four species at various temperatures are displayed. As stated earlier, with increasing temperature, sulfur dioxide concentration increases more rapidly than hydrogen chloride concentration. The weight percent of species in the solid phase was compared and calcium sulfate and calcium chloride were of major interest due to their role in chlorine and sulfur capture. The Elk Creek coal with and without limestone addition had a weight percent ratio of calcium sulfate to calcium chloride of 3.8:1 and 3.65:1, respectively, at 1700°F (1200 K). The Darmac roof coal had a weight percent ratio of calcium sulfate to calcium chloride of 73:1. The greater amount of calcium sulfate relative to calcium chloride suggests that the sulfur is captured more efficiently than chlorine. In fact, this supports the earlier observation that the Darmac coal had an unacceptable hydrogen chloride emission level. The Elk Creek coal shows a greater balance between the calcium sulfate and calcium chloride. With limestone addition, the ratio of calcium sulfate

FIGURE 4
ELK CREEK COAL

HCl (g), SO2 (g), CaSO4 (s), and CaCl2 (s)

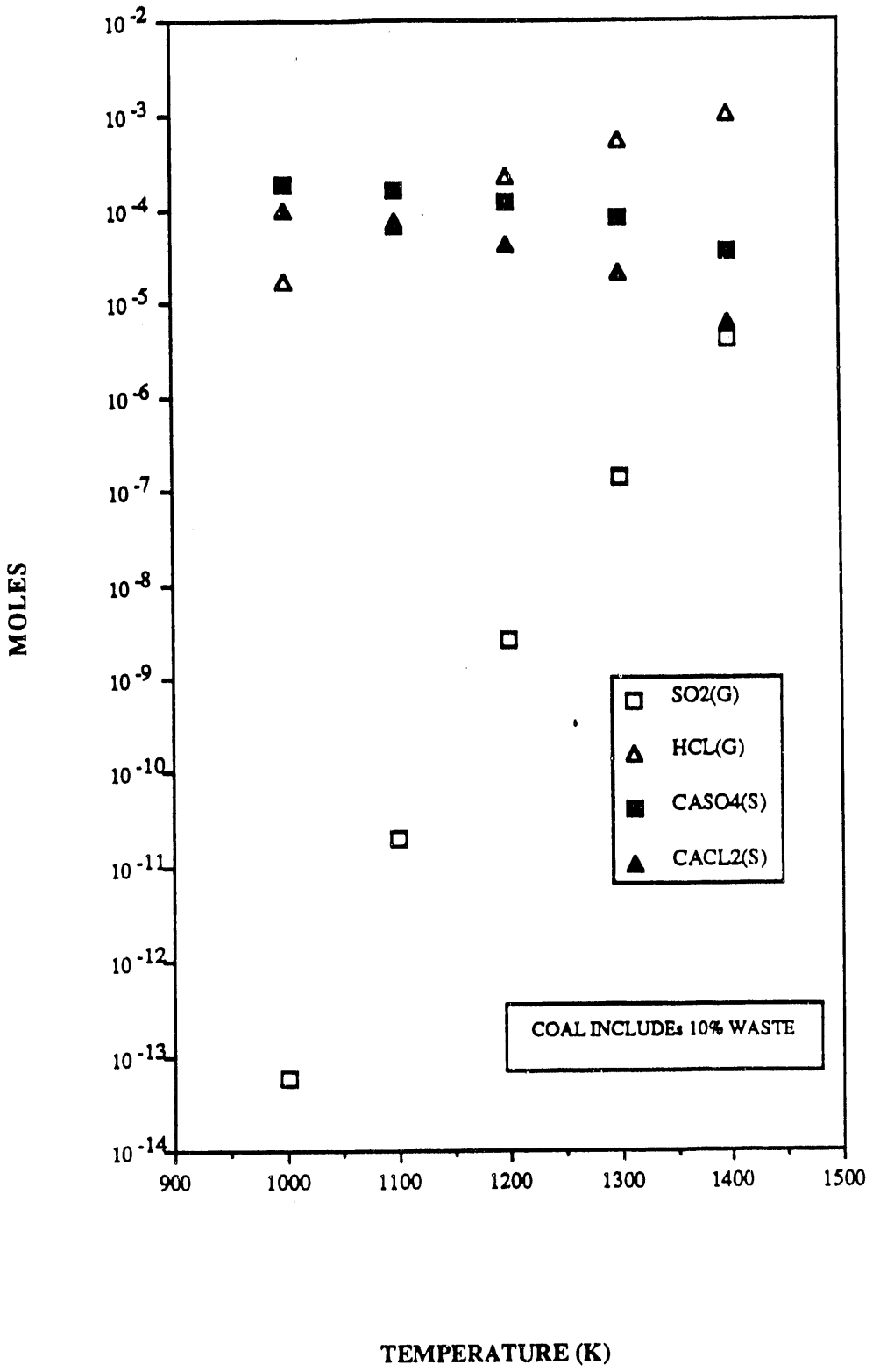


FIGURE 5

ELK CREEK COAL WITH LIMESTONE ADDITION

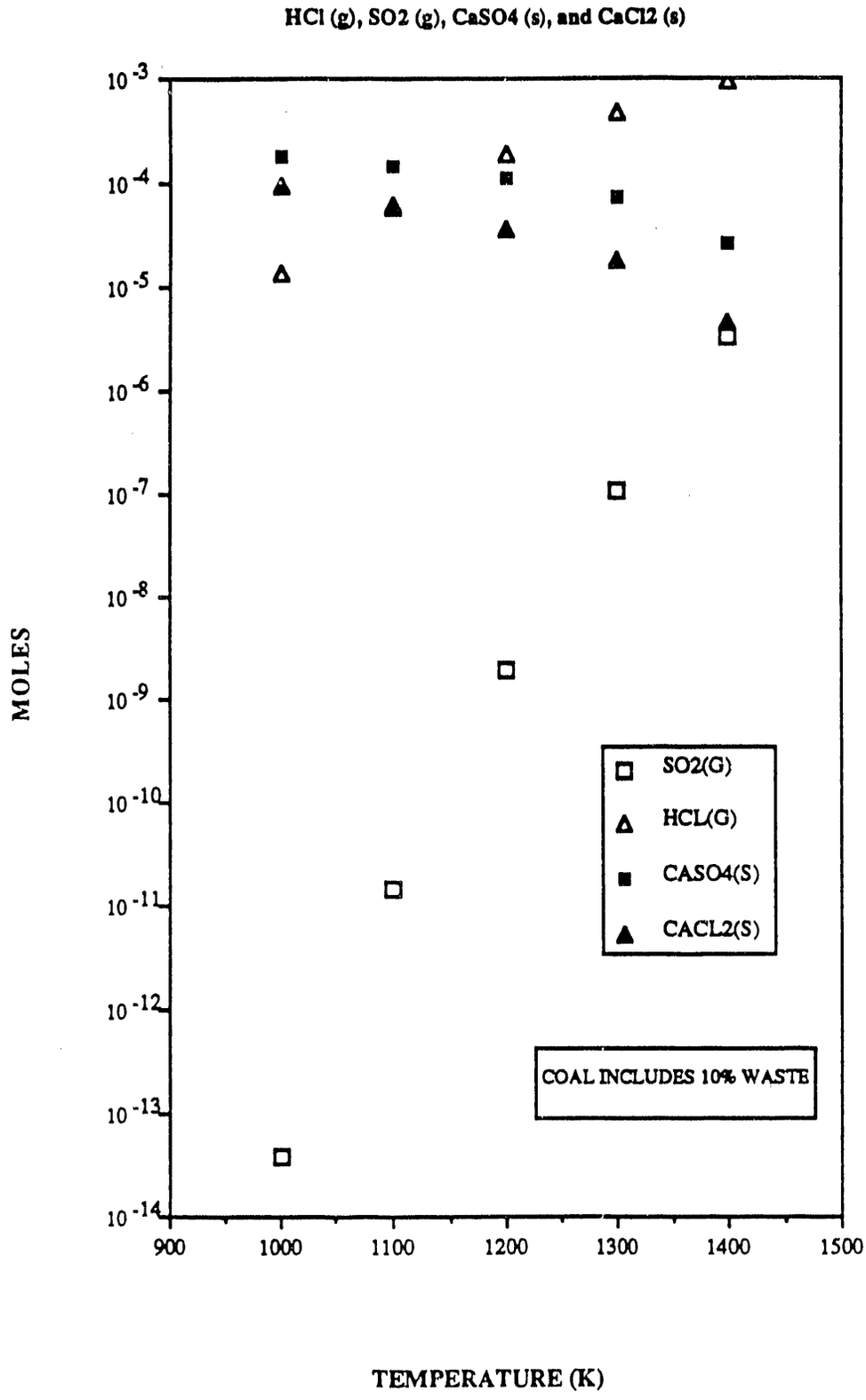
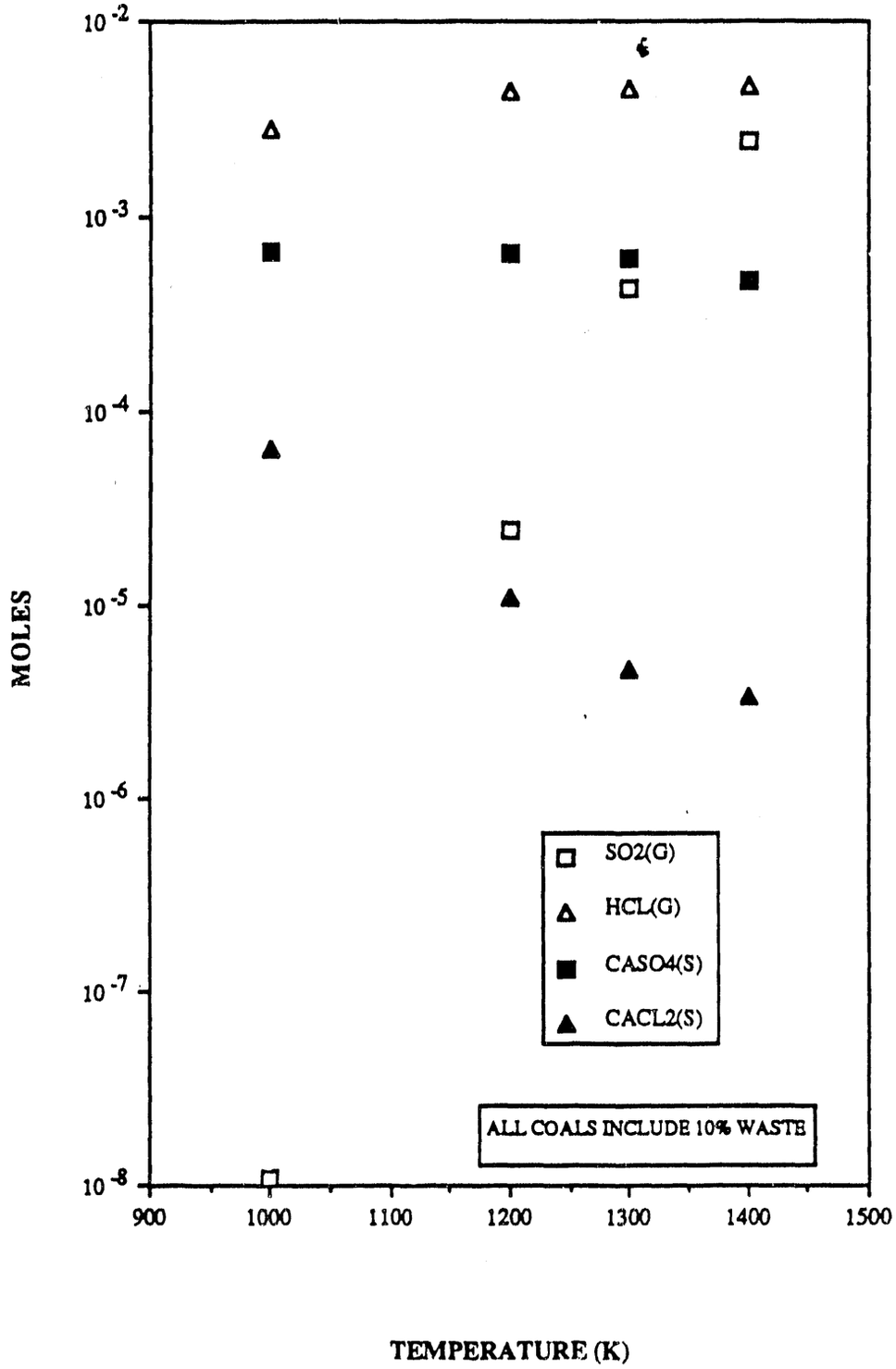


FIGURE 6

DARMAC ROOF COAL

HCl (g), SO2 (g), CaSO4 (s), and CaCl2 (s)



to calcium chloride increases slightly. In all cases the sulfate makes up a greater weight percent of the total solid phase than the chloride form.

Ratio of Liquid to Solid Inorganic Phases

While certain temperature conditions may favor chlorine or sulfur capture when using certain coals or additives, these same temperatures may not be appropriate for maintenance of a fluid bed. If temperatures in the bed are too high, liquid phases may form resulting in agglomeration of the bed. The approach used in this study was to determine the total weight of both liquid and solid phases formed at temperatures ranging from 1340°F (1000 K) to 2060°F (1400 K) for both coals. In Figure 7, the results of the calculations are shown. In general, the Darmac roof coal inorganics formed very little liquid phase. The Elk Creek coal with and without limestone addition had a more substantial liquid phase; however, it is difficult to say at what level the liquid may begin to interfere with operation of the bed. It is apparent from Figure 7 that between 1880°F (1300 K) and 2060°F (1400 K) there is a threefold increase in the liquid to solid ratio. At this temperature, there is sufficient melting of the inorganics that agglomeration potential would be significant. Operation of the bed temperature below 1880°F (1300 K) would be advisable.

Summary of Results

Based on the thermodynamic data presented here and calculated emissions for hydrogen chloride and sulfur dioxide, the following generalizations can be made.

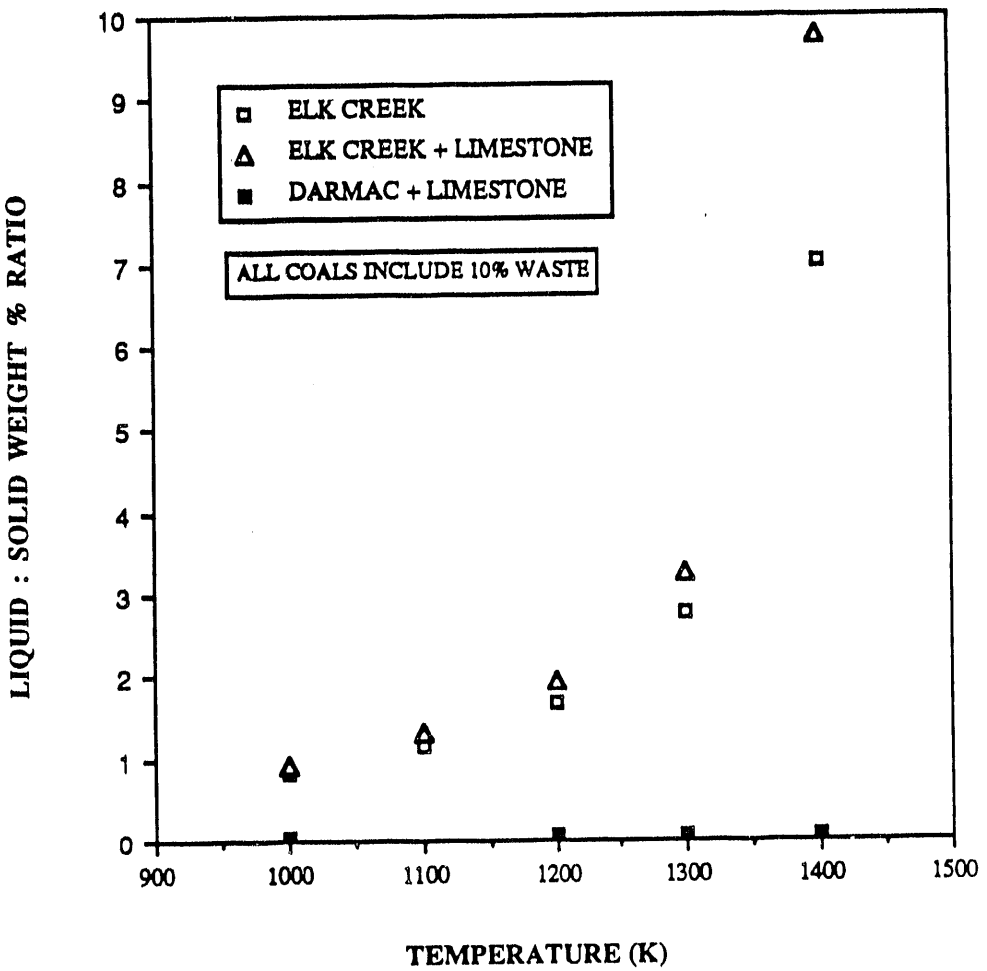
- The Elk Creek coal and the inorganic bed it produces will adequately capture chlorine at a level acceptable to the 4 pounds per hour standard, have acceptable sulfur dioxide emissions, and show minimal melting at temperatures between 1340°F (1000 K) and 1520°F (1100 K) when firing with 15% excess air. This temperature range would be best for an initial operational bed temperature.

- The Darmac roof coal and the inorganic bed it produces does not display an adequate chlorine capture capability. Based on this criterion, the coal would not be appropriate for use incinerating plastics at the level stated in earlier assumptions even though sulfur dioxide levels may be acceptable up to 1700°F (1200 K) when firing with 15% excess air and the liquid phase formed at high temperatures is extremely small and therefore represents a low potential for agglomeration.

FIGURE 7

RATIO OF WEIGHT PERCENT OF LIQUID TO SOLID PHASE

WEIGHT % OF GAS, LIQUID, AND SOLID PHASES



The assumptions made in the calculations represent a worst case scenario. If the level of waste combustion was much lower than originally assumed, it would significantly alter the levels of chlorine and sulfur emissions. After these calculations were performed, it was learned that only 200 pounds of infectious waste per day would be fired in the proposed circulating fluidized bed combustor. Incineration of 200 pounds of infectious waste per day would contain considerably less plastics than the assumed quantity in the above calculations. The assumption of 104 pounds of plastic per hour was used to generate the prior calculations. Assuming a worst case scenario of sixty pounds of plastic per day (which would be equivalent to the plastics being 30% of the infectious waste stream as compared to the more normal 30% of the total waste stream), the resulting changes in total waste, plastic, and coal to waste ratio is outlined in Table 17. Given the changes in the waste feed rates, a reduction in the chlorine to the system of 98% would be anticipated. This may result in the Darmac coal being a possible candidate coal provided sulfur dioxide emissions could be reduced. A reduction of 98% chlorine may also result in being able to operate at higher temperatures without exceeding the HCl emission levels or producing low-temperature melting phases in the bed which may result in agglomeration.

TABLE 17
CHANGES TO WASTE, PLASTIC, AND COAL:
WASTE FIRING RATIO BASED ON COMBUSTION
OF 200 POUNDS OF INFECTIOUS WASTE PER DAY

		FIRST ASSUMPTION[a] (LBS. PER HOUR)	SECOND ASSUMPTION (LBS. PER HOUR)
Elk Creek	Waste	347	8.3
	Plastic	104	2.5
	Coal:Waste	90:10	99:1
Darmac	Waste	473	8.3
	Plastic	142	2.5
	Coal:Waste	90:10	99:1

[a]Assumption used for emission calculations and thermodynamic calculations

The approach used in this task is to give a rough approximation of possible emission levels of hydrogen chloride and sulfur dioxide. Given more specifics as to the actual coal

to be used, firing rates, waste feed composition, and temperature regimes, a better approximation would be possible. Overall the initial results suggest that adequate chlorine capture within the bed is possible along with controlling sulfur emissions. The variables which should be of concern are the coal character, operating temperature, the percentage of the feedstock which is waste, and the waste composition.

Conclusions

The conclusions from Task 1, Evaluate AFBC Combustion Technology, are presented in three sections. The first, model compounds, discusses the conclusions from the survey of chlorine-containing drugs and possible model compounds for Task 4 testing. The second summarizes the results from the survey of hazardous wastes disposal in industrial boilers and the potential of using a circulating fluidized bed combustor as a hospital waste combustor. The third presents the conclusions from a study to evaluate chlorine capture in the circulating fluidized bed combustor.

Model Compounds

A survey of chlorine-containing drugs and possible model compounds for combustion was conducted to identify compounds for Task 4, Pilot Plant Testing. Several drugs were found to contain chlorine, however, there are only five different ways in which the chlorine is chemically incorporated into the structure. These are:

1) 1° Aliphatic carbon;
2) Amine hydrochloride;
3) Aromatic carbon;
4) Ionic; and
5) Vinylic carbon.

Consequently, it should be possible to model the combustion behavior of all the chlorine-containing drugs with just five model compounds. The model compounds recommended for future experimental work are:

1) (2-Chloroethyl) benzene to model a chlorinated 1o aliphatic carbon;
2) Benzyltriethylammonium chloride to model an amine hydrochloride;
3) 2-Chlorobenzoic acid to model a chlorinated aromatic carbon;

4) Potassium chloride to model an ionic chloride; and
5) 1-Chloro-2-methylpropene to model a vinylic chloride.

In addition to chlorine-containing drugs, two other sources of chlorine were considered. The first is plastics with the predominant chlorine-containing polymer being polyvinyl chloride. Since polyvinyl chloride is widely available, it can be used as its own model compound. The other source of chlorine would be pathological wastes. Presumably the major chlorine form in the human body would be as chloride ion in body fluids; ionic chloride would be modeled by potassium chloride as discussed above.

Survey of Hazardous Waste Disposal in Industrial Boilers

A survey of the disposal of hazardous wastes in industrial boilers was conducted to: review existing disposal technologies and their advantages and disadvantages; discuss air emissions; and evaluate the potential for using a fluidized bed combustor as a hospital waste disposal system. Existing disposal technologies reviewed included incineration and autoclaving.

Castaldini, et. al., (1986) reviewed the disposal of hazardous wastes in industrial boilers and furnaces. Their conclusions as related to the objective of this proposal follow.

- Cofiring of hazardous wastes as a small percentage of the base fuel (about 5 to 10%) appears to be a viable method of disposing of most hazardous organic material.

- Cofiring many wastes may produce lower levels of criteria pollutant and trace element emissions than either traditional coal or oil combustion.

- The conditions found in many types of watertube boilers appear to be sufficient to destroy all hazardous organic materials. The conditions found in firetube boilers do not appear to be sufficient to destroy all hazardous organic materials. There is too great a likelihood that cold tube-wall quenching of the waste degradation reactions is possible before destruction can occur.

- Watertube boilers whose furnace exit temperature are greater than 1500°F and whose furnace mean residence times are greater than one second appear to be best candidates for the destruction of simple hazardous organic waste streams.

- Complex organic waste streams are likely to require approximately 360°F higher temperatures (refering to boilers in general, excluding fluidized beds).

Each of these points supports the premise of the original proposal.

Polychlorinated dibenzodioxins (dioxins) and polychlorinated dibenzofurans (furans) emissions from hospital waste incinerators are on the average one to two orders of magnitude higher per gram of waste burned than emissions from municipal incinerators. Possible reasons for higher emission levels are:

1) the frequent startups and shutdowns these incinerators undergo;
2) less stringent emission controls;
3) poorer combustion control; and
4) differences in the waste feed composition as compared with municipal solid waste.

Points 1-3 are not a concern in the proposed circulating fluidized bed combustor. No supporting evidence for point 4 has been found.

Combusting hospital waste in a coal-fired circulating fluidized bed combustor appears to be a promising alternative technology for the destruction of hazardous wastes and it appears that parallel conclusions for hospital wastes can be drawn. Circulating fluidized bed combustors can meet the stringent permit regulations of the Environmental Protection Agency for hazardous waste incineration which is 99.99% destruction of hazardous chemicals and 99% retention of acid gases. It is believed that these standards can also be met with a coal-fired fluidized bed combustor cofiring small quantities of hospital wastes, however, pilot-scale testing is necessary to confirm this.

Circulating fluidized bed combustors have been shown to operate cleanly, efficiently, and economically. Their simple design uses high turbulence in the reaction zone to eliminate afterburners and scrubbers and allows for operating temperatures as low as 1450°F. Proven performance on industrial wastes includes the following benefits:

- Combustion efficiency > 99.99%;
- HCl capture > 99%;
- No scrubbers or wet sludge product;
- No afterburners or auxiliary fuel;
- Waste volume reduction up to 40:1;
- Highest boiler efficiency in the industry; and
- NO_x and CO emissions < 100 ppmv.

No information was found during a survey involving the use of a circulating fluidized bed combustor as a hospital waste combustor. Circulating fluidized bed combustors have been used in the destruction of hazardous wastes such as those produced in industrial processes. The wastes were either solid or aqueous mixtures of organo-chlorine fuels. The combustion of hospital wastes should behave similarly to hazardous waste combustion. In fact, the emissions from the proposed scenario at the Good Samaritan Hospital may even be less of a concern than those from a hazardous waste combustor. The fuel in the proposed cofired hospital waste incinerator would be a combination of coal and hospital waste (~99% coal and ~1% hospital infectious waste) instead of solely hazardous waste.

Prospects for Chlorine Capture

The survey of the literature and thermodynamic calculations have not refuted the hypothesis on which the project is based. It appears that the concept of destroying hospital waste in a coal-fired fluidized bed combustor is a valid one offering some potential for in-bed capture of chlorine-containing compounds.

Based on thermodynamic data and calculated emissions for hydrogen chloride and sulfur dioxide, the following generalizations can be made.

- The use of a compliance coal and the inorganic bed it produces should adequately capture chlorine at a level acceptable to the 4 pounds per hour standard, have acceptable sulfur dioxide emissions, and show minimal melting temperatures between 1340°F and 1520°F. This temperature range should be best for an initial operational bed temperature.

- The use of a noncompliance high ash coal and the inorganic bed it produces does not appear to display adequate chlorine capture capability due to the high sulfur content resulting in sulfur competition with the chlorine reacting with the calcium oxide. Based on this criterion, the coal would not be appropriate for destroying plastics at the level stated in Section 4.1.2 even though the liquid phase formed at high temperatures is extremely small and therefore represents a low potential for agglomeration.

The assumptions made earlier in the calculations represent a worst case scenario. Firing a lower level of wastes would significantly alter the levels of emission of chlorine and sulfur.

incineration of 200 pounds of infectious waste per day would contain considerably less plastics than the assumed quantity in the calculations. Given the lower waste feed rate, a reduction in the chlorine to the system of 98% would be anticipated. By using only 200 pounds of waste per day, it may be possible to use a noncompliance coal provided sulfur dioxide emission levels could be reduced. Pilot-scale testing is necessary to screen candidate coals. A reduction of 98% chlorine may also result in being able to operate at higher temperatures without exceeding the HCl emission levels or producing low-temperature melting phases in the bed which may result in agglomeration.

The theoretical approach used in this task is to give a rough approximation of possible emission levels of hydrogen chloride and sulfur dioxide. Overall the initial results suggest that adequate chlorine capture within the bed is possible along with controlling sulfur emissions. The variables which should be of concern are the coal character, operating temperature, the percentage of the feedstock which is waste, and the waste composition.

TASK 2 - DEVELOP WASTE HANDLING SYSTEM

One critical aspect of the AFBC co-firing of coal and hospital waste feasibility study is the development of an appropriate materials handling system for the introduction of hospital wastes into the combustion chamber. This sytem must be able to properly handle the waste without creating contamination and posing undue health risks to operators.

The first step required to fulfill this task involved investigation of the solid waste handling, storage, and transport regulations of the Environmental Protection Agency and the Pennsylvania Department of Environmental Resources. These regulations along with the operating requirements of the AFBC system provided the parameters upon which the handling system concept was developed.

An evaluation of existing hospital waste management techniques was then performed. Actual field review of waste handling systems of hospitals and private waste management companies, and also review of available literature was conducted. During this task, advantages and disadvantages of the various available technologies were identified.

Using the information assembled during the initial investigative steps, a conceptual design of the waste handling system was developed. This design is compatible with the physical needs of the combustor, while it also provides safe and efficient handling of hospital waste.

Hospital Waste Management And Regulation

For many years, environmentalist groups have been attempting to bring the issues of waste disposal to national attention. For the most part, their criticism of our throw-away society and prediction of garbage mountains and overflowing landfills have gone unheeded. After all, garbage is easy to ignore when it is being collected on a regular basis and hauled out of sight (and therefore out of mind). Even when the infamous New York City garbage barge travelled nearly 6,000 miles in search of a destination, the general public did little more than make light of the absurdity of the situation.

While issues of waste management may be regarded with apathy by most people and dismissed as "someone else's problem", improper disposal of a component of the waste stream -- medical waste -- has captured the public's attention. Medical waste, by virtue of its nature and origin, has always been regarded by the general public as unsightly and sometimes revolting. Now, with the fear of AIDS spreading more rapidly than the disease itself, medical waste is also viewed by the public as a threat to human life and health. This fear may or may not be scientifically justified. William Rutala, research associate professor in the Division of Infectious Diseases at the University of North Carolina and a representative for the Association for Practitioners in Infection Control at congressional hearings states, "From a purely scientific standpoint, there's no microbiological evidence that suggests hospital waste is more infective than residential waste" (Kunes, 1988). Many medical experts support this opinion.

Regardless of justification, fear has a way of demanding attention and initiating action. In this case, lawmakers and environmental resource protection agencies have been forced by the public to make hospital waste management a priority.

Federal Regulation

The Environmental Protection Agency (EPA) reports approximately 3.2 million tons of medical wastes from hospitals are generated each year (U.S. Congress Office of Technology Assessment, 1988). This figure does not include garbage produced by research labs, nursing homes, outpatient clinics, and offices of private doctors and dentists. Experts estimate that between 10 to 15 percent of all medical waste is designated as infectious (U.S. Congress Office of Technology Assessment, 1988).

Other than figures assessing the magnitude of waste being created by our nation's hospitals, very little information has been generated to aid in writing regulations. In particular,

the degree of risks posed by medical wastes is not known. For this reason the EPA has not promulgated regulations for hospital waste management, pending results of additional research. While the EPA has evaluated management techniques for infectious waste, considerable evidence that these wastes cause harm to human health and the environment is needed to support Federal rulemaking (EPA, 1986). It should be noted that Federal regulations do exist for components of the hospital waste stream which pose additional hazards due to such characteristics as toxicity, radioactivity, and ignitability.

In response to requests for technical advice on the issue, the EPA has published the EPA Guide for Infectious Waste Management (May 1986). This document was developed to provide guidance on the management of infectious waste. Excerpts from this document follow.

Definition of Infectious Waste

The definition of infectious waste has been debated for years. Regulatory agencies, hospitals, and research laboratories have different perspectives and objectives which influence their views; therefore, there is no universally accepted definition for infections waste. Moreover, there is inconsistency in the terminology used to define these wastes. For example, the terms infectious, pathological, biomedical, biohazardous, toxic, and medically hazardous have all been used to describe infectious waste.

For purposes of this guidance document, infectious waste is defined as waste capable of producing an infectious disease. This definition requires a consideration of certain factors necessary for induction of disease. These factors include:

a. presence of a pathogen of sufficient virulence;
b. dose;
c. portal of entry; and
d. resistance of host.

Therefore, for a waste to be infectious, it must contain pathogens with sufficient virulence and quantity so that exposure to the waste by a susceptible host could result in an infectious disease. In the table that follows, six categories are recommended EPA infectious waste categories.

TABLE 18
INFECTIOUS WASTE CATEGORIES

WASTE CATEGORY	EXAMPLES[a]
Isolation wastes	refer to Centers for Disease Control (CDC), Guidelines for Isolation Precautions in Hospitals, July 1983
Cultures and stocks of infectious agents and associated biologicals	specimens from medical and pathology laboratories cultures and stocks of infectious agents from clinical, research, and industrial laboratories; disposable culture dishes, and devices used to transfer, inoculate and mix cultures wastes from production of biologicals discarded live and attenuated vaccines
Human blood and blood products	waste blood, serum, plasma, and blood products
Pathological waste	tissues, organs, body parts, blood, and body fluids removed during surgery, autopsy, and biopsy
Contaminated sharps	contaminated hypodermic needles, syringes, scalpel blades, pasteur pipettes, and broken glass
Contaminated animal carcasses, body parts, and bedding	contaminated animal carcasses, body parts, and bedding of animals that were intentionally exposed to pathogens

[a] These materials are examples of wastes covered by each category. The categories are not limited to these materials.

The EPA has identified an optional infectious waste category which consists of miscellaneous contaminated wastes. While there is not a unanimity of opinion regarding the hazard posed by these wastes, EPA believes that the decision whether to handle these wastes as "infectious" should be made by a responsible authorized person or committee at the individual facility. However, the Agency recommends that wastes from patients known to be infected with blood-borne diseases should be managed as infectious waste (for example, dialysis waste from known hospitals and patients).

TABLE 19
OPTIONAL INFECTIOUS WASTE CATEGORIES

MISCELLANEOUS CONTAMINATED WASTES	EXAMPLES
Wastes from surgery and autopsy	soiled dressings, sponges, drapes, lavage tubes, drainage sets, underpads and surgical gloves
Miscellaneous laboratory wastes	specimen containers, slides, and cover slips; disposable gloves, lab coats, and aprons
Dialysis unit wastes	tubing, filters, disposable sheets, towels, gloves, aprons, and lab coats
Contaminated equipment	equipment used in patient care, medical laboratories, research, and in the production and testing of certain pharmaceuticals

Segregation of Infectious Waste

EPA recommends:

- segregation of infectious waste at the point of origin;

- segregation of infectious waste with multiple hazards as necessary for management and treatment;
- use of distinctive, clearly marked containers or plastic bags for infectious waste; and
- use of the universal biological hazard symbol on infectious waste containers, as appropriate.

Packaging of Infectious Waste

EPA recommends:

- selection of packaging materials that are appropriate for the type of waste;
  - plastic bags for many types of solid or semi-solid infectious waste
  - puncture-resistant containers for sharps
  - bottles, flasks, or tanks for liquids
- use of packaging that maintains its integrity during storage and transport;
- use of plastic bags that are impervious, tear resistant, and distinctive in color or markings;
- closing the top of each bag by folding or tying as appropriate for the treatment or transport;
- placement of liquid wastes in capped or tightly stoppered bottles or flasks; and
- no compaction of infectious waste or packaged infectious waste before treatment.

Storage of Infectious Waste

EPA recommends:

- minimizing storage time;
- proper packaging that ensures containment of infectious waste and the exclusion of rodents and vermin;
- limited access to storage area; and
- posting of universal biological hazard symbol on storage area door, waste containers, freezers, or refrigerators.

Transport of Infectious Waste

EPA recommends:

- avoidance of mechanical loading devices which may rupture packaged wastes;

- frequent disinfection of carts used to transfer wastes within the facility;
- placement of all infectious waste into rigid or semi-rigid containers before transport off-site; and
- transport of infectious waste in closed leak-proof trucks or dumpsters.

Treatment of Infectious Waste

For the purposes of this document, EPA defines treatment as any method, technique, or process designed to change the biological character or composition of waste.

EPA recommends:

- establishing standard operating procedures for each process used for treating infectious waste;
- monitoring of all treatment processes to assure efficient and effective treatment;
- use of biological indicators to monitor treatment (other indicators may be used provided that their effectiveness has been successfully demonstrated);
- the following treatment techniques for each of the six infectious waste categories (Table 20); and
- the following treatment methods for miscellaneous contaminated wastes (when a decision is made to manage these wastes as infectious):
  - wastes from surgery and autopsy - incineration or steam sterilization
  - miscellaneous laboratory wastes - incineration or steam sterilization
  - dialysis unit wastes - incineration or steam sterilization
  - contaminated equipment - incineration, steam sterilization, or gas/vapor sterilization.

Disposal of Treated Infectious Waste

EPA recommends:

- contacting State and local governments to identify approved disposal options (institutional programs must conform to State and local requirements);
- discharge of treated liquids and ground up solids (such as pathological waste or small animals) to the sewer system;
- land disposal of treated solids and incinerator ash; and
- rendering body parts unrecognizable before land disposal (for aesthetic reasons).

TABLE 20
RECOMMENDED TECHNIQUES FOR TREATMENT OF INFECTIOUS WASTE [a]

TYPE OF INFECTIOUS WASTE [b]	RECOMMENDED TREATMENT TECHNIQUES				
	STEAM STERILIZATION	INCINERATION	THERMAL INACTIVATION	CHEMICAL DISINFECTION [c]	OTHER
Isolation waste	X	X			
Cultures and stocks of infectious agents and associated biologicals	X	X	X	X	
Human blood and blood products	X	X		X	X [d]
Pathological wastes	X [c]	X			X [f]
Contaminated sharps	X	X			
Contaminated animal carcasses, body parts, bedding:					
• carcasses and parts	X [e]	X			
• bedding		X			

[a] The recommended treatment techniques are those that are most appropriate and, generally, in common use; alternative treatment technique may be used to treat infectious waste, if it provides effective treatment.
[b] See Chapter 2 for descriptions of infectious waste types.
[c] Chemical disinfection is most appropriate for liquids.
[d] Discharge to sanitary sewer for treatment in municipal sewerage system is appropriate (provided that secondary treatment is available).
[e] For aesthetic reasons, steam sterilization should be followed by incineration of the treated waste or by grinding with subsequent flushing to the sewer system in accordance with State and local regulations.
[f] Handling by a mortician is appropriate (burial or cremation).

Responsibilities Of The State

In the absence of Federal regulation, the control of infectious waste has been the responsibility of State health and environmental departments. According to the latest survey by the National Solid Waste Management Association, 32 states already regulate infectious waste disposal (Kunes, 1988). However, the laws vary widely from state to state. Even basic definitions of infectious waste are inconsistent. In some cases state regulations are in place but are not properly enforced. In spite of these factors, one common trend is apparent: the States are generally tightening control of infectious waste disposal by writing more specific regulations and enforcing them by imposing considerable fines for noncompliance.

Because of the dynamic nature of this issue, a review of current regulations for each state was not conducted as part of this study. The EPA has included in the EPA Guide for Infectious Waste Management a summary of regulations for each state. This summary is included in Appendix B.

The Commonwealth Of Pennsylvania Regulations

As the potential host state of the AFBC proof-of-concept test facility, Pennsylvania regulations must be considered. Unfortunately changes in present requirements and standards are imminent. On July 13, 1988, Governor Casey signed into law new legislation requiring that the Department of Environmental Resources (DER) develop a Pennsylvania Infectious and Chemotherapeutic Wastes Plan. In addition to this plan, the DER must review and revise existing regulations and standards for the handling, storage, and disposal of infectious and chemotherapeutic wastes. Until the adoption of the plan by the state Environmental Quality Board, a moratorium has been placed on the issuance of permits for new infectious waste incinerators. The DER may reissue permits to operators of existing facilities, subject to certain conditions (Pennsylvania General Assembly, 1988).

The regulations presented in the following sections are likely to change upon adoption of the new plan. Among other practices not currently regulated, the DER is required by law to include regulations for a manifest system and the licensing of infectious and chemotherapeutic waste transporters.

Definitions

Regulations governing infectious and chemotherapeutic waste management are published in **The Pennsylvania Code Title 25 Environmental Resources. Chapter 271 Municipal Waste Management** contains general guidelines for total waste management including infectious and chemotherapeutic wastes. Within this chapter are definitions of terms. The following list includes definitions of terms that are pertinent to this study.

Chemotherapeutic waste - Waste resulting from the production or use of antineoplastic agents used for the purpose of stopping or reversing the growth of malignant cells. Chemotherapeutic waste does not include waste containing antineoplastic agents that are listed as hazardous waste under Subsection 75.261 (relating to criteria, identification, and listing of hazardous waste).

Disposal - The deposition, injection, dumping, spilling, leaking, or placing of solid waste into or on the land or water in a manner that the solid waste or a constituent of the solid waste enters the environment, is emitted into the air, or is discharged to the waters of this Commonwealth.

Incinerator - An enclosed device using controlled combustion for the primary purpose of thermally breaking down solid waste, and which is equipped with a flue as defined in Subsection 121.1 (relating to definitions).

Infectious waste - Municipal waste which, unless processed, disposed, stored, collected, or transported in accordance with this article, is or may be contaminated by a disease-producing microorganism or material, or may harm or threaten human health. The term includes the following wastes unless they are generated by individual residence.

i. Wastes generated by hospitalized patients who are isolated, or on blood and body fluid precautions, in order to protect others from their severe and communicable disease.

ii. Cultures and stocks of etiologic agents.

iii. Animal waste blood and animal blood products which are known or are suspected to contain contagious zoonotic pathogens, and human waste blood and blood products.

iv. Tissues, organs, body parts, blood, and body fluids that are removed during surgery and autopsy.

v. Wastes generated by surgery or autopsy of septic cases or patients with infectious diseases.

vi. Wastes that were in contact with pathogens in any type of laboratory work, including collection containers, culture dishes, slides, plates, and assemblies for diagnostic tests; and devices used to transfer, inoculate, and mix cultures.

vii. Sharps.

viii. Wastes that were in contact with the blood of patients undergoing hemodialysis at hospitals or independent treatment centers.

ix. Carcasses and body parts of animals exposed to contagious zoonotic pathogens.

x. Animal bedding and other wastes that were in contact with animals suffering from contagious zoonotic diseases due to natural infection or laboratory research, and their excretions, secretions, carcasses, or body parts.

xi. Waste biologicals - for example, vaccines - produced by pharmaceutical companies for human or veterinary use.

xii. Food and other products that are discarded because of contamination and etiologic agents.

xiii. Equipment and equipment parts contaminated with etiologic agents.

Municipal waste - Garbage, refuse, industrial lunchroom, or office waste and other material, including solid, liquid, semisolid, or contained gaseous material resulting from operation of residential, municipal, commercial, or institutional establishments and from community activities; and sludge not meeting the definition of residual or hazardous waste under this section from a municipal, commercial, or institutional water supply treatment plant, waste water treatment plant, or air pollution control facility.

Municipal waste landfill - A facility using land for disposing of municipal waste. The facility includes land affected during the lifetime of operations including, but not limited to, areas where disposal or processing activities actually occur, support facilities, borrow areas, offices, equipment sheds, air and water pollution

control and treatment systems, access roads, associated on-site and contiguous collection, transportation and storage facilities, closure and post-closure care and maintenance activities, and other activities in which the natural land surface has been disturbed as a result of or incidental to operation of the facility. The term does not include a construction/demolition waste landfill or a facility for the land application of sewage sludge.

Processing - Technology used for the purpose of reducing the volume or bulk of municipal or residual waste or technology used to convert part or all of the waste materials for off-site reuse. Processing facilities include, but are not limited to, transfer facilities, composting facilities, and resource recovery facilities.

Resource recovery facility - A municipal waste processing facility using incineration of municipal waste to recover usable energy in a combustion unit, as defined in Subsection 121.1. The term includes land affected during the lifetime of operations, including, but not limited to, areas where processing activities actually occur, support facilities, borrow areas, offices, equipment sheds, air and water pollution control and treatment systems, access roads, associated on-site or contiguous collection, transportation and storage facilities, closure and post-closure care and maintenance activities, and other activities in which the natural land surface has been disturbed as a result of or incidental to operation of the facility.

Sharps - Broken glass that has been in contact with pathogenic organisms, hypodermic needles and syringes, suture needles, disposable razors, pasteur pipettes, and scalpel blades.

Solid waste - Waste, including, but not limited to, municipal, residual or hazardous wastes, including solid, liquid, semisolid, or contained gaseous materials.

Special handling waste - Municipal waste that requires the application of special storage, collection, transportation, processing, or disposal techniques due to the quantity of material generated or its unique physical, chemical, or biological characteristics. The term includes sewage sludge, infectious waste, chemotherapeutic waste, and ash residue from a municipal waste incineration facility.

Treatment - A method, technique or process, including neutralization, designed to change the physical, chemical, or biological character or composition of waste to neutralize the waste or to render the waste non-hazardous, safer for transport, suitable for recovery, suitable for storage, or reduced in volume.

Waste - A material whose original purpose has been completed and which is directed to a disposal or processing facility or is otherwise disposed. The term does not include source separated recyclable materials or material approved by the Department for beneficial use under Subsection 271.232 (relating to beneficial use).

Storage and Handling

Guidelines for storage and handling of infectious and chemotherapeutic wastes are found in **Chapter 285 Storage and Transportation.**

Infectious waste shall be contained in a manner that:

1. Affords protection from animals, rain and wind;
2. Prevents the spread of infectious agents; and
3. Does not provide a breeding place or food source for insects or rodents.

Infectious waste must be separated from other waste at the point of origin and placed in bags, or rigid or semi-rigid containers. The bags or containers must be red in color. All infectious waste bags and containers must be labeled "infectious waste" or marked with the universal biohazard symbol. Infectious waste sharps must be placed in leakproof, rigid, puncture-resistant plastic containers.

Infectious waste may not be stored at the waste producing facility for more than the following periods of time.

1. Twenty-four hours at room temperature (18 to 28° C) for blood, body fluids, body parts, and cultures and stocks of etiologic agents.
2. Three days at room temperature (18 to 28° C) for infectious waste other than blood, body fluids, body parts, and cultures and stocks of etiologic agents.
3. Five days in a refrigerator (2 to 7° C) not used for food or patient related items.
4. Ninety days in a freezer (-20 to -18° C) not used for food or patient related items.

If the waste processing facility is separate from the waste producing facility, infectious waste may not be stored at the waste processing facility for more than any of the following periods of time:

1. Twenty-four hours at room temperature (18 to 28° C);
2. Five days in a refrigerator (2 to 7° C) not used for food or patient related items; and
3. Thirty days in a freezer (-20 to -18° C) not used for food or patient related items.

Regulations pertaining to chemotherapeutic waste containment are similar to those for infectious waste, with a few exceptions. Chemotherapeutic waste must be placed in yellow bags or containers and labeled with the words "chemotherapeutic waste" or the universal biohazard symbol. There is no time limit specified for the storage of chemotherapeutic waste prior to incineration.

Infectious and chemotherapeutic waste may not be transported in the same containers. Infectious and chemotherapeutic waste must be transported in separate vehicles from those used for other waste. Vehicles must be identified with signs or decals indicating that infectious or chemotherapeutic, or both, are being transported. Compaction type vehicles may not be used to transport infectious or chemotherapeutic waste.

Operating Requirements

Chapter 283 Resource Recovery contains general operating guidelines for waste processing facilities, including incinerators. The requirements in this chapter are in addition to those requirements in **Chapter 271 Municipal Waste Management.**

In this chapter, infectious waste is addressed as a special handling waste. A person or municipality that incinerates infectious waste must monitor the waste to ensure that pathogens have been destroyed. Microbiological analysis of composite samples of the ash residue must be submitted to the DER prior to disposal of ash from the facility, and also, at a minimum, quarterly during the life of the facility.

Infectious waste will be considered to be noninfectious after incineration if one of the following has occurred.

1. The indicator spores are determined by a laboratory analysis to have been destroyed.
2. For incineration using a test other than an indicator spore, a laboratory analysis determines that sterilization has occurred.

Chemical analyses of the ash must be submitted at least annually during the life of the facility.

In addition to the permit requirements under Chapter 283, waste incinerators must possess a permit under the Air Pollution Control Act (35 P.S. 4001-4015). Permit regulations pertaining to emissions standards are located in **Chapter 127 Construction, Modification, Reactivation, and Operation of Sources.** As required by Chapter 127, Best Available Technology (BAT) standards for hospital/infectious waste incinerators must be achieved for permit approval. The most current revision of the BAT document is included in Appendix C.

Disposal

Chapter 273 Municipal Waste Landfills sets forth requirements for persons or municipalities that operate municipal waste landfills. Infectious and chemotherapeutic wastes are addressed as specific wastes.

Infectious waste may not be disposed at a municipal waste landfill unless:

1. The waste has first been rendered noninfectious by sterilization or incineration and certified as noninfectious; and
2. The method by which the waste is sterilized or incinerated possesses a permit from the Department under Chapter 283, if required.

Compactors, grinders, or similar devices may not be used to reduce the volume of infectious waste before the waste has been rendered noninfectious.

Chemotherapeutic wastes may not be disposed at municipal waste landfills unless the waste is first incinerated at a processing facility that possesses a permit from the Department under Chapter 283, and also under the Air Pollution Control Act (35 P.S. 4001-4015).

Ash residue that has been determined non-infectious may be handled, stored, and landfilled under the regulations for ash residue from municipal waste incineration.

Following completion of Task 2, the Pennsylvania Environmental Quality Board issued "Proposed Rule Making for Municipal and Residual Waste Management: Infectious and Chemotherapeutic Waste". Prior to becoming effective, the amendments will be published in the Pennsylvania Bulletin as final rule making. This has not yet occurred.

The Proposed Rule Making document was reviewed for any impacts on the conceptualized AFBC incineration unit. Although the requirements are more specific concerning

handling, storage, and transport of infectious wastes, no major changes from prior regulations were identified as problems for the proposed AFBC system.

The previously noted clause which restricts compacting, grinding, or size reduction is still stipulated in the proposed rules. An additional statement has been incorporated into the proposed rules -- "However, disinfection and volume reduction may take place concurrently". A follow-up meeting was held with DER Bureau of Waste Management representatives Mr. Ronald Hassinger, Chief Waste Determination Section, and Mr. Stephen Socash, Chief Municipal Residual Waste Permit Section. The planned waste feed system was reviewed relative to environmental safeguards and compliance with the intent of proposed rules permitting size reduction concurrent with disinfection. Both individuals expressed their opinion that the feed system will be acceptable.

Another meeting was scheduled to review the AFBC system with Mr. Hartwin Weiss, Chief Engineering Services, in DER's Air Quality Program. The Lebanon VA Medical Facility is within Mr. Weiss's region for permit review and approval. The primary regulatory requirements discussed during this meeting were the high temperatures specified for primary and secondary combustion chambers and the use of best available control technology for reduction of emissions. Mr. Weiss indicated that the temperatures were presented as guidelines for existing incinerators. Results from the AFBC combustion testing should be used in the permit application to demonstrate the ability to achieve desired incineration efficiencies at lower temperatures due to greater retention time and the recirculation of combustion gases.

Current Hospital Waste Disposal Practices

Prior to development of a materials handling system concept, existing hospital waste disposal procedures and technology were evaluated. Several Central Pennsylvania area hospitals were visited and surveyed in order to assemble information pertaining to current hospital waste management practices. The data collected through these surveys, in addition to published articles and reports, were utilized to determine possible problems associated with feeding hospital waste into the AFBC. These factors were then considered in designing the materials handling system concept.

Segregation of Wastes

Accidental exposure to infectious waste is often closely linked to problems resulting from inadequately packaged and contained wastes as they are moved about the hospital or transported off-site for disposal. To avoid such problems, the EPA recommends that medical wastes be segregated at the point of origin. Many states, including Pennsylvania, require waste segregation.

Segregation involves placing special handling wastes in bags, boxes, or containers that are distinctly and clearly marked for the containment of either infectious or chemotherapeutic waste. Infectious liquid waste and sharps, i.e., needles, broken glass, scalpel blades, etc., should be placed in plastic containers to avoid accidental puncture of plastic bags and leakage of infectious waste. After segregation of waste into appropriate containers, infectious and chemotherapeutic waste should be stored separately to avoid possible contamination of general housekeeping trash. In some hospitals, wastes are further separated depending upon the method of disposal of each type of waste. These methods are discussed in the next section.

Disposal Options

Landfilling

In the past, most solid hospital waste was landfilled along with municipal waste. In recent years however, the cost of landfilling and the reluctance of landfills to accept infectious waste has made this a much less attractive method of disposal. Some states, Pennsylvania among them, will no longer allow disposal of unsterilized infectious waste in municipal landfills. Because of special permit requirements in Pennsylvania, many landfill operators will not accept sterilized infectious waste either.

Autoclaving

In states where landfilling sterilized infectious waste is permitted, autoclaving is an option. Autoclaving, or steam sterilization, is a process using steam to sterilize medical wastes prior to disposal in a landfill. Typically, bags of infectious waste are placed in a chamber into which steam is then introduced. To ensure complete sterilization, steam

temperatures are generally maintained at 250° F or greater for 15 to 30 minutes (Rutala, Stiegel, and Sarubbi; 1982).

The disadvantages associated with autoclaving have rendered this method of sterilization impractical for many hospitals. Autoclave units have very limited capacity; sometimes only one or two bags can be sterilized in a 30 minute period. In addition, operational problems can result in incomplete destruction of infectious pathogens. In fact, properly sterilized waste looks no different than unsterilized waste. Therefore, landfill operators are reluctant to accept red bag waste, regardless of its infectious potential.

Incineration

As the number of available landfills decreases each year, incineration of wastes has become the chosen hospital waste disposal alternative. Incineration reduces the volume of waste, thereby reducing the cost of ultimate disposal in a landfill. The high temperatures necessary for combustion of wastes also destroy infectious pathogens and render the waste innocuous. One disadvantage associated with existing incineration systems is the potential for air pollutant emissions. Unstable combustion temperatures due to the varied nature of medical wastes can allow for the release of toxic substances into the atmosphere. The problems with alternative technologies were discussed in the Task 1 section of this report.

According to recent EPA estimates, five thousand "excess air" hospital incinerators are operating around the country (Kunes, 1988). These units are typically older incinerators designed to burn only pathological waste. As other waste disposal options have been eliminated due to regulatory and economic factors, many hospitals have begun burning all types of infectious waste in these incinerators. Because this type of unit is operated with high excess air levels, incomplete combustion and toxic pollutant and particulate emissions are common problems. In states where emission standards are highly restrictive, these incinerators must be retrofitted with scrubber systems in order to control release of acid gases and dioxins.

Most of the incinerators built for medical waste in the last 15 to 20 years have been "controlled air" incinerators (U.S. Congress Office of Technology Assessment, 1988). These units burn waste in two or more chambers under conditions of both low and excess stoichiometric oxygen requirements. The primary combustion chamber is designed to heat, dry, and pyrolize the waste under sub-stoichiometric conditions, causing the release of moisture and volatile organics from the waste. These organic compounds are then thermally destructed in the secondary chamber under excess air conditions. Similar to excess air

incinerators, many controlled air models are not capable of meeting stringent air pollution standards, and therefore require installation of flue gas scrubber systems.

A third, and less common, incineration system design is the "rotary kiln" incinerator. Similar to controlled air units, rotary kiln incinerators employ a primary chamber in which waste is heated and volatized and a secondary chamber in which combustion of volatile organics is completed. The primary chamber consists of a horizontal rotating kiln. At one end, waste material is fed continuously into the rotating kiln. Ash residue is continuously discharged at the opposite end. Due to the turbulence created by rotation of the primary chamber, particulate entrainment in the flue gases is generally higher than for other incinerator designs.

Feed and ash removal systems for hospital waste incinerators range from manually operated to fully automatic systems. In general, large continuously operating incinerators employ automated handling systems, while smaller incinerators are better suited to manual systems.

Most mechanical loader designs currently offered consist of a hopper and ram feed assembly. For smaller units, manual charging doors are common. Ash removal may be accomplished either by raking and shoveling ash into containers, or for large units, mechanical systems. Some mechanical ash removal techniques include a system whereby ash is moved along the incinerator floor by pulsations created by air cushions, and also various ram systems which push ash out of the incinerator chamber (U.S. Environmental Protection Agency, 1987). A drag tank can be incorporated to facilitate water cooling of ash prior to removal to storage bins.

With the exception of some rotary kiln designs, most incinerators do not require grinding of waste prior to feeding the combustion chamber.

Future Management

Many hospitals do not have in-house incinerator capability and therefore must send their infectious waste off-site for disposal. In some cases private hauling companies are hired to transport waste to approved landfills. Unfortunately, in states where no manifest systems are required to track the waste, unscrupulous haulers have dumped the waste illegally and kept the profits.

Because of the liability involved with illegal dumping, many hospitals choose to contract the services of medical waste management companies. Such companies often operate their own regional incinerators designed specifically for handling infectious waste.

They provide cradle-to-grave treatment of the waste, including supplying bags and containers to separate waste, hauling waste to incinerator site, incineration, and disposing ash. Most companies have tracking systems in place and provide the hospital with evidence of legal disposal.

The cost of infectious waste disposal by hospital waste management specialists is high. National hospital officials warn that the cost to large teaching hospitals for removal of infectious waste this year will be upwards of $1 million. Regardless of the costs involved, increasingly stringent regulation of infectious waste disposal will force hospitals to employ outside services. In some states the fines for violation of infectious waste disposal regulations are in the range of several thousand dollars per day of violation (Kunes, 1988)

Materials Handling Conceptualization

Material Handling And Storage

Infectious and chemotherapeutic wastes must be separated at the point of origin and placed in the appropriate bags or containers and labeled or marked accordingly as previously stated.

For ease in handling wastes, storage areas for the wastes should be located in close proximity to the processing system. Storage areas must be secured to deny access to unauthorized persons and marked with warning signs indicating storage of infectious and/or chemotherapeutic waste. These storage areas must be contained in an appropriate manner that allows protection from animals, wind and rain, prevents the spread of infectious agents, and does not provide a breeding place or food source for insects, rodents, and animals. Refrigerator and freezer capabilities must be available to store the infectious waste as required by regulations. The refrigerator and freezer are also necessary for waste storage in the event of an equipment breakdown in the material size reduction unit or in the combustion unit. Arrangements should be made with an outside waste hauler to pick up and deliver the packaged waste to another incinerator in the event of long-term equipment failure.

The bags, boxes, or containers used for containment of infectious or chemotherapeutic waste must be no larger than the feed opening size of the material size reduction unit. The size of the feed opening has been established at 40 inches by 25 inches. Based on current practices, the size of the bags, boxes, or containers used for storage are smaller than the feed opening size of the conceptual design of the material size reduction

unit. The waste containers should range in weight from approximately 25 to 50 pounds. To permit ease of handling, the maximum weight of 50 pounds should not be exceeded.

The majority of hospital waste materials can be dealt with in the feed and combustor system design. One possible exception is large metal objects such as surgical pins implanted in the arms or legs of patients. From a survey of several hospitals, it was found that these metal objects could be segregated from other waste materials and sterilized separately with little inconvenience to the hospital staff.

Material Size Reduction Unit

Unlike most traditional incinerator designs, the AFBC requires that the waste stream consist of particles no larger in size than two-inch-minus. For this reason, some type of size reduction unit must be designed for processing the waste prior to feeding the waste into the combustion chamber. To avoid regulatory problems, the size reduction unit will be integrated with the combustor and incorporate sterilization.

The conceptual design of the material size reduction unit is illustrated in Figure 8 and Figure 9. The main component of this unit is a Model 1000-E shredding system, designed and manufactured by Shredding Systems Inc. (similar shredders are manufactured by companies such as Mac/Saturn Corporation). This industrial shredder is of heavy duty construction, primarily stainless steel. It has the proper infeed opening, cutter diameter, cutter thickness, and horsepower to process the 10,000 pounds of infectious and general waste per week anticipated, and also to produce the desired discharge particle size. To avoid system upsets, mechanical damage and/or de-fluidization in the combustion unit, the maximum feed size into the combustor has been determined to be two-inch-minus.

The Model 1000-E is a Rotary Shear Shredder which works on a low speed, high torque principle. This unit also features an auto-reversing, non-jamming capability. When overfeeding occurs, the machine automatically detects it by an increase in amperage draw. When the amperage reaches a preset level, the machine shifts into a reversing mode, clearing the cutting area. The machine then continues in the forward position and will continue this process until the material has been processed. The unit has an automatic shut-down feature after three (3) reversals. Most importantly, this auto-reversing, auto-shut-down feature protects the machine from damage, thus reducing costly downtime and machine repairs. Other benefits of this design are low energy usage, low maintenance, and low noise.

This Rotary Shear Shredder has been tested and evaluated for the shredding and handling of materials such as, but not limited to, hospital and/or pharmaceutical waste, hazardous/nuclear waste, in-plant industrial waste, municipal waste, drums, and plastics. The following table provides a list of examples of material test shredded and evaluated by Shredding Systems Inc.

The conceptual design of the material size reduction unit, as illustrated on Figures 8 and 9, consists of two hoppers or compartments above the cutting chamber. Compartment "A" is where the infectious waste is initially inserted into the handling system. Compartment "A" has an infeed opening of 40 inches by 25 inches with a height of 30 inches. A single door is positioned atop the handling system. After material has been inserted into compartment "A", the single door should be closed prior to the opening of the double drop doors. The opening of these doors allows the waste material to fall into compartment "B". After the material passes through the double drop doors, the doors shall then close. Compartment "B" is 40 inches by 25 inches and has a height of 48 inches. The infectious material is now introduced into the shredder. The cutting of the material is accomplished as the material is drawn past the interfaces of the two counter-rotating blades driven by a 40 horsepower electric motor. It is the close tolerance of these blades that performs the shearing action. As the reduced or shredded material passes through the cutting chamber, the material falls directly into a discharge chute. Installation of steep angle chutes and control of the combustor pressures will facilitate gravity feed of the shredded waste. One method for preventing blockage of the chute leading into the combustor would be to force the material down the discharge chute with a series of compressed air jets. The discharge chute is directly connected to the combustor (see Figure 8). Another feed option is use of pneumatic (pressurized) injection. With this approach shredded material would exit the cutting chamber and fall directly into a compartment. The material then is pneumatically injected immediately above the fluidized bed media. Finally, a screw auger feed system has potential to provide a uniform feed rate. Specific feed systems will be evaluated in greater detail and tested along with the shredding system at DONLEE Technologies' combustion test unit prior to installation at the Lebanon VA Facility.

This conceptual design of the material size reduction unit and AFBC are built as one unit so as to prevent contamination of the atmosphere. All doors and connections between individual components of the system are sealed. Disinfectant atomizers are positioned in both compartments "A" and "B" and also in the discharge chute. These atomizers emit a misting spray, chemical in nature, to sterilize the system prior to any access into the compartments for maintenance and/or any other reason access may be required. If the

TABLE 21

MATERIAL TEST SHREDDED AND EVALUATED

Aluminum Cans
Automobile Fuel Tanks
Bailed Cardboard
Beverage Cans
Bullet Proof Windows
Candy Bars
Carpet
Chairs
Chocolate
Cigarettes
Cigarette Cartons
Computers
Computer Chips
Computer Circuit Boards
Computer Paper
Couches
Disposable Diapers
Dryers
Electrical Components
Extruded Aluminum
Fiberglass
Fiber Drums
Fiber Optic Cable
Film
Food
General Plant Waste
HEPA Filters
Herculite
IV Bags
Leather
Metal
Metal Turnings
Mylar
Natural Rubber
Nuclear Fuel Rods
Off-Road Tires
Oversized Bulky Wastes
Paint Filters
Pallets
PET Bottles
Pharmaceuticals
Plastic
PVC Pipe
PVC Purgings
Railroad Ties
Rope
Sausage Wrappers
Shoes
Steel Drums
Tables
Telephone Books
Tires
Tire Bead Material
Tire Retread Material
Tree Stumps
Truck Tires
Toys
Washers
Wax
Weapons (Military)
Wire
Wood

shredder is operating while material is inserted through the double drop doors, then the disinfectant atomizer in compartment "A" should be programmed to run prior to the opening of the single door. This is another safety factor to prevent possible contamination of the waste processing area.

An optional item under consideration for installation in the material size reduction unit is a viewing window in the hopper and discharge chute. This is one way to monitor the system. Another method of monitoring is to install a video camera into the system. These two methods can readily identify any equipment malfunction.

Another optional item is the use of a "dumper", a device which automatically feeds the system. The waste is inserted into the "dumper" which then is mechanically raised and fed into the hopper.

Ash Or Residue Disposal

Within the present design configuration, the Donlee AFBC unit provides for removal of ash by gravity flow from beneath the combustor. Provisions will be made for cooling of the ash prior to transport to an interim storage area. Depending on the storage area's location and quantity of material, the ash removal and transport could be accomplished manually or automatically via a screw auger or conveyor system.

The operator of the facility which destroys infectious waste is required to monitor the waste residue to ensure that pathogens have been destroyed. The operator must submit a microbiological analysis of the ash residue to the Department of Environmental Resources at a minimum, quarterly during the life of the facility. The operator must submit a chemical analysis of the ash residue, at least annually during the life of the facility, to the Department of Environmental Resources. These analyses must be on forms provided by the Department.

Infectious waste will not be recognized as noninfectious after incineration unless the indicator spores have been destroyed as determined by a laboratory analysis.

Storage and containment of ash residue must be performed in a manner so as to prevent the release, dispersal, or discharge of ash residue into the air, water, or onto land. Storage must be in an enclosed container or area, which may include a sufficiently ventilated building and on a pad that is no more permeable than 1×10^{-7} centimeters per second.

Transportation of ash residue must be in an enclosed or covered vehicle that prevents the dispersal of the ash residue.

TASK 3 - BENCH-SCALE COMBUSTOR DESIGN

The DONLEE CFB technology has several distinct features which make it uniquely suited for destruction of hospital wastes. In the DONLEE CFB design, the excess heat generated during the combustion process is mainly extracted by heat exchangers installed in an adjacent fluidized bed. The combustion temperature in the main fluidized bed is controlled by changing the solids recirculation rate between the main and cooling fluidized beds. The existing DONLEE 10 mm BTU/hour CFB demonstration unit required design modifications prior to implementing the combustion testing program in Task 4. As originally designed, the pilot plant had the cooling surface in the combustion chamber itself rather than in an adjacent cooling bed. Removal of existing surface and design, manufacture, and installation of an adjacent cooling bed, together with its water circulation system represented a major modification to the pilot plant. In addition, instrumentation was installed to facilitate continuous monitoring of stack gases.

The method of operation of the DONLEE CFB design is as follows. The solids carried out from the main fluidized bed, after being captured by the hot cyclones, are recycled back into the main fluidized bed via a partitioned, sealed sluice adjacent to the main fluidized bed which provides a cooling effect. The allowable temperature difference between the fluidized bed and the combustor exit is controlled by maintaining the proper fluidized bed mean particle size and superficial gas velocity which provides a mean suspension density sufficient to sustain the required maximum allowable temperature difference desired for any given fuel. The temperature difference between the fluidized bed and combustor exit is minimized by the solids being recycled from the cooling bed and injected into the combustor's freeboard area at some distance above the fluidized bed level and below the combustor exit.

In the DONLEE CFB design, the excess heat generated during the combustion process is mainly extracted by heat exchangers installed in an adjacent fluidized bed. The combustion temperature in the main fluidized bed is controlled by changing the solids recirculation rate between the main and cooling fluidized beds.

In summary, the distinguishing features of the improved DONLEE CFB design (illustrated in Figure 10) are as follows:

- A major portion of the combustion air is introduced under the fluidized bed as the remaining part is injected into the bed (as fuel transporting air);
- The excess heat generated during combustion is mainly extracted by the heat exchangers installed in a cooling fluidized bed adjacent to the main bed;

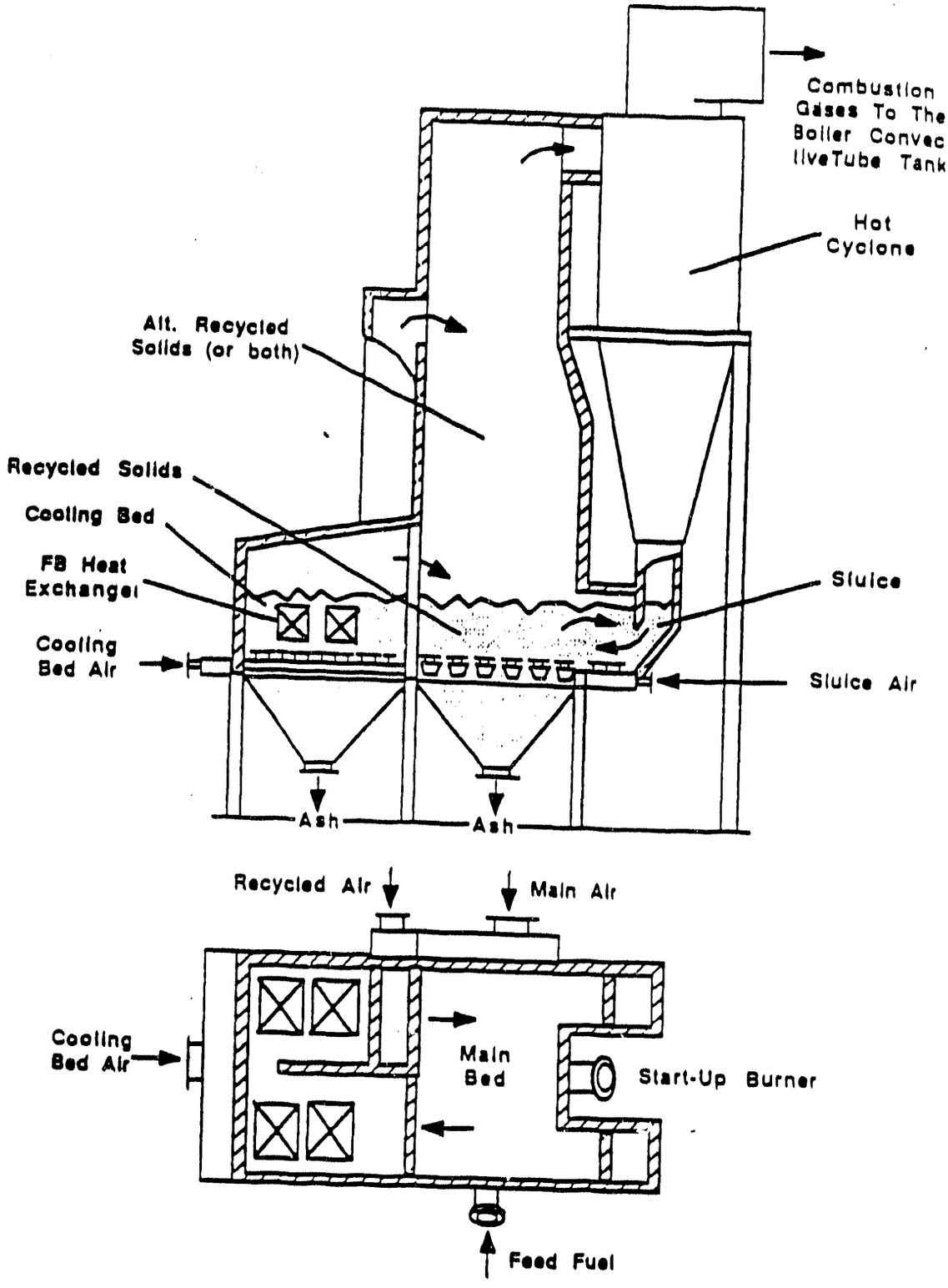


FIGURE 10

DONLEE TECHNOLOGIES' CIRCULATING FLUIDIZED BED COMBUSTOR (CFBC)

- The solids carried out of the main fluidized bed are recycled after being captured by hot cyclones into the main fluidized bed via a partitioned air sluice; and

- Good sulfur capture efficiency is maintained by controlling the temperature difference between combustor exit and fluidized bed through mean particle size and superficial velocity to sustain the necessary suspension density.

The final step in Task 3 was preparation of the detailed bench-scale test program. Initial tests were aimed at attaining stable operating conditions within the CFB unit. Subsequent testing consisted of evaluating emissions and combustion efficiencies using three different coals and various mixtures of surrogate waste materials. Details of the test program are provided with the evaluation of test results under Task 4.

TASK 4 - PILOT PLANT TESTING

Optimization Tests

It was decided that a series of test runs would be necessary, prior to testing for combustion of hospital waste, in order to optimize operation of the pilot plant and confirm its operating characteristics.

An Optimization Test Matrix was drawn up which comprised 22 separate test runs each of 2 hours duration (Table 22). This matrix was designed to examine the effects of:

- upper combustor velocity;
- combustor exit temperature;
- Ca/S molar ratio;
- excess air level;
- main bed pressure drop;
- main bed stoichiometric ratio; and
- load level.

The test matrix was used as a guide and was adhered to as closely as possible, bearing in mind that precise coal, limestone, and air flow measurements were not available at the time of the test (these were checked by later calculation from all test data). Also at this time, the combustor temperature was controlled manually (not automatically as for the

TABLE 22

OPTIMIZATION TEST MATRIX

(PREDICTED PERFORMANCE)

TEST OBJECTIVE		EXAMINE EFFECTS OF UPPER COMBUSTOR VELOCITY ON COMBUSTION			EXAMINE EFFECTS OF COMBUSTOR EXIT TEMPERATURE ON COMBUSTION			EXAMINE EFFECTS OF CA/S MOLAR RATIO ON SULFUR CAPTURE			EXAMINE EFFECT OF EXCESS AIR ON COMBUSTION EFFICIENCY			EXAMINE EFFECTS OF MAIN PRESSURE DROP ON PERFORMANCE			EXAMINE EFFECTS OF MAIN BED STOICHIOMETRIC RATIO ON PERFORMANCE			EXAMINE EFFECTS OF LOAD ON PERFORMANCE				TOTAL AMMOUNT CONSUMED
TEST RUN NUMBER		1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C	7D	LBS
TEST RUN DURATION	(HRS)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	–
	UNIT																							
Bituminous coal feed rate	pph	580	658	812	812	812	812	812	812	812	812	812	812	812	812	812	812	812	812	650	487	325	163	6372*
High ash coal feed rate	pph																							0
Anthracite coal feed rate	pph																							0
Limestone feed rate	pph	189	227	285	285	285	285	212	285	318	285	285	287	285	285	285	285	285	285	212	159	106	53	2074*
Ash extraction rate	pph	240	288	336	336	336	336	305	336	368	336	336	336	336	336	336	336	336	336	269	202	134	67	2330*
Surrogate Waste feed rate	pph																							0
PVC feed rate	pph																							0
Liquid feed rate	pph																							0
Water feed rate	pph																							0
Chemical A feed rate	pph																							0
Chemical B feed rate	pph																							0
Chemical C feed rate	pph																							0
Chemical D feed rate	pph																							0
Metal feed rate	pph																							0
Glass feed rate	pph																							0
Main bed air flow rate	pph	3950	4870	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5160	5760	6420	4500	3210	2540	2580	–
Sluice air flow rate	pph	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	–
Coal chute air flow rate	pph	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	–
Cooling bed air flow rate	pph	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	–
Lift channel air flow rate	pph	1480	1380	1220	1560	1320	1330	1340	1320	1330	1410	1320	1330	1320	1320	1330	1440	1320	1340	1420	1530	1640	1820	–
Secondary air flow rate	pph	838	1200	1770	1540	1770	1780	1740	1770	1780	900	1770	2560	1780	1770	1770	2280	1770	1130	824	482	250	258	–
Total air flow rate	pph	7310	8770	10200	10200	10200	10200	10200	10200	10200	9440	10200	11000	10200	10200	10200	10200	10200	10200	8180	6580	5870	5710	–
Combustor exit temperature	°F	1800	1800	1800	1550	1800	1700	1800	1800	1300	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1310	820	–
Main bed temperature	°F	1450	1540	1570	1480	1570	1710	1570	1570	1550	1530	1570	1580	1570	1570	1570	1480	1570	1800	1550	1500	1800	1800	–
Lift channel temperature	°F	880	720	880	1170	880	800	1010	880	880	1130	880	880	880	880	880	1070	880	870	710	430	280	250	–
Main bed pressure drop	IN.W.C	24	24	24	24	24	24	24	24	24	24	24	24	22	24	26	24	24	24	24	24	24	24	–
Excess air	%	30	30	30	30	30	30	30	30	30	20	30	40	30	30	30	30	30	30	30	30	60	282	–
Ca/S Molar Ratio		2.5	2.5	2.5	2.5	2.5	2.5	2	2.5	3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–
Combustor velocity	F/S	10	12	14	13.8	14	14.7	14	14	14	13	14	15	14	14	14	14	14	14	11.2	9	6.7	3.7	–
Main bed stoichiometric	ratio	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.74	0.82	0.9	0.82	0.82	1.02	1.08	–

* Total amounts of coal, limestone and ash reflect firing with 2 hours between tests or double the material from the 2-hour tests.

surrogate waste tests). The coal used was obtained locally in Pennsylvania and its analysis is given in Table 23. It had both a high fines and moisture content which rendered it less than an ideal one for reliable feeding by the existing pilot plant feed system, and some interruptions to the test program were encountered. Nevertheless a total of 56 useful data points was obtained. Gas analyzers continuously monitored O_2, CO, CO_2, SO_2 and NO_x throughout the testing.

TABLE 23: HOFFLINGHOUSE COAL ANALYSIS

Carbon	59.50%
Hydrogen	4.04%
Oxygen	6.92%
Nitrogen	1.41%
Sulfur	1.83%
Ash	15.95%
Moisture	10.35%
Higher heating value	10,770 Btu/lb

Optimization of limestone selection was outside the scope of the Phase 1 project and a readily available local limestone was purchased. The analysis of this limestone is given in Table 24.

TABLE 24: THOMASVILLE LIMESTONE ANALYSIS

Calcium Carbonate	80.7%
Magnesium Carbonate	9.9%
Inerts	9.4%

Analysis of all ash samples for organic carbon content has not yet been fully completed, but inspection of Loss on Ignition (LOI) values for the ash samples indicates that combustion efficiency is not sensitive to upper combustor velocity. Test data values ranged from 10 to 13.5 ft/s.

If there is no calcium carbonate in the ash, then the Loss on Ignition is the result of residual carbon being burned. Hence, the combustion efficiency can be determined directly. If there is a small amount of calcium carbonate present in the ash, however, as is the case, then there is a further loss of mass by the thermal evaluation of carbon dioxide. In this

instance, the LOI values are only indicative of combustion efficiency, and are not accurate measurements.

As expected, however, there was a positive trend for increased combustion efficiency with increased combustor operating temperature, as demonstrated by the data reduction using the ash analyses completed. It was decided to use a nominal combustor operating temperature of 1600°F for the surrogate waste tests. This is at the high end of the range typically used in other CFB systems burning bituminous coal, and provides a reasonable trade-off between combustion efficiency and sulfur capture. This temperature is also higher than that predicted for optimum chlorine capture and it was felt that this would provide a realistically conservative test for the basic concept of chlorine reaction with limestone.

NO_x emissions were also investigated with respect to combustor operating temperature and, again, as expected, there was a positive trend of increasing NO_x with increasing temperature. Typically, however, at 1600°F, NO_x levels of 150 ppm (0.2 lb/10^6 Btu) or less were achieved.

In the excess air level range of 25% to 45%, as was maintained for the majority of tests, the combustion efficiency appeared to be insensitive to excess air. Again, this observation was based on ash LOI values.

It was felt that the bed material inventory in the combustor, as indicated by the main bed pressure drop, may have an effect on the combustion system performance. This proved to not be the case for main bed pressure drop values in the range of 20 to 30 inches W.G.

The stoichiometric ratio in the main bed was also investigated as a variable. The stoichiometric ratio is defined as the amount of air actually supplied to the bed divided by the theoretical amount of air required for stoichiometric combustion of the fuel. It was found that there was a trend for increasing ash LOI with reducing stoichiometric ratio. The opposite effect was found with NO_x emissions, as stoichiometric ratio reduced, so did NO_x emissions. Since NO_x emissions were generally at low levels, it was felt that a good compromise on combustion efficiency would be obtained by operating at a main bed stoichiometric ratio of 1:1.

It must be remembered that during these tests, operating parameters were intentionally varied to examine the effects on combustion efficiency. Combustion efficiencies for 7 of the tests, with completed ash carbon analyses, ranged from 90% to over 99%. The 90% combustion efficiency on one test resulted partly from a relatively lower average combustor temperature of 1520°F. The remaining 6 tests had combustion efficiencies ranging from 97% to over 99%. For about 60% of the tests, carbon analyses on the ash have not been completed at this time, and thus, their combustion efficiencies are not included in this

discussion. Another indication of good combustion efficiency, however, was that 50% of the data points showed CO emissions less than 120 ppm with the majority being less than 200 ppm.

In the case of sulfur capture, the two very well established main variables which have been considered are Ca/S molar ratio and temperature. It should be remembered; however, that some of the other variables may well have secondary effects on sulfur capture. For results with the relatively narrow temperature range of 1600° ± 15°F, 85% sulfur removal with a Ca/S molar ratio of 3:1 was achieved. It is recognized that this Ca/S ratio is somewhat higher than that which typically is claimed in CFB combustion systems and likely reasons for this are given below.

a. The limestone selected was readily available from a local source at Thomasville. Work done at Penn State University indicates that this is not a very reactive limestone.

b. Out of concern with respect to solids transport within the system, a fine particle limestone was selected. The mean particle size was 140 microns and it is believed that an appreciable amount escaped the system before it could react. This is borne out by preliminary flyash analyses which show the unburnt carbon quantity to be about half the total LOI quantity. Presumably the remaining LOI is due to CO_2 driven off from unreacted $CaCO_3$. The concern about solids transport was in fact unwarranted and a larger limestone particle size could be used.

c. The flue gas residence time in the combustor for the majority of results was less than 1 second. A commercial unit would be designed for a residence time of 1.5 seconds. Two data points showed a sulfur capture of greater than 95% with a Ca/S molar ratio of about 2.5:1. Both of these were at about 1570°F and within the excess air range of all the results (i.e., about 25 to 45%). The main difference between these and other results is that they were obtained at a part-load condition which resulted in a gas residence time of about 1.5 seconds.

Mean combustor temperatures greater than 1615°F gave appreciably lower sulfur capture figures. From the results obtained, it can be stated that, on average, mean combustor temperatures less than 1585°F give higher sulfur capture figures, but there may be other reasons for this as previously discussed.

TABLE 25

SURROGATE WASTE TEST MATRIX

(PREDICTED PERFORMANCE)

TEST OBJECTIVE		DETERMINE OPTIMUM OPERATING TEMP. FROM SURROGATE DESTRUCTION, EMISSIONS & COMBUSTION STANDPOINTS				EXAMINE EFFECTS OF DIFFERENT SURROGATE FEED RATES TO PROVIDE A DATA BASE							EXAMINE EFFECTS OF CHLORINE COMPOUNDS ON STACK AND ASH EMISSIONS				EXAMINE EFFECTS OF FEEDING METAL AND GLASS			INVESTIGATE WITH HIGH ASH COAL		DETERMINE OPTIMUM TEMP. FOR ANTHRACITE OPERATION AND INVESTIGATE SURROGATE DESTRUCTION					TOTAL QUANTITIES LBS
TEST RUN NUMBER		8 (a)		8 (b)		9 (a)		9 (b)		9 (c)		10 (a)		10 (b)		11 (a)		11 (b)		12		13 (a)		13 (b)		
TEST RUN DURATION (HRS)		40	8	16	8	16	8	16	8	16	8	16	8	16	8	12	12	12	12	24	8	8	8	8	8	8	
	UNIT																										
Bituminous coal feed rate	pph	812	812	812	812	812	812	812	812	812	812	812	812	812	812	812	812	812	812								19480
High ash coal feed rate	pph																			952	952						28544
Anthracite coal feed rate	pph																					803	803	803	803	803	25696
Limestone feed rate	pph	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	285	40	40	40	40	40	7350
Ash extraction rate	pph	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	443	443	98	98	98	98	98	6788
Surrogate Waste feed rate	pph		100		100		50		100		150		50		150		114		114		150					150	10758
PVC feed rate	pph		60		60		30		60		60		30		60		48		48		60					60	6552
Liquid feed rate	pph		40		40		20		40		60		20		60		48		48		60					60	4504
Water feed rate	pph		40		40		20		40		60		18		48		48		48		60					60	4176
Chemical A feed rate	pph												1.3		3.9												42
Chemical B feed rate	pph												0.8		2.4												26
Chemical C feed rate	pph												0.8		2.4												26
Chemical D feed rate	pph												1.1		3.3												36
Metal feed rate	pph																10		10								240
Glass feed rate	pph																10		10								240
Main bed air flow rate	pph	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	5760	–
Sluice air flow rate	pph	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	–
Coal chute air flow rate	pph	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	–
Cooling bed air flow rate	pph	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	680	–
Lift channel air flow rate	pph	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	1320	–
Secondary air flow rate	pph	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	1770	–
Total air flow rate	pph	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	10200	–
Combustor exit temperature	°F	From Test 2	From Test 2	Test 2 + 70°F	Test 2 + 70°F	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	From Test 8	Test 8 + 40°F	Test 8 + 80°F	Test 8 + 120°F	Test 13(a)	Test 13(a)	–
Main bed pressure drop	IN.W.C.	FROM TEST 5																									
Excess air	%	FROM TEST 4																									
Ca/S Molar Ratio		FROM TEST 3																									
Combustor velocity	Ft/S	FROM TEST 1																									
Main bed stoichiometric	ratio	FROM TEST 6																									
Flue gas & ash sampling and analysis required		–	yes	–	yes	–	yes	–	yes	–	yes	–	yes	–	yes	–	–	–	yes	–	yes	–	–	–	–	yes	

Finally, as far as the optimization tests were concerned, part load runs were conducted. This exercise showed that stable operation could be maintained with a fuel heat input of 20% that of full load operation (i.e., 5:1 turndown ratio).

Surrogate Waste Tests

The surrogate waste test matrix (see Table 25) was designed to simulate, as closely as possible, actual operation of a full scale unit. At the start of tests, there was an extended period of operation, without feeding surrogate waste, in order to get the bed as close to equilibrium composition as possible. Following this, the unit was operated continuously and surrogate waste fed in for 8 hour periods. This was to simulate hospital waste only being fed into a full scale unit during the day shift.

It was determined that, with the exception of Tests 10 and 11, the basic surrogate waste would simply be 60% PVC/40% water by weight. This was to be fed in discrete 12-1/2 lb slugs to represent a worst possible situation of passing a 50 lb bag of infectious waste almost instantaneously into the shredder. The composition of an actual infectious waste, based on survey information from the Lebanon VA hospital, was taken as:

- 20% plastics;
- 60% paper;
- 10% liquid; and
- 10% metal and glass.

In the absence of good information, it was conservatively assumed that 75% of the plastics would be PVC. Thus, for a 50 lb bag, the PVC weight would be 50 x 0.2 x 0.75 = 7.5 lb. Assuming that practically all the liquid is water, the water weight would be 50 x 0.1 = 5 lb. Hence, the chosen slug feed size of 7.5 + 5 = 12.5 lb.

Tests 8(a) and 8(b) were designed to investigate the effects of two different operating temperatures based on a PVC feed rate of 60 lb/h (i.e., an equivalent infectious waste feed rate of 400 lb/h based on the above composition). It was noted from surveys at other hospitals that the plastics content of infectious waste could be as high as 40%, so halving the equivalent feed rate to possibly 200 lb/h. Thus, the approach taken was felt to be conservative, providing a strenuous test for the basic project concepts.

During Test 8(a), as each slug of PVC/water was fed into the combustor, it was observed that SO_2 and CO emissions had a short time duration "spike", but bed temperatures

only dropped about 10°F. Of more concern however, as each slug was fed, there was a puff of smoke out of the stack.

At first it was thought that almost instantaneous evaporation of the water was causing the problem and so slugs of dry PVC were then fed in. The same thing happened and it became apparent that rapid devolatilization and combustion of the PVC was the culprit. Having demonstrated that the water did not have a significant effect on the combustion process, it was decided that, for all subsequent tests, the dry PVC would be mixed with the limestone and fed continuously. This experience demonstrated that the waste handling system conceptualized in Task 2 would have to be modified by incorporation of a feed regulating device (either a ram or screw feeder) between the shredder and combustor.

Tests 9(a), 9(b), and 9(c) were designed to investigate the effects of different waste feed rates. Nominal PVC feed rates of 30, 60, and 90 lb/h were chosen.

Tests 10(a) and 10(b) were designed to investigate the effects of the surrogate chlorine-containing chemicals selected in Task 1. It was determined by Pennsylvania State University that the 5 types of molecular structure represented by the chosen chemicals were likely to occur in the following approximate proportions:

A - 2-Chloroethyl Benzene	0.3;
B - Benzyltriethylammonium Chloride	0.1875;
C - 2-Chlorobenzoic Acid	0.1875;
D - Potassium Chloride	0.25; and
E - 1-Chloro-2-Methylpropene	0.075.

Since chemical E is a suspected carcinogen, and represents the smallest proportion of the total chemicals, it was decided not to use it and the proportions of the other chemicals were adjusted to:

A - 2-Chloroethyl Benzene	0.33
B - Benzyltriethylammonium Chloride	0.2
C - 2-Chlorobenzoic Acid	0.2
D - Potassium Chloride	0.27

It was assumed, again conservatively, that of the total liquid in an infectious waste, 80% would be water and 20% would be chemicals. It was originally intended to run tests 10(a) and 10(b) with two different PVC (and chemical feed rates), but because of the practical difficulties associated with continuously feeding the chemicals into the combustor, it was

decided to use an average PVC feed rate for test 10(b) (60 lb/h) and to feed in all the available chemicals to ensure their disposal (A - 1.4 lb/h, B - 0.8 lb/h, C - 1.1 lb/h, D - 1.4 lb/h). Test 10(a) was then run as a baseline test without any PVC or chemical feed.

The likelihood of glass and metal (bottles, sharps, etc) in actual infectious wastes is an important concern. Tests 11(a) and 11(b) were designed to simply feed metal shavings at 10 lb/h and broken glass at 10 lb/h for 2 consecutive days in order to examine the possible effects on the combustion system. The glass did not cause any bed material agglomeration and most of it, together with the metal, was accumulated as discrete particles at the bottom of the bed without any noticeable affect on fluidization. This implies that, in a full scale unit, metal and glass can be periodically removed from the combustion system by operating the combustor solids drain at a probable frequency of once per day.

Tests 8, 9, 10, and 11 were conducted with a Pennsylvania bituminous coal with a sulfur content of 1.62%. The coal ultimate analysis is given on Table 26. The limestone used for all surrogate waste tests was the same as that used for the optimization tests (see Table 24).

TABLE 26: SURROGATE WASTE TEST COALS

	BITUMINOUS COAL (%)	HIGH ASH BITUMINOUS (%)	ANTHRACITE (%)
Carbon	75.29	71.95	77.56
Hydrogen	4.26	4.10	1.68
Oxygen	2.29	1.87	0.70
Nitrogen	1.20	1.17	0.80
Sulfur	1.62	3.59	0.60
Ash	10.91	13.59	13.57
Moisture	4.42	3.72	5.01
HHV (Btu/lb)	13514	12999	12730

Test 12 was essentially a repeat of Test 9(c) but using a high ash Pennsylvania bituminous coal. The term "high ash" is used as a means of distinction as the actual ash content was 13.59% (see Table 26). What is probably of more significance is that the sulfur content is 3.59%.

Test 13(a) was with a Pennsylvania anthracite (see Table 26) and its purpose was to establish the most appropriate combustor operating temperature. The combustion characteristics of anthracite are significantly different from those of bituminous coal. Having

established the operating temperature, Test 13(b) was again essentially a repeat of Test 9(c) but using anthracite as the main fuel.

For the surrogate waste tests, in addition to continuous O_2, CO_2, SO_2, NO_x and CO emissions monitoring, stack flue gas samples were taken to be analyzed for dioxins and furans, HCl and hydrocarbons. Ash samples from each test run were screened for dioxins and furans content. Assessment of the HCl emissions results, however, show that while there is a good deal of variation due to the different operating conditions for the tests, typically chlorine capture in excess of 50% can be achieved. The overall test average chlorine capture was 51%, ranging from 7% to 77%. Specific trends related to operating temperature, surrogate feed rate, or type of coal, could not be identified, however.

Analysis of Surrogate Waste Test Results

Test 8(a) will not be considered in any further discussions. Due to the feeding of the PVC in slugs during this test, high emissions resulted for dioxins/furans and polyaromatic hydrocarbons. These emissions, however, are not representative of the later tests where the PVC was fed on a continuous basis and where the emissions were much lower and well within any guidelines.

Gas emissions were monitored continuously for O_2, CO, CO_2, SO_2, and NO_x. Stack flue gas samples were collected to be analyzed for dioxins/furans, HCl, and hydrocarbons. The dioxin/furan and polyaromatic hydrocarbons samples were collected via modified EPA Method 5 tests. The HCl tests were run before and after each modified EPA Method 5 test. All sampling and analytical procedures were performed according to established EPA test methods or test methods that are required by PA DER (Energy Systems Associates, July, 1990).

Table 27 gives the ranges of the various emissions during these tests. The SO_2 emissions met the New Source Performance Standards (NSPS) for Small Boilers (U.S. Environmental Protection Agency, 1989) in all tests. The bituminous coal tests had sulfur dioxide emissions of 0.34 to 1.13 lb/106 Btu. The high ash bituminous coal sulfur dioxide emissions were only 0.11 lb/106 Btu with a sulfur capture of over 97%. The two anthracite coal tests had sulfur emissions of 0.40 and 0.25 lb/106 Btu. These results, although acceptable, are not as good as they otherwise may have been due to the low residence time in the unit and the poor reactivity of the limestone, demonstrated by the carbonate that remained in the ash. The high carbonate in the ash indicates that the limestone is not fully calcined in the unit, and can only be partially utilized.

A general increasing/decreasing trend in the sulfur dioxide emissions was noted for increasing/decreasing the molar calcium-to-sulfur ratio. However, no general trend of increasing/decreasing sulfur dioxide emissions could be discerned for decreasing/increasing the combustor temperature from 1600°F. This again is probably due to the low reactivity of the limestone and the short residence time in the unit.

The NO_x emissions all meet the NSPS regulations (U.S. Environmental Protection Agency, 1989). The emissions for the bituminous coal tests ranged from 0.20 to 0.38 lb/106 Btu. The high ash bituminous coal test had emissions of 0.56 lb/106 Btu, the highest value. The anthracite coal test emissions were 0.28 and 0.25 lb/106 Btu. A general trend of increasing NO_x emissions with increasing combustor temperature was noted for all of the tests, as expected.

The CO emissions ranged from 59 - 195 ppmv at 7% O_2. Note that the incinerator guideline for the equivalent waste feed rates is 100 ppmv at 7% O_2 in Pennsylvania (Pennsylvania Department of Environmental Resources, Bureau of Air Quality, 1989). Three of the 9 bituminous coal tests emitted less than 100 ppmv at 7% O_2. The high ash bituminous coal test had the highest concentration of CO of 195 ppmv at 7% O_2. The two anthracite tests had concentrations of CO of 59 and 118 ppmv at 7% O_2.

TABLE 27
EMISSIONS LEVELS VERSUS REGULATIONS

POLLUTANT	—RANGE OF EMISSION LEVEL— (ppmv)[a]	(lb/106 Btu)	REGULATION
SO_2			1.2 lb/106 Btu [b]
High	414	1.13	
Low	35	0.11	
Average	238	0.63	
NO_x			1.0 lb/106 Btu [b]
High	242	0.56	
Low	100	0.20	
Average	149	0.29	
CO			100 ppmv @ 7% O_2 [c]
High	195	-----	
Low	59		
Average	112		
Total suspended Particulates	No Data Collected	No Data Collected	0.03 gr/DSCF @ 7% O_2 [c]

TABLE 27
(CONTINUED)

POLLUTANT	---RANGE OF EMISSION LEVEL--- (ppmv)[a]	(lb/106 Btu)	REGULATION
HCl			30 ppmv @ O_2 or 90% capture [c]
High	2867	----	
Low	113		
Average	1153		
PAH[d]			No Definite Regulation [e]
High	4.05×10^{-3}	----	
Low	1.17×10^{-4}		
Ave.	1.58×10^{-3}		
Dioxins/Furans as EPA TOXIC EQUIVALENTS of 2, 3, 7 8 - TCDD			0.15 ng/ Nm^3 @ 7% O_2 [f] and 10 ng/kg of Waste Feed [g]
High	0.078 ng/Nm^3 @ 7% O_2	1.51 ng/Kg of Waste	
Low	0.025 ng/Nm^3 @ 7% O_2	0.37 ng/Kg of Waste	
Ave.	0.045 ng/Nm^3 @ 7% O_2	0.79 ng/Kg of Waste	
Total PCDD/ PCDF			No Definite Regulations in Pennsylvania
High	2.48 ng/Nm^3 @ 7% O_2	----	
Low	0.78 ng/Nm^3 @ 7% O_2		
Ave.	1.51 ng/Nm^3 @ 7% O_2		

Notes for Table 27:

[a]Part-per-Million on a volume, wet basis
[b]New Source Performance Standards (NSPS) for Boilers with smaller than 100×10^6 Btu/hr heat input (U.S. Environmental Protection Agency, 1989)
[c]Incinerator guideline for Pennsylvania for 300 to 2000 lb/hr feedrate (Pennsylvania Department of Environmental Resources, Bureau of Air Quality, August, 1988)
[d]Polyaromatic hydrocarbons
[e]No definite regulation of levels of the PAH are specifically listed (Energy Systems Associates, August 20, 1990)
[f]0.15 ng/Nm^3 @ 7% O2 corresponds to the concentration of dioxins/furans from the Hershey Medical Center (Bureau of Air Quality, PA DER, August, 1990), and results in an ambient concentration of less than 0.30×10^{-7} ng/Nm^3 (PA DER, Bureau of Air Quality, August, 1989), as required.

TABLE 27
(CONTINUED)

[g]10 ng/Kg of Waste Feed or 99% reduction in dioxin emissions is the proposed regulation for Hospital Waste incinerators in California.
Dioxins here refers to total dioxins/furans expressed in EPA Toxic Equivalents (State of California Air Resources Board Stationary Source Division, May 25, 1990).

Total suspended particulates were not measured during these tests. However, the emission limit of 0.03 gr/DSCF is one which has been well demonstrated as being achievable by a suitably designed bag filter as part of a CFB combustion and steam generation system.

The range of hydrogen chloride (HCl) emissions is given in Table 27. As can be seen, none of the emissions meet the PA DER requirement of 30 ppmv at 7% O_2 (PA DER Bureau of Air Quality, August, 1989). However, Table 28 shows that the emissions concentrations agree fairly well with uncontrolled or baghouse-only systems. Also note that, to meet the PA DER requirement, a scrubber system would be required, and that PA DER does indeed require a scrubber system for a hospital waste incinerator. The combustor planned in the next phase of the project will have a scrubber system to handle the HCL emissions.

The polyaromatic hydrocarbons (PAHs) for the tests ranged from 1.17×10^{-4} to 4.05×10^{-3} ppmv at 7% O_2. All of the tests had emission concentrations less than or equal to 4.05×10^{-3} ppmv (or 4.05 ppb).

The dioxins and furans, expressed as total PCDD (polychlorinated dioxins) and PCDF (polychlorinated furans) as EPA Toxic Equivalents in ng/Nm^3, ranged from 0.025 to 0.078 ng/Nm^3 at 7% O_2. The Hershey Medical Center incinerator typically has an emissions concentration of 0.15 ng/Nm3 (Bureau of Air Quality, PA DER, August, 1990), and the results meet the PA DER required ambient annual concentration of 0.30×10^{-7} ng/Nm^3 (PA DER Bureau of Air Quality, August, 1989). Thus, all of the tests would meet the same criteria. Note that the emissions are roughly half, or less, (with the lowest being 0.025 ng/Nm^3) than those at Hershey Medical Center. The newly proposed control measure for dioxins and furans from hospital waste incinerators in California is 99% reduction in dioxins or an emission limit of 10 ng of dioxins/Kg of waste fed (State of California Air Resources Board Stationary Source Division, May 25, 1990). Here dioxins refer to total dioxins/furans expressed as EPA Toxic Equivalents. On this basis, our emissions are equivalent to 0.37 to 1.51 ng/Kg of waste. All tests have emissions that are nearly an order of magnitude lower

than the California control measure. Two values are greater than 1.0 ng/Kg at 1.34 and 1.51 ng/Kg. The average emission limit was 0.79 ng/Kg of waste ranging from 0.37 to 1.51 ng/Kg of waste. In general, the dioxin/furan emission decreases as the combustion efficiency increases. Referring to Table 29, one notes that the total PCDD/PCDF emissions from the test work (See Table 27) are several orders of magnitude lower than those from hospital waste incinerators.

TABLE 28: DATA/FACTORS FOR HYDROGEN CHLORIDE EMISSIONS FROM HOSPITAL WASTE INCINERATORS (RADIAN CORPORATION, DECEMBER, 1988)

HOSPITAL	ADD-ON CONTROL DEVICE/ HEAT RECOVERY	INCINERATOR FEED RATE (LB/HR)	HCL CONCENTRATION (PPMV)	EMISSION FACTOR (LB/TON FEED)
Cedar Sinai	Fabric filter/Yes	980		
High			521.0	16.3
Low			403.0	12.7
Average			462.0	14.5
St Agnes	None	783		
High			926.0	15.5
Low			764.0	12.0
Average				
845.013.7				
Royal Jubilee	None	1,930		
High			1,520.0	18.2
Low			983.0	14.8
Average			1,252.0	16.5
Illinois Unit	None	500-800		
High			1,490.0	10.6
Low			170.0	6.6
Average			550.0	8.6
Queen of the Valley	NR			
High		412	445	8.7
Low		374	282	6.4
Average		396	341	7.2
Swedish-American	NR			
High		175	174	12.0
Low		172	172	12.9
Average		174	173	12.5
University of Michigan NR				
High		1,493	928	45.4
Low			644	31.1
Average			788	37.8
Athabasca	None	85	41.0	14.0
Misericordia	None	740	670.0	13.6
Misercordia	None	740	687.3	13.0
Royal Alex	None/Yes	1,160	553.0	17.4
Royal Alex	None/Yes	1,200	562.0	15.4
Foothills	None	2,500	702.0	15.0

TABLE 28
(CONTINUED)

HOSPITAL	ADD-ON CONTROL DEVICE/ HEAT RECOVERY	INCINERATOR FEED RATE (LB/HR)	HCL CONCENTRATION (PPMV)	EMISSION FACTOR (LB/TON FEED)
Lethbridge General	Wet Scrubber/Yes	1,060	44.6	1.2
University of Alberta	Wet Scrubber/Yes	1,400	64.7	0.1
University of Alberta	Wet Scrubber/Yes	1,400	25.4	0.9
Bonnyville	None	130	62.2	3.4
Willingdon	None	130	308.0	5.0
Lacombe	None	150	234.5	3.0
Ft. McMurray	None	265	700.0	10.0
Ontario Hospitals	None	408	NR	17.4
St. Michaels	None	465	2,[illegible]95.0	20.5
Queen Elizabeth II	None	575	115.0	4.6
Queen Elizabeth II	None	700	287.0	3.9
Queen Elizabeth II	None	700	378.0	5.2
Red Deer	None/Yes	185	726.0	59.8

TABLE 29: CHLORINATED DIBENZO-P-DIOXINS/DIBENZOFURANS EMISSIONS FROM HOSPITAL WASTE INCINERATORS (RADIAN CORPORATION, DECEMBER, 1988)

	CEDAR SINAI MEDICAL CENTER LOS ANGELES, CA		ST. AGNES MEDICAL CENTER FRESNO, CA	ROYAL JUBILEE HOSPITAL VICTORIA, B.C.
	FABRIC FILTER (ng/Nm^3)	UNCONTROLLED (ng/Nm^3)	UNCONTROLLED (ng/Nm^3)	UNCONTROLLED (ng/Nm^3)
Total PCDD				
High	130.0	259.0	450.0	83.5
Low	129.0	163.0	290.0	51.8
Average	129.5	210.3	370.0	68.9
Total PCDF				
High	435.0	695.0	785.0	196.5
Low	106.0	441.0	704.0	117.3
Average	270.5	570.7	744.5	155.6
Total PCDD/PCDF				
High	565.0	954.0	1235.0	280.0
Low	235.0	604.0	994.0	169.1
Average	400.0	781.0	1114.5	224.5

The ash sample screening showed that the dioxins and furans content of the ash samples was less than 200 ng/kg. A composite ash sample was made from the individual samples from all the surrogate waste test runs and this composite was analyzed to meet the requirements of the Pennsylvania Department of Environmental Resources (PA DER) Form 41 for disposal of incinerator ash. This analysis included EP Toxicity tests. See Table 30 for the results. The results of the Form 41 analysis show that the ash from the surrogate waste testing can be disposed of in a sanitary landfill. Recent changes in the ash disposal requirements in Pennsylvania have resulted in the ashes generated during this test program (both Optimization and Surrogate Waste Tests) being required to be resampled and reanalyzed prior to disposal in a landfill. The analyses to be performed on the composite sample are TCLP (Toxicity Characteristic Leaching Procedure) and Module 1 Analyses.

Recent research into the composition of infectious hospital waste now indicates that the PVC content is unlikely to exceed 10% of the total waste. This means that, based on the reference PVC feed rate of 60 lb/hr for the surrogate tests, and from an emissions standpoint, the equivalent infectious waste feed rate was 600 lb/h. Assuming a typical infectious waste heating value of 8500 Btu/lb, the surrogate feed rate used was about 5 times greater than the original concept of 10% waste/90% coal.

Consideration of the tests, and the results to date, provides a high level of confidence that the proposed techniques for waste disposal in a proof-of-concept plant will be successful.

TABLE 30: EP TOXICITY TEST DATA FOR COMPOSITE SAMPLE FROM SURROGATE WASTE TESTS

METAL	LEACHATE CONCENTRATION (mg/L)	MAXIMUM ALLOWED CONCENTRATIONS (mg/L)
Arsenic	<0.1	5.0
Barium	0.76	100.0
Cadmium	<0.01	1.0
Chromium	0.02	5.0
Lead	<0.1	5.0
Mercury	<0.1	0.2
Selenium	<0.1	1.0
Silver	<0.01	5.0

TASK 5 - CONCEPTUAL DESIGN COST ESTIMATES FOR A FULL SCALE, PROOF OF CONCEPT FACILITY

A conceptual design and cost estimate were completed for a full scale hospital waste disposal facility. The selected site for this analysis was the Lebanon VA Hospital in Lebanon, Pennsylvania. There is sufficient space adjacent to the existing boiler house to install the unit and accessory facilities at the Lebanon VA Hospital. This conceptual CFB unit was specified to produce 12,000 lb./hr. of steam from a total heat input (coal plus waste) of about 15 mm BTU/hr. This size was established based on a four to one summer turndown to attain a 3,000 lb./hr. low steam usage level. As a design basis, it was assumed that this unit would destroy 10,000 lb./week of total waste from the Lebanon VA with about 15% of this waste being infectious. In addition, this combustor would be used to destroy about 300 lb./week of infectious waste from the Good Samaritan Hospital also located in Lebanon. The total waste feed rate for this incinerator will be approximately 5% of the total feed to the unit (coal plus waste).

Figure 11 depicts the conceptual layout of the CFB building and associated materials handling facilities. As planned, the system can be located in the immediate vicinity of the Lebanon VA Hospital's existing boiler house without interfering with utility lines. The CFB unit will be contained in a pre-engineered building with rolling steel doors. This construction is consistent with a recently constructed building in the same area.

Coal will be received by truck and dumped into a below ground 5-ton hopper with a grizzly. The dump area will be partially enclosed to prevent dust problems. Coal will be transported from the hopper by bucket elevator to coal storage silo. Storage capacity will be provided to ensure at least one week's supply, approximately 90 tons. A 50-ton limestone silo will provide roughly two weeks of supply. The silo will be equipped with a dust collector. Each coal silo and the limestone silo will feed material to a three-ton surge hopper equipped with a screw feeder.

Bottom and fly ash will be collected in receiving bins equipped with water cooling capability. The ash will be removed by drag conveyors and transported to storage bins. Once the ash has been sampled and test results received, the approved material will be transported to an approved landfill by the coal trucks.

Figure 12 shows a plan view of the CFB layout including a top view and floor elevation. Cross-sectional drawings A-A and B-B are presented in Figure 13. Dust collection will be accomplished using baghouse filters. Continuous monitoring equipment will be installed for stack gases. Provisions have been made for purchase of a scrubber to help ensure that

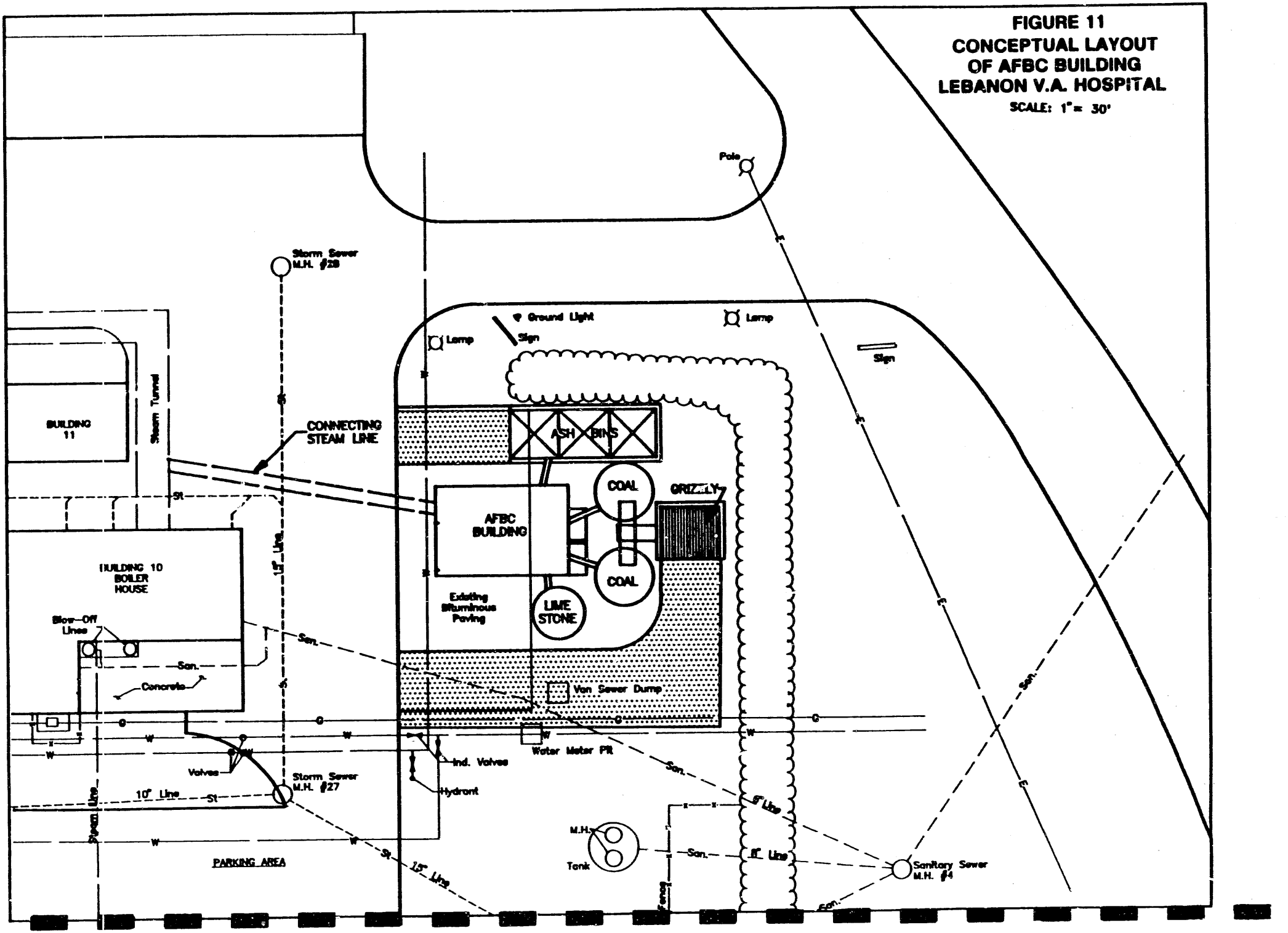
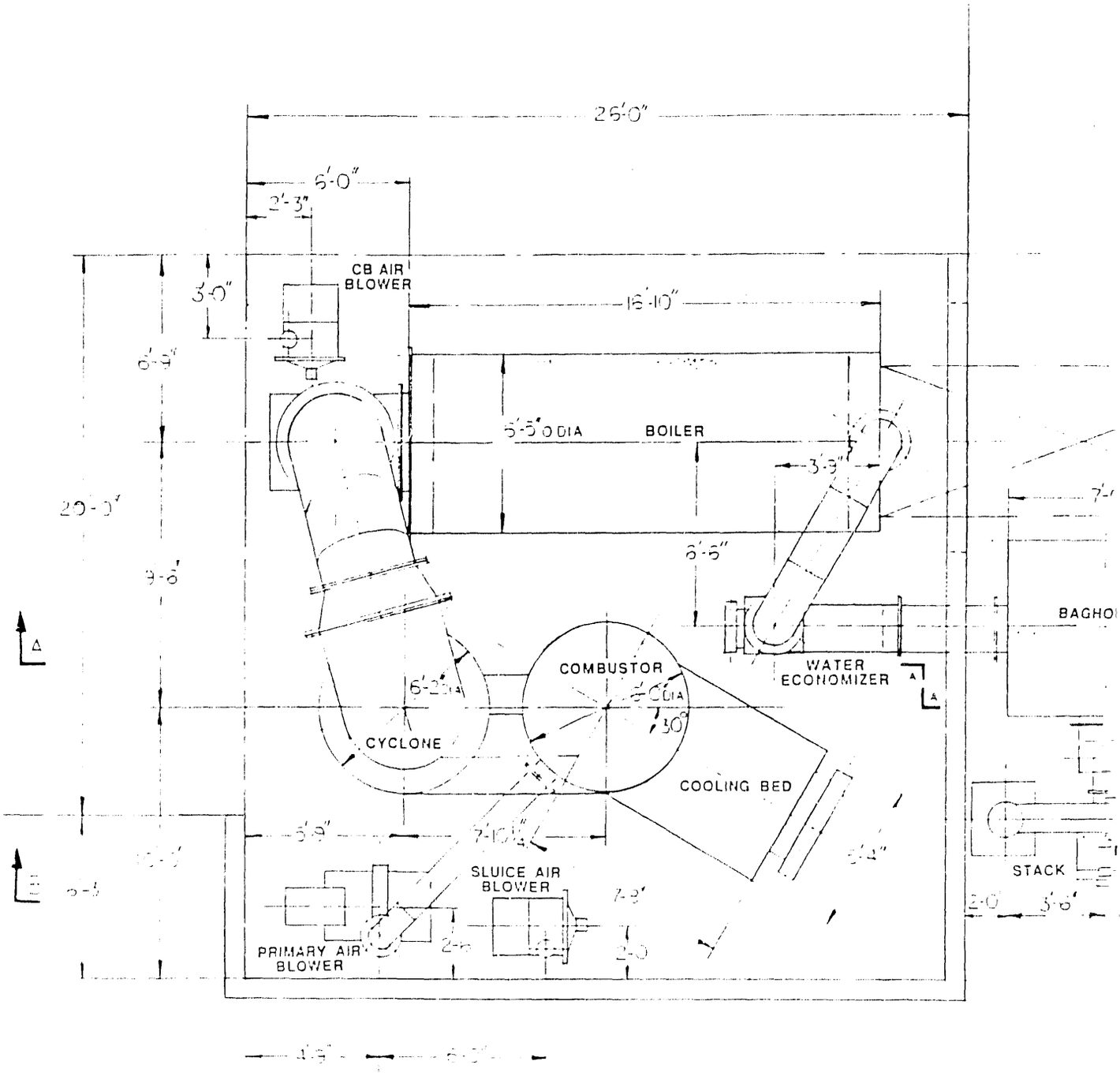


FIGURE 11
CONCEPTUAL LAYOUT
OF AFBC BUILDING
LEBANON V.A. HOSPITAL
SCALE: 1" = 30'
Pole
Storm Sewer
M.H. #28
Ground Light
Lamp
Sign
Lamp
Sign
BUILDING
11
Steam Tunnel
CONNECTING
STEAM LINE
ASH BINS
COAL
GRIZZLY
AFBC
BUILDING
COAL
LIME
STONE
Existing
Bituminous
Paving
BUILDING 10
BOILER
HOUSE
Blow-Off
Lines
San.
Concrete
Von Sewer Dump
Water Meter Pit
Ind. Valves
Hydrant
Valves
Storm Sewer
M.H. #27
10" Line
Steam Line
PARKING AREA
M.H.
Tank
San.
8" Line
Sanitary Sewer
M.H. #4
Fence
15" Line


26'-0"
5'-0"
2'-3"
CB AIR BLOWER
3'-0"
16'-10"
6'-9"
5'-5" DIA
BOILER
3'-9"
20'-0"
9'-6"
6'-5"
BAGHO
A
COMBUSTOR
WATER ECONOMIZER
6'-2" DIA
5' DIA
30°
CYCLONE
COOLING BED
5'-9"
7'-10½"
SLUICE AIR BLOWER
STACK
PRIMARY AIR BLOWER
2'-0
5'-6"

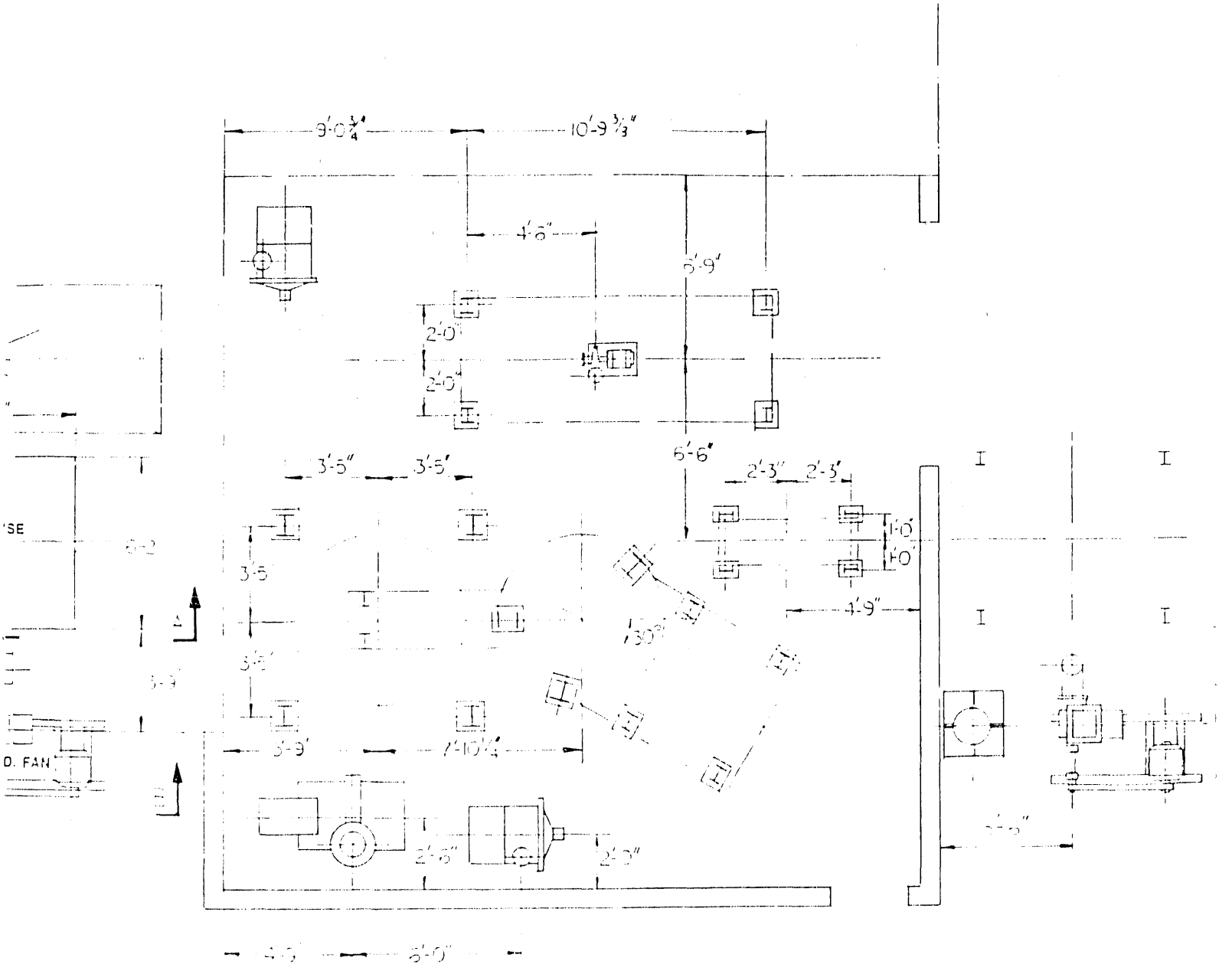
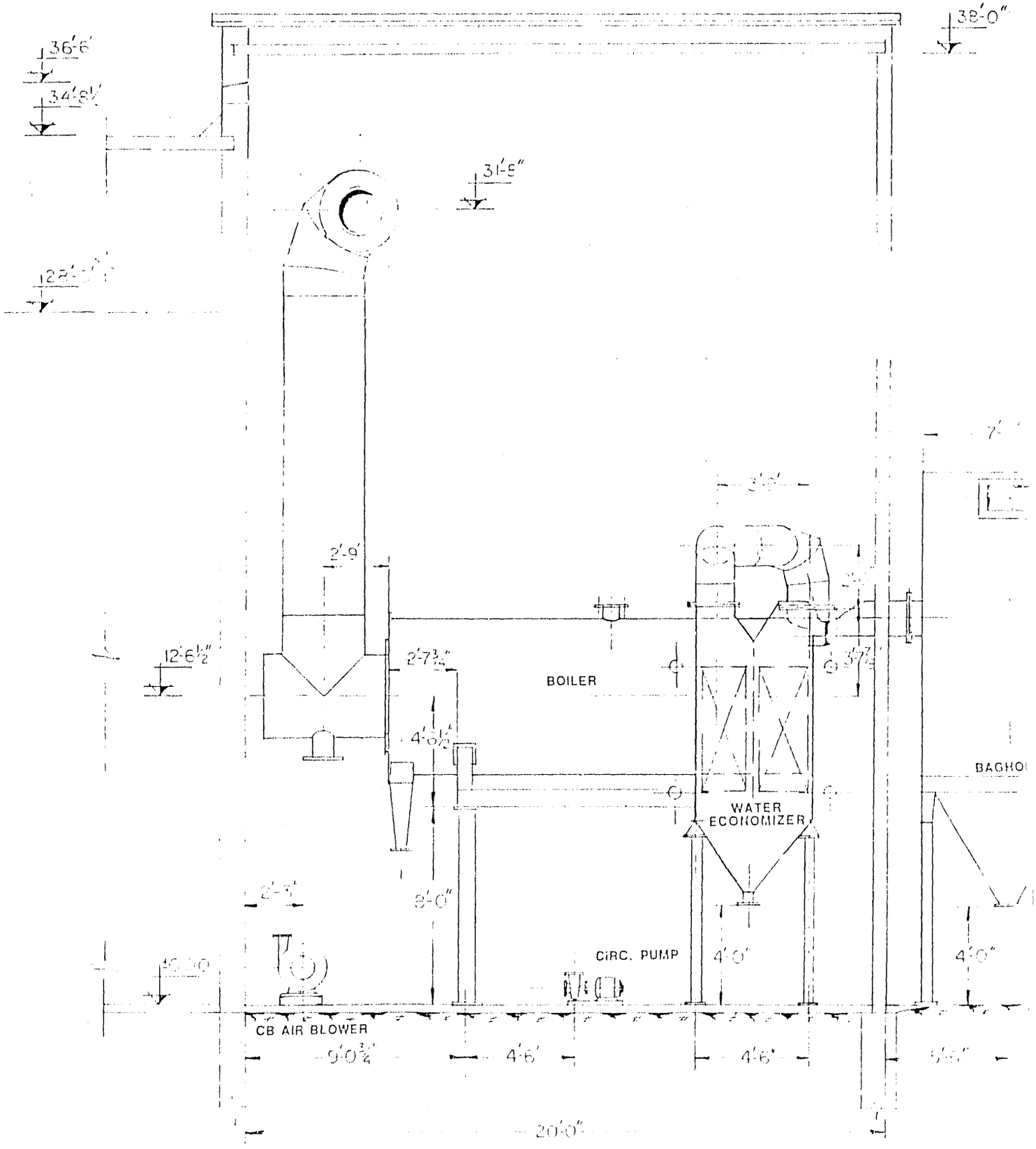


FIGURE 12
PRIMARY LAYOUT
CFB LEBANON V.A. HOSPITAL,
TOP VIEW AND FLOOR ELEVATION

DONLEE TECHNOLOGIES INC.


38'-0"
36'-6"
34'-8½"
31'-8"
12'-6½"
2'-9"
2'-7¾"
4'-6½"
BOILER
WATER ECONOMIZER
BAGHO
8'-0"
CIRC. PUMP
4'-0"
4'-0"
CB AIR BLOWER
9'-0¾"
4'-6"
4'-6"
20'-0"

SECTION A - A

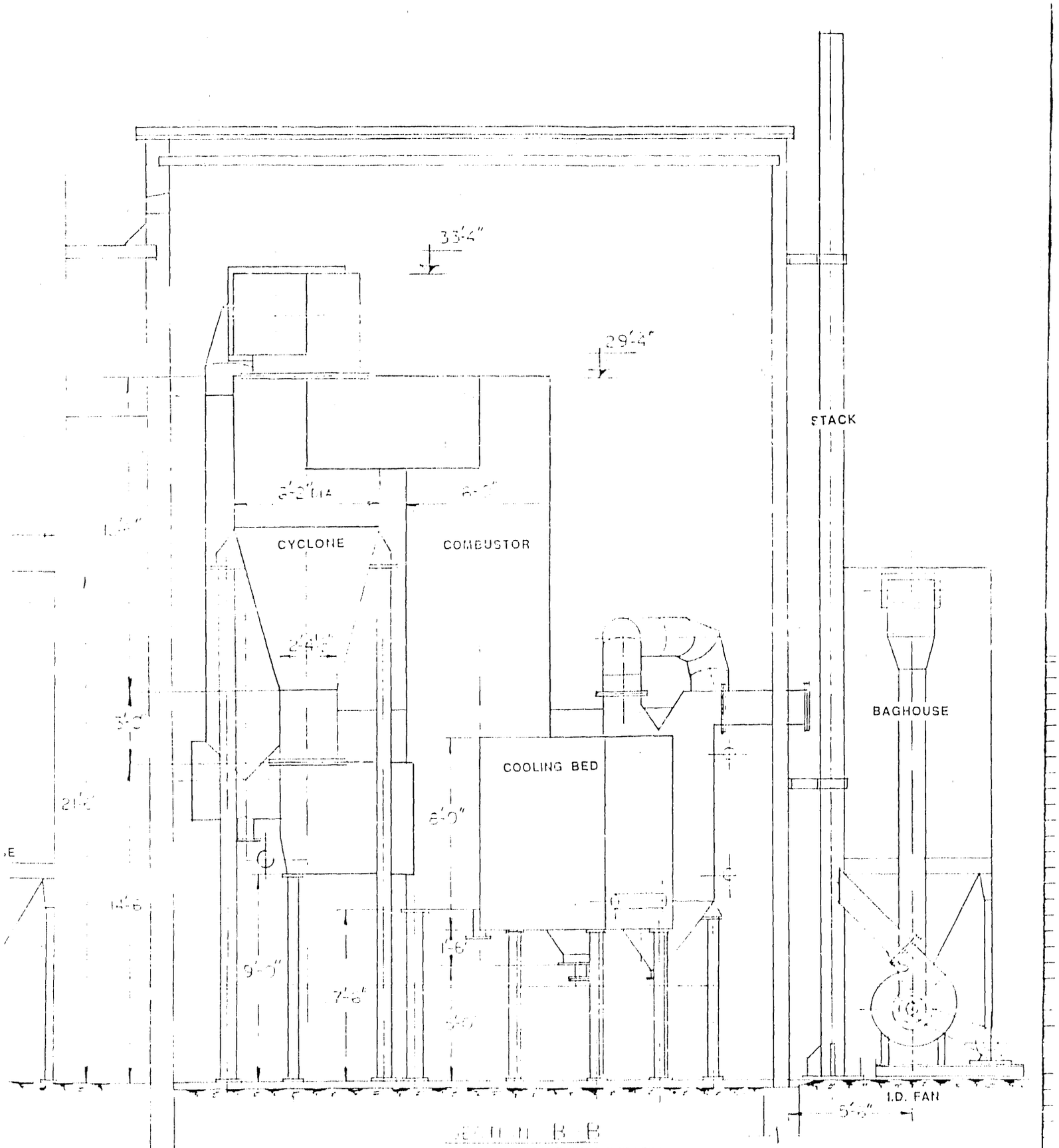


FIGURE 13
PRIMARY LAYOUT
CFB LEBANON V.A. HOSPITAL,
SECTION A-A AND B-B

the permit application will be approved by DER. Based on test results, the required capacity of the scrubber should be greatly reduced due to the ability to capture chlorine and sulfur in the limestone bed.

It should be noted that the CFB drawings do not show the waste size reduction and feed unit. Specific design features for this unit will be finalized during the initial stages of Phase 2. Based on shredder tests conducted by the project team at the manufacturer's facilities, it was determined that two shredders in series will be incorporated into the design. All types of non-infectious hospital materials along with other items were processed during the preliminary shredder testing. The materials were introduced into the feeder hopper in red bags and boxes of the size specified in the conceptual design stage. Long strands of plastic were frequently observed in the shredded wastes. The second shredder will help reduce the overall size of material to the desired maximum 2 inch limit.

Another design modification was made as a result of the preliminary tests. A hydraulic ram will be incorporated into the second hopper chamber to assist the cutters in grasping larger smooth objects such as bed pans and sharps containers. This is an optional component offered by the shredder manufacturer.

All of these features will be included along with the material feed device for installation at DONLEE's test facility. The complete waste processing system will be retrofit to the existing CFB pilot unit. A series of tests using non-infectious materials will be conducted to demonstrate the acceptability of size reduction, material feed rates, and isolation of waste materials from the operators during processing. Any necessary design modifications will be made and tested prior to delivery of the system to the Lebanon VA Medical Facility.

A cost/benefit analysis was developed considering two separate scenarios that are available to the Lebanon VA Medical Facility. Scenario #1 assumes that compliance with more stringent state regulations for disposal of infectious wastes is achieved by contracting with an outside service such as a regional incinerator as compared to the installation of the CFB unit. Scenario #2 evaluates the cost to purchase, permit, and operate a new gas incinerator at the Lebanon facility as compared to the installation of the CFB unit. In each case, the costs for operating the CFB unit are incorporated as annual expenditures which are offset against the benefits or avoided costs (savings) of the alternatives. Tables 31 and 32 summarize pertinent assumptions for each scenario which were utilized in the discounted cash flow analyses. Both inflated and constant dollar cash flows were calculated in these analyses and are shown in Tables 33 and 34. The analyses show a definite cost advantage for the use of the CFB unit at the Lebanon VA site for both scenarios.

TABLE 31
COST SCENARIO #1

ASSUMPTIONS

* No upgrade for oil/gas facility
* CFB capital investment = $1,600,000
* 75% of CFB capital investment in Year 0
* 25% of CFB capital investment in Year 1

1988 gas/oil cost/lb. steam	$0.005790
Coal required (tons/week)	88.9
Coal cost/lb. steam	$0.001725
Coal cost/ton	$36.00
Limestone required (tons/week)	25.5
Limestone cost/lb. steam	$0.000206
Limestone cost/ton	$15.00
Ash disposal (tons/week)	36.3
Ash disposal cost/lb. steam	$0.000294
Ash disposal cost/ton	$15.00
Power cost/lb. steam	$0.000313
Additional labor cost - Year 1	$154,300
Testing cost/year	$10,000
Total waste rate (lb./week)	10,000
Infectious waste rate % of total waste	15%
Infectious waste tons/year	39
Off-site "Red bag" waste disposal cost/lb.	$0.50
Good Samaritan "red bag" disposal cost/lb.	$0.30
Good Samaritan infectious waste lb./week	300
Good Samaritan infectious waste tons/year	7.8
General waste lb./week	8,500
General waste tons/year	221
Off-site disposal cost/lb. - general waste	$0.10
Gas/oil escalation rate/yr.	5.20%
Bituminous coal escalation rate/yr.	4.00%
Power escalation rate/yr.	1.50%
Limestone escalation rate/yr.	2.50%
Labor escalation rate/yr.	4.00%
Repair and maintenance escalation rate/yr.	4.00%
Ash disposal escalation rate/yr.	4.00%
"Red bag" disposal escalation rate/yr.	10.00%
General waste disposal escalation rate/yr.	6.00%
Testing escalation rate/yr.	3.00%
Interest rate	7.00%

TABLE 32

COST SCENARIO #2

ASSUMPTIONS

* No upgrade for oil/gas facility
* CFB capital investment = $1,600,000
* New gas/oil facility capital investment = $1,000,000
* 75% of CFB capital investment in Year 0
* 25% of CFB capital investment in Year 1

1988 gas/oil cost/lb. steam	$0.005790
Coal required (tons/week)	88.9
Coal cost/lb. steam	$0.001725
Coal cost/ton	$36.00
Limestone required (tons/week)	25.5
Limestone cost/lb. steam	$0.000206
Limestone cost/ton	$15.00
Ash disposal (tons/week)	36.3
Ash disposal cost/lb. steam	$0.000294
Ash disposal cost/ton	$15.00
Power cost/lb. steam	$0.000104
Additional labor cost - Year 1	$77,150
Testing cost/year	$5,000
Total waste rate (lb./week)	10,000
Infectious waste rate % of total waste	15%
Infectious waste lb./week	0
Infectious waste tons/year	0
"Red bag" waste disposal cost/lb.	$0.50
Good Samaritan "red bag" disposal cost/lb.	$0.30
Good Samaritan infectious waste lb./week	300
Good Samaritan infectious waste tons/year	7.8
General waste lb./week	0
General waste tons/year	0
Off-site disposal cost/lb. - general waste	$0.10

PRICE ESCALATION

Gas/oil escalation rate/yr.	5.20%
Bituminous coal escalation rate/yr.	4.00%
Power escalation rate/yr.	1.50%
Limestone escalation rate/yr.	2.50%
Labor escalation rate/yr.	4.00%
Repair and maintenance escalation rate/yr.	4.00%
Ash disposal escalation rate/yr.	4.00%
"Red bag" disposal escalation rate/yr.	10.00%
General waste disposal escalation rate/yr.	6.00%
Testing escalation rate/yr.	3.00%
Interest rate	7.00%

TABLE 33
COST SCENARIO #1
EXISTING OIL/GAS FACILITY
VS. CFB UNIT
(INFLATED)

TIME	TOTAL COST CUMULATIVE SAVINGS	PRESENT VALUE FACTOR	PRESENT VALUE ($)
Year 0	($1,143,446)	1.00000	($1,143,446
Year 1	($203,489)	0.93458	($190,177)
Year 2	$213,843	0.87344	$186,779
Year 3	$221,235	0.81630	$180,594
Year 4	$242,118	0.76290	$184,711
Year 5	$264,605	0.71299	$188,660
Year 6	$288,816	0.66634	$192,450
Year 7	$314,881	0.62275	$196,092
Year 8	$342,940	0.58201	$199,594
Year 9	$373,146	0.54393	$202,966
Year 10	$405,661	0.50835	$206,217
Year 11	$440,663	0.47509	$209,356
Year 12	$478,342	0.44401	$212,389
Year 13	$518,904	0.41496	$215,327
Year 14	$562,572	0.38782	$218,175
Year 15	$609,588	0.36245	$220,943
Net Present Value			$1,480,631

COST SCENARIO #1
EXISTING OIL/GAS FACILITY
VS. CFB UNIT
(CONSTANT DOLLARS)

TIME	TOTAL COST CUMULATIVE SAVINGS	PRESENT VALUE FACTOR	PRESENT VALUE ($)
Year 0	($1,143,446)	1.00000	($1,143,446)
Year 1	($226,064)	1.00000	($226,064)
Year 2	$171,231	1.00000	$171,231
Year 3	$158,731	1.00000	$158,731

TABLE 33

(CONTINUED)

TIME	TOTAL COST CUMULATIVE SAVINGS	PRESENT VALUE FACTOR	PRESENT VALUE ($)
Year 4	$158,731	1.00000	$158,731
Year 5	$158,731	1.00000	$158,731
Year 6	$158,731	1.00000	$158,731
Year 7	$158,731	1.00000	$158,731
Year 8	$158,731	1.00000	$158,731
Year 9	$158,731	1.00000	$158,731
Year 10	$158,731	1.00000	$158,731
Year 11	$158,731	1.00000	$158,731
Year 12	$158,731	1.00000	$158,731
Year 13	$158,731	1.00000	$158,731
Year 14	$158,731	1.00000	$158,731
Year 15	$158,731	1.00000	$158,731
Net Present Value			$865,219

TABLE 34

COST SCENARIO #2

EXISTING OIL/GAS FACILITY

VS. CFB UNIT

(INFLATED)

TIME	TOTAL COST CUMULATIVE SAVINGS	PRESENT VALUE FACTOR	PRESENT VALUE ($)
Year 0	($389,824)	1.00000	($389,824)
Year 1	$49,533	0.93458	$46,293
Year 2	$225,111	0.87344	$196,620
Year 3	$234,141	0.81630	$191,128
Year 4	$250,886	0.76290	$191,399
Year 5	$268,686	0.71299	$191,569
Year 6	$287,605	0.66634	$191,643
Year 7	$307,710	0.62275	$191,626
Year 8	$329,073	0.58201	$191,524
Year 9	$351,770	0.54393	$191,340

TABLE 34

(CONTINUED)

TIME	TOTAL COST CUMULATIVE SAVINGS	PRESENT VALUE FACTOR	PRESENT VALUE ($)
Year 10	$375,882	0.50835	$191,079
Year 11	$401,493	0.47509	$190,746
Year 12	$428,695	0.44401	$190,346
Year 13	$457,583	0.41496	$189,881
Year 14	$488,261	0.38782	$189,356
Year 15	$520,835	0.36245	$188,774
Net Present Value			$2,333,502

SCENARIO #2

EXISTING OIL/GAS FACILITY

VS. CFB UNIT

(CONSTANT DOLLARS)

TIME	TOTAL COST CUMULATIVE SAVINGS	PRESENT VALUE FACTOR	PRESENT VALUE ($)
Year 0	($389,824)	1.00000	($389,824)
Year 1	$33,280	1.00000	$33,280
Year 2	$192,341	1.00000	$192,341
Year 3	$185,341	1.00000	$185,341
Year 4	$185,341	1.00000	$185,341
Year 5	$185,341	1.00000	$185,341
Year 6	$185,341	1.00000	$185,341
Year 7	$185,341	1.00000	$185,341
Year 8	$185,341	1.00000	$185,341
Year 9	$185,341	1.00000	$185,341
Year 10	$185,341	1.00000	$185,341
Year 11	$185,341	1.00000	$185,341
Year 12	$185,341	1.00000	$185,341
Year 13	$185,341	1.00000	$185,341
Year 14	$185,341	1.00000	$185,341
Year 15	$185,341	1.00000	$185,341
Net Present Value			$2,245,236

Following are some additional comments concerning these evaluations.

- The cost savings associated with steam generation from the CFB is computed by applying the historical costs to produce the same quantity of steam with the existing gas/oil units against the coal, limestone, and ash disposal costs projected for the CFB.

- Additional labor for Scenario #1 reflects hiring of four (4) operators for the CFB. In Scenario #2, the additional labor is reduced to two (2) operators based on the assumption that two operators will be required with a new gas incinerator.

- Additional testing results from periodic analyses of ash and stack gases with the CFB having a higher cost due to the larger quantity of ash generated compared to the gas incinerator.

- Both scenarios reflect income based on a fee of $0.30 per pound for incineration of infectious wastes from the Good Samaritan Hospital. This rate excludes the cost for transport which is included in the rate applied for outside disposal of the VA Medical Center's infectious waste in Scenario #1.

- The general waste disposal savings in Scenario #1 considers the capability to incinerate the VA facilities' non-infectious waste in the CFB unit. This savings is eliminated in Scenario #2 based on the assumption that general waste can also be disposed of in the gas incinerator.

- Escalation rates were established through evaluation of CPI trends along with assessment of impacts related to increasing costs of waste disposal due to more stringent regulations.

- The coal price represents a bituminous coal utilized in the combustion test program. With modifications to the materials handling system, the smaller sized anthracite products could be used and represent a competitively priced fuel supply option.

The capital investment in Scenario #1 represents 50% of the cost for design, fabrication, installation, and monitoring (one year) of the CFB unit as shown in Table 35. Included in the capital cost are: coal receiving facility; 100 ton coal storage silo; 50 ton limestone storage bin; and two 10 ton ash storage bins. In the second scenario, the $600,000 capital investment is the cost differential between the CFB unit and a state-of-the-art gas incinerator.

TABLE 35
ESTIMATED COST FOR DESIGN, FABRICATION, INSTALLATION, AND MONITORING

COMPONENT	COST
Shredder Purchase/Testing	$121,480
Shredder Move to Lebanon	15,000
Fans and Blowers	25,500
Baghouse	18,000
Circulating Pump	4,200
Startup Burner	3,000
Valves and Dampers	17,300
Gas Analyzers/Conditioner	54,100
Control Room	8,500
Controls/Computer	45,000
Instruments	16,000
Combustor, Cyclone, and Cooling Bed	127,400
Ducting	7,500
Piping	7,700
Boiler	9,000
Insulation	13,800
Refractory	96,700
Chimney	9,400
Painting	8,500
Coal, Limestone, and Ash Storage, Handling Feed; Site Preparation; Foundations; Steelwork; Building; Electrical; and Installation	563,000
Contingency	48,700
G&A	308,636
Subtotal Equipment	$1,528,416
Engineering Design, Procurement, and Commissioning	$1,043,465
Permitting and Coal, Limestone, and Ash Agreements	$142,432
One Year Test Program	488,639
Report Preparation	20,243
Subtotal Engineering/Testing	$1,694,779
Total Project	$3,223,195

Based upon the discounted cash flow analyses, the circulating fluidized bed combustor approach offers the Lebanon VA Medical Center a substantial cost savings under both scenarios evaluated. Scenario #1 will result in a payback of the initial $1.6 million in nine (9) years with a $1.48 million in additional benefits during the next 15 years. Under Scenario #2, the incremental capital of $0.6 million has a three (3) year payback with more than $2.33 million return on investment over the 15 year period.

The cost for ash disposal represents an area of uncertainty. Proposed regulations will place greater demands on landfills concerning the suitability of materials. The U.S. Environmental Protection Agency has expanded the ash testing requirements for all states beginning September 25, 1990. Specific requirements appeared in the "Federal Register" on March 29, 1990. In place of testing for EP-Toxicity, ash will require the new Toxicity Characteristics testing for hazardous waste determination. The Toxicity Characteristic Leaching Procedure (TCLP), which utilizes a more aggressive leaching solution, replaces the EP-Toxicity test. The number of parameters to be tested has increased to 39, including 25 new organic parameters added to the eight metals, four insecticides, and two herbicides.

Comparison economics have an ash disposal cost of $15 per ton. This value represents a conservative cost for back haul and disposal at a permitted strip mine landfill. At the present time, utility operated power plants and cogeneration plants are utilizing these sites as cost effective locations for ash disposal. Although the bulk of the ash generated at the Lebanon VA Facility will come from the coal and bed materials, there is no assurance that DER will allow disposal at these low cost landfills. A sensitivity analysis was performed to evaluate the impact of increased ash disposal costs on the project economics. The economic scenarios were run with ash disposal costs of $30, $35, and $40 /ton. Table 36 presents the results of the discounted cash flow analyses.

TABLE 36
ASH DISPOSAL COST
SENSITIVITY ANALYSIS (ESCALATED)

YEAR $/TON	NPV $ X 10^6 SCENARIO #1	NPV $ X 10^6 SCENARIO #2
$15	1.48	2.33
$30	1.19	2.05
$35	1.10	1.95
$40	1.00	1.86

As can be seen, the incremental ash disposal costs do have a significant effect on the net present value (NPV). However, even at $40 per ton, both scenarios show distinct cost advantages for the CFB unit.

CONCLUSIONS

Hospitals are experiencing a waste management crisis. Many older hospital waste incinerators cannot maintain stable temperatures and resident times necessary to completely destroy toxic substances. The number of landfills able to safely handle these substances is limited and decreases each year. Improvements to existing disposal methods as well as development of new technologies are necessary to remedy the hospital waste disposal problem.

Hazardous waste disposal in industrial boilers and the potential of using a circulating fluidized bed combustor for destroying hospital wastes were surveyed. Circulating fluidized bed combustors can meet the stringent permit regulations of the Environmental Protection Agency for hazardous waste incineration which is 99.99% destruction of hazardous chemicals and 99% retention of acid gases. The combustion of hospital wastes should behave similarly to hazardous waste combustion. A coal-fired fluidized bed combustor cofiring small quantities of hospital waste has the potential to meet standards equivalent to those for hazardous waste incineration in a clean, efficient, and economical manner. The simple design of circulating fluidized bed combustors uses high turbulence in the reaction zone that allows lower operating temperatures compared to industrial boilers. Proven performance combusting industrial wastes includes: combustion efficiency >99.99%; HCl capture >99%; no scrubbers or wet sludge product; no afterburners or auxiliary fuel; waste volume reduction up to 40 to 1; highest boiler efficiency in the industry; and NO_x and CO emissions <100 ppmv. Destroying hospital waste in a coal-fired fluidized bed combustor offers potential for in-bed capture of chlorine-containing compounds based on a survey of literature and therrmodynamic calculations. The theoretical approach was appropriate to establish baseline data and predict fluidized bed combustor benefits; however, pilot-scale testing was necessary to confirm actual performance.

Chlorine-containing drugs were surveyed to determine possible model compounds for use in circulating fluidized bed combustor testing. Chlorine is chemically incorporated into the structure of drugs in five ways. Therefore, five model compounds were selected for testing. The structure type and model compounds follow:

1° Aliphatic carbon	(2-Chloroethyl) benzene
Amine hydrochloride	Benzyltriethylammonium chloride
Aromatic carbon	2-Chlorobenzoic acid

Ionic	Potassium chloride
Vinylic carbon	1-Chloro-2-methylpropene[a]

A conceptual waste handling system was developed for introduction of hospital wastes into the combustion chamber without contamination or posing undue health risks to operators. Prior to conceptual design, solid waste handling, storage, and transport regulations were investigated and existing hospital waste management techniques were evaluated.

Medical waste is regarded by the public as a high priority issue and, in turn, lawmakers have made hospital waste management a priority. Federal guidelines fall into the categories of segregation, packaging, storage, transport, treatment, and disposal of infectious waste. Additionally, the states are generally tightening control of infectious waste disposal through regulations enforced by considerable fines for noncompliance.

Pennsylvania was chosen as the host state of the AFBC proof-of-concept test facility. Therefore, current Pennsylvania regulations were considered although changes in present requirements and standards are imminent. Similar to Federal guidelines, Pennsylvania regulates storage, handling, and disposal of infectious and chemotherapeutic waste as well as operating requirement guidelines for waste processing facilities.

The AFBC unit requires waste stream particles no larger than two-inch-minus of feed size. Therefore, a size reduction unit will be integrated with the combustor and incorporate sterilization.

The DONLEE Technologies' AFBC demonstration unit was chosen for pilot-scale testing prior to installation of a proof-of-concept facility. Design modifications were completed before testing began. The improved DONLEE CFB design has the following distinguishing features:

- A major portion of the combustion air is introduced under the fluidized bed as the remaining part is injected into the bed (as fuel transporting air);
- The excess heat generated during combustion is mainly extracted by the heat exchangers installed in a cooling fluidized bed adjacent to the main bed;
- The solids carried out of the main fluidized bed are recycled after being captured by hot cyclones into the main fluidized bed via a partitioned air sluice; and

- Good sulfur capture efficiency is maintained by controlling the temperature difference between combustor exit and fluidized bed through mean particle size and superficial velocity to sustain the necessary suspension density.

Prior to combustion of hospital wastes, 22 test runs of two hours duration were conducted to test the effects of: upper combustor velocity and exit temperature; Ca/S molar ratio; excess air level; main bed pressure drop and stoichiometric ratio; and load level. After completion of preliminary tests, surrogate waste tests were performed. Conclusions of the testing procedure are summarized below.

- Combustion efficiency is not sensitive to upper combustor superficial velocity within the range of 10 to 13.5 ft./s.
- A combustor operating temperature of 1,600°F gives high combustion efficiency (>97%), good sulfur capture (>85%), and low NO_x emissions (<150 ppm).
- Combustion efficiency is not sensitive to excess air level within the range of 25 to 45%.
- Combustion efficiency is not sensitive to main bed pressure drop within the range of 20 to 30 inches WC.
- A main bed stoichiometric ratio of 1:1 gives high combustion efficiency (>97%), good sulfur capture (>85%), and low NO_x emissions (<150 ppm).
- Good sulfur capture (>85%) is obtained with a calcium to sulfur molar ratio of 3:1 or less.
- Stable low load operation at 20% of full load heat input can be achieved.
- Controlled, continuous feed, rather than slug feed, of the hospital waste is required.
- Feed rates of 10 lb./h of broken glass and 10 lb./h of metal shavings did not cause any bed agglomeration problems.
- An average of 50% of the infeed chlorine was captured in the combustion system.

- With respect to chlorine capture, no trends could be discerned related to either the operating temperature, waste feed rate, or the type of coal.

- When firing hospital waste, the SO_2 emissions were always below the 1.2 lb./10^6 BTU/h NSPS limit for small coal-fired boilers.

- The NO_x emissions were always well below the 1 lb./10^6 BTU NSPS limit.

- The CO emission levels were marginal when compared to the PA DER limit of 100 ppm for medical waste incinerators.

- The HCl emission levels are of the same order of magnitude as from medical waste incinerators without flue gas scrubber systems. A scrubber will be necessary to attain the PA DER limit of 30 ppm for medical waste incinerators.

- The highest dioxin/furan emission level is about half of that permitted by PA DER for the Hershey Medical Center incinerator, and an order of magnitude less than the latest proposed limit for the State of California.

- The dioxin/furan emission levels are two to three orders of magnitude less than those from selected medical waste incinerators without scrubbers.

- The ash from the unit meets the requirements of the PA DER Form 41 and the E.P. Toxicity test. It does not require a hazardous waste landfill for disposal.

- The reference surrogate waste feed rate was equivalent to an infectious waste feed rate of about 50% of the total heat input. This compares to the original concept of 10% of total heat input.

Consideration of test results provided a high level of confidence that proposed techniques for waste disposal in a proof-of-concept plant will be successful. The Lebanon VA Medical Center in Lebanon, Pennsylvania was the selected site for a full scale hospital waste disposal facility conceptual design and cost estimate. A cost/benefit analysis was developed for two scenarios available to the Lebanon VA facility. Scenario #1 assumes that compliance with more stringent state regulations for disposal of infectious wastes is achieved by contracting with an outside service such as a regional incinerator as compared to the installation of the CFB unit. Scenario #2 evaluates the cost to purchase, permit, and operate

a new gas incinerator at the Lebanon VA facility as compared to the installation of the CFB unit. The analyses show a definite cost advantage for the use of the CFB unit at the Lebanon VA site for both scenarios.

Scenario #1 will result in a payback of the initial $1.6 million in nine (9) years with a $1.48 million in additional benefits during the next 15 years. Under Scenario #2, the incremental capital of $0.6 million has a three (3) year payback with more than $2.33 million return on investment over the 15 year period. Ash disposal costs used for this analysis were conservative ($15) based on proposed regulations. However, even at $40 per ton, both scenarios show distinct cost advantages for the CFB unit.

ON-GOING INVESTIGATIONS

In order to complete Task 2 - Develop Waste Handling System, additional work is continuing. Newly proposed infectious and chemotherapeutic waste management regulations appeared in the "Pennsylvania Bulletin" on April 14, 1990. These regulations concern permitting and operation of medical waste incineration facilities including handling of processed waste. The new regulations must be reviewed for how they relate to the waste handling system which was developed. Included within the regulations are new criteria which must be met. The results of Task 4 combustion tests must be assessed for the ability to meet new criteria.

Meetings will be held with the Department of Environmental Resources (DER) representatives of both Bureau of Air Quality and Bureau of Solid Waste Management. During these meetings, appropriate permit forms will be gathered. At the same time, DER will be advised of the project concept and possibilities for future development.

Permit related evaluations will be performed to ensure compliance with all existing requirements. All relevant permit forms will be initiated. This includes items such as dispersion modeling and demonstration that the new source is justifiable as a result of economic or social development.

Task 4 - Combustor Development and Testing requires additional work prior to completion. As previously stated, a detailed analysis of combustion test results must be conducted for comparison to new criteria established.

Additionally, the shredding system will be investigated in detail. The hospital waste shredding system will be designed with strict and detailed specifications for a bid package. Competitive bids fitting the specifications will be obtained. Based on the bids received, a shredder system will be purchased and delivered to the pilot plant.

Drawings will be created showing the shredder system installation including any pilot plant modifications necessary to complete the installation. All necessary materials (steelwork, refractory, electrical equipment, etc.) will be purchased, then the pilot plant will be modified, and the shredder system will be installed.

After installation, the shredder system will be tested for operational reliability. Non-infectious waste material will be shredded for a test duration of 100 hours.

Prior to completion of Task 5 - Conceptual Design and Cost Estimates of Full Scale, Proof-of-Concept Facility, numerous activities must be performed. Stack gas and ash testing

procedures may need modifications to comply with new regulations. Other necessary modifications include changes to the material processing and feed system as well as other components of the combustion unit. A detailed specifications package will be generated and reviewed for all equipment and services. Included in the specification package will be the following.

- Fans and blowers
- Dry injection fabric filter
- Circulating pumps
- Chimney
- Coal storage, handling, and feeding
- Limestone storage, handling, and feeding
- Ash handling and storage (including coolers)
- Start-up burner
- Valves and dampers
- Emission monitoring equipment
- Control room
- Instruments
- Ducting and piping
- Heat recovery boiler, economizer, and sootblowers
- CFB combustor, cyclone, and cooling bed
- Bed material cleaning system
- Controls/computer package
- Controls installation
- Steelwork, stairways, and platforms
- Electrical equipment and installation
- Vendor equipment installation
- Site preparation and foundations
- Plant enclosure and utilities
- Painting
- Insulation materials and installation
- Refractory materials and installation

More detailed designs for installation of the proof-of-concept system at the Lebanon VA Medical Facility are necessary. Process and performance design calculations must be conducted for a 20,000 lbs./hr. facility. Combustion and steam generation system process flow diagrams and arrangements drawings of CFB combustor, cyclone, and cooling bed are also necessary.

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APPENDIX A - SPECIES INCLUDED IN DATABASE

Species		
Gas (G)	Liquid (L)	Solid (S)
Na	Al_2O_3	Al_2O_3
K	$Al_6Si_2O_{13}$	$Al_6Si_2O_{13}$
O_2	$CaAl_2Si_2O$	$CaAl_2Si_2O$
S	Ca_2Al_2SiO	Ca_2Al_2SiO
Cl_2	$NaAlSiO_4$	SiO_2
H_2	$NaAlSi_3O_8$	Na_2SO_4
Na_2SO_4	Na_2SO_4	$CaAl_2O_4$
CO	SiO_2	$CaSO_4$
CO_2	$CaSO_4$	$CaSiO_3$
SO_2	$CaAl_2O_4$	NaCl
SO_3	Ca_2SiO_4	$CaCl_2$
HCl	CaO	$KAlSiO_4$
NaOH	$CaSiO_3$	$KAlSi_2O_6$
H_2O	$CaCl_2$	KCl
CClO	NaCl	
Cl_2O_2S	NaOH	
ClS	K_2SO_4	
$SiCl_4$	$KAlSi_3O_8$	
K_2SO_4	$KAlSiO_4$	
KOH	KCl	
H_2SO_4	KOH	

Appendix B

STATE REGULATIONS PERTAINING TO
INFECTIOUS WASTE MANAGEMENT (1986)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Alabama	1975 Code of Alabama, Section 22-21-20. Alabama State Board of Health Rules and Regulations for Nursing Homes and Hospitals.	All infectious waste generated by nursing homes and hospitals must be incinerated on site.	Bureau of Licensure and Certification State Health Department Room 652 State Office Building Montgomery, Alabama 36130-1701 (205) 261-5105
	No regulations.	Policy is to recommend treatment of infectious waste prior to disposal.	Alabama Department of Environmental Management Land Division 1751 Federal Drive Montgomery, Alabama 36130 (205) 271-7700
Alaska	Laws of Alaska, Title 44, Chapter 46; Title 46, Chapter 3.	All infectious waste generated by medical and veterinary facilities must be incinerated prior to final disposal. The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Air and Solid Waste Management Department of Environmental Conservation Pouch O Juneau, Alaska 99811 (907) 465-2666

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Arizona	Arizona Revised Statutes, Title 36, Article 2, General Hospitals. Regulation R9-10-220, Environmental Services, Subsection E.	All infectious waste must be either (1) autoclaved and disposed of in an approved sanitary landfill, or (2) incinerated in an approved incinerator. Variances are given for disposal of untreated waste when there is insufficient treatment capacity.	Bureau of Health Care Institution Licensure Arizona Department of Health Services 1740 West Adams Street Phoenix, Arizona 85007 (602) 255-1115
Arkansas	Act 414 of 1961, as amended by Act 444 of 1965 and Act 454 of 1965. Rules and Regulations for Hospitals and Related Institutions in Arkansas.	All infectious waste generated by hospitals and related institutions must be incinerated or disposed of by other approved methods. Revisions are expected in 1986.	Department of Health Division of Health Facilities Services 4815 W. Markham Street Little Rock, Arkansas 72205-3867 (501) 661-2201
	The Solid Waste Management Act (237) of 1971. Arkansas Hazardous Waste Management Act of 1979 (Act 406 of 1979).	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Solid Waste Management Division Department of Pollution Control and Ecology P.O. Box 9583 8001 National Drive Little Rock, Arkansas 72219 (501) 562-7444

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
California	California Health and Safety Code Chapter 6.5, Article 2, Section 25117.5 California Administrative Code, Title 22. Division 4, Chapter 30: Minimum Standards for Management of Hazardous and Extremely Hazardous Waste; Infectious Waste Regulations, effective November 16, 1985.	Infectious waste must be incinerated, sterilized or treated by other approved methods.	California Department of Health Services Hazardous Materials Management Section 714/744 P Street Sacramento, California 95814 (916) 324-1798
Colorado	Colorado Revised Statutes, 1973, as amended; Title 25, Article 15, Parts 1, 2, and 3: Hazardous Waste Management Act.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Waste Management Division Colorado Department of Health 4210 E. 11th Avenue Denver, Colorado 80220 (303) 320-8333 Ext. 4364
	Chapter 4, Regulations Governing General Hospitals.	Pathological waste must be incinerated. Off-site disposal in approved sites is possible.	Division of Health Facilities Regulations Colorado Department of Health 4210 E. 11th Avenue Denver, Colorado 80220 (303) 320-8333 Ext. 6306

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Connecticut	Connecticut General Statutes of 1979, Public Act 79-605. Code 22A-4483 and 22A-115.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Hazardous Waste Management Department of Environmental Protection State Office Building 165 Capitol Avenue Hartford, Connecticut 06106 (203) 566-4869 or 566-5712
Delaware	Delaware Code, Title 7, Chapter 60: Solid Waste Act. Delaware Solid Waste Disposal Regulations, August 1974.	Infectious waste disposal is approved on a case-by-case basis. None has been allowed to go to landfills untreated since the approval process was initiated. Revised regulations have been proposed.	Waste Management Section Department of Natural Resources and Environmental Control 89 King Highway P.O. Box 1401 Dover, Delaware 19903 (302) 736-4781

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
District of Columbia	District of Columbia Hazardous Waste Management Act of 1977, D.C. Law 2-64.	The District has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations	Department of Consumer and Regulatory Affairs and Environmental Control Division 5010 Overlook Avenue, SW Washington, DC 20032 (202) 767-8414
Florida	Florida Resource Recovery and Management Act (Florida Statutes Annotated, Title 27, Public Health, Chapter 403, Part IV, Enacted by the Laws of 1974, Chapter 342, as amended). Florida Resource Recovery and Management Regulations: Rules of the Department of Environmental Regulation, Chapter 17-7.04.	Infectious waste must be incinerated or treated by an approved treatment method before being placed in a landfill.	Solid Waste Management Program Department of Environmental Regulation Twin Towers Office Building, 6th Floor 2600 Blair Stone Road Tallahassee, Florida 32301 (904) 488-0300 and Department of Health and Rehabilitative Services 1317 Winewood Blvd. Tallahassee, Florida 32301 (904) 488-2905

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Georgia	Code of Georgia, Annotated, Title 43, Chapter 43-16: Solid Waste Management Act of 1972, as amended. Georgia Department of Natural Resources Rules and Regulations for Solid Waste Management, Chapter 391-3-4, 1972, as amended through 1974.	Infectious waste is considered a special waste. Policy is to require incineration or autoclaving before land disposal.	Land Protection Branch Environmental Protection Division Department of Natural Resources Room 724 270 Washington Street, S.W. Atlanta, Georgia 30334 (404) 656-2833
Hawaii	Hawaii Environmental Laws and Regulations, Vol. I, Title 19, Chapter 342, Part V, as amended by Chapter 230, Laws of 1974. Title 11, Department of Health, Chapter 58, Solid Waste Management Control Regulations, November 1981.	All infectious waste must be treated or otherwise rendered safe before disposal. Double bagging is considered a means of rendering an untreated waste safe.	Air and Solid Waste Permit Section Department of Health Amelco Building, 3rd Floor 645 Halekauwila Street Honolulu, Hawaii 96813

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Idaho	Idaho Code, Title 39, Chapter 1. Idaho Solid Waste Management Regulations, Title I, Chapter 6.	All solid waste must be managed to prevent health hazards, public nuisances, and pollution of the environment during treatment, storage and disposal. Policy is to recommend that infectious waste be double bagged prior to disposal.	Hazardous Materials Bureau Department of Health and Welfare State House Boise, Idaho 83720 (208) 334-4107
Illinois	Illinois Revised Act 101-105, January 1985. State of Illinois Rules and Regulations 35, Subtitle G, Subpart F, Sections 700.601-700.605	All infectious hospital waste must be rendered innocuous by sterilization or incineration before disposal.	Division of Land Pollution Control Environmental Protection Agency 2200 Churchill Road Springfield, Illinois 62706 (217) 782-6762 or 782-6760

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Indiana	Indiana Code, Title 13, Article 7, Environmental Management Act.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations. Regulations are being drafted.	Division of Land Pollution Control State Board of Health 1330 West Michigan Street, Rm A304 Indianapolis, Indiana 46206 (317) 243-9100
	Refuse Disposal Act: recodified as Indiana Solid Waste Disposal Law IC-36-9-30. Rule 330 IAC 4.	Written approval must be obtained before disposal of infectious waste in a sanitary landfill.	
Iowa	Iowa Code 1985, Section 455B.304. 900--100.3(2) Iowa Administrative Code (IAC)	Land disposal of infectious waste is prohibited unless a special waste authorization is granted that requires autoclaving or formalin treatment before land disposal.	Air and Waste Permit Branch Program Operations Division Iowa Department of Water, Air and Waste Management Henry A. Wallace Building 900 East Grand Street Des Moines, Iowa 50319 (515) 281-8692

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Kansas	Kansas Statutes Annotated, Chapter 65, Article 34, as amended. Kansas Administrative Regulations, Title 28. Public Health, Article 29, Regulation 27, Effective May 1984.	Infectious waste must be incinerated, treated before land disposal, or ground to the sewer. Untreated infectious waste may be sent to a hazardous waste land disposal facility or to a sanitary landfill with authorization from the Department.	Solid Waste Management Section Department of Health and Environment Forbes Field, Building 321 Topeka, Kansas 66620 (913) 862-9360, Ext. 309
Kentucky	Kentucky Revised Statutes, 224.005(227)(a).	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Division of Waste Management Cabinet of Natural Resources and Environmental Protection 18 Reilly Road Frankfort, Kentucky 40601 (502) 564-6716
	Certificate of Need and Licensure Law, as revised, (originally effective January 1, 1973). 902 Kentucky Administrative Regulations, 20:009, Hospital Facility Regulation.	Hospitals must have an incinerator capable of destroying infectious waste. Hospitals which satisfy the treatment, packaging, and transportation requirements can secure waivers to incinerate the waste in city facilities. Revised regs effective 6/4/85 require that sharp waste (needles, glass, etc.) be separated from other infectious waste. Sharp waste is to be packaged in rigid containers for either incineration or disposal in approved landfills.	Division for Licensing and Regulation Department of Human Resources 275 E. Main Street Frankfort, Kentucky 40601 (502) 564-2800

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Louisiana	Louisiana Revised Statutes, Act 449, 30: 1133, Environmental Affairs Act.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations. Policy is to allow disposal of treated infectious waste in selected sanitary landfills.	Hazardous Waste Division Department of Natural Resources P.O. Box 44066 Baton Rouge, Louisiana 70804 (504) 342-1216
Maine	Title 38 of Maine Revised Statutes Annotated.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Bureau of Oil and Hazardous Waste Materials Department of Environmental Protection State House — Station 17 Augusta, Maine 04333 (207) 289-2651
Maryland	Annotated Maryland Code, Health Environment Article, Sections 9-210(g) and 9-229, effective July 1, 1984. Amended Guidelines for the Disposal of Infectious Waste, effective July 1, 1984.	Infectious waste cannot be disposed of in a landfill. Incineration is the preferred method of treatment.	Air Management Administration Department of Health and Mental Hygiene 201 West Preston Street, 2nd Floor Baltimore, Maryland 21201 (301) 225-5360

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Massachusetts	Massachusetts General Laws, Chapter 111, Subsections 3 and 51-56, and Chapter 111D. 105 CMR 130.354. Hazardous Infectious Waste Disposal Regulations; and 105 CMR 180.275, Regulation for Disposal of Infectious Materials from Independent Laboratories. Massachusetts General Laws, Chapter 21-C.	Infectious waste must be incinerated or treated before disposal.	Massachusetts Department of Public Health 150 Tremont Street Boston, Massachusetts 02111 (617) 727-2700
	Massachusetts General Laws, Chapter 21-C.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Division of Solid and Hazardous Waste 1 Winter Street Boston, Massachusetts 02108 (617) 292-5582
Michigan		As of December 28, 1985, Michigan deleted its list of infectious wastes from the regulations.	Office of Hazardous Waste Management Michigan Department of Natural Resources P.O. Box 30038 Lansing, Michigan 48909 (517) 373-1720

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Minnesota	Minnesota Statutes Annotated Chapters 115A and 116, Enacted by Laws of 1980, as amended. Minnesota Code of Agency Rules, Title 6, Part 4, as amended SW1-12 and SW6-2viii.	Land disposal of infectious waste is prohibited.	Division of Solid and Hazardous Waste Minnesota Pollution Control 1935 West County Road B-2 Roseville, Minnesota 55113 (612) 296-7373
Mississippi	No laws or regulations pertaining to infectious waste management.		Division of Solid/Hazardous Waste Management Bureau of Pollution Control Department of Natural Resources P.O. Box 10385 Jackson, Mississippi 39209 (601) 961-5171
Missouri	Missouri Hospital Licensing Law, Chapter 197 of Missouri Revised Statutes, Rules and Regulations for Hospitals.	Infectious waste generated by hospitals must be either incinerated or autoclaved before being sent to a landfill permitted to accept the waste. Waste is required to be treated on site. The state expects to revise regulations later this year.	Missouri Department of Health Bureau of Hospital Licensing P.O Box 570 Jefferson City, Missouri 65102 (314) 751-2713

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Missouri	Missouri Hazardous Waste Management Law, Chapter 260 of Revised Statutes of Missouri, 1985, as amended.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Waste Management Program Department of Natural Resources P.O. Box 176 Jefferson City, Missouri 65102 (314) 751-3241
	Missouri Solid Waste Management Law, Chapter 260.200 of Revised Statutes of Missouri, 1975. Missouri Solid Waste Management Rules and Regulations, 10CSR80, Chapters 1-5.	Sterilized infectious waste may be disposed of in any permitted solid waste landfill.	
Montana	Montana Solid Waste Management Act of 1976. Administrative Rules of Montana, Title 16, Chapter 14, Subchapter 5, Solid Waste Management/Refuse Disposal.	Policy is to recommend treatment of infectious waste before land disposal.	Solid and Hazardous Waste Management Bureau Department of Health and Environmental Sciences Cogswell Building, Rm B201 Helena, Montana 59620 (406) 444-2821
	Montana Hazardous Waste Act of 1981.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Nebraska	Nebraska Environmental Protection Act, Section 81-1501 through 81-1540.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Land Quality Division Department of Environmental Control State House Station P.O. Box 94877 Lincoln, Nebraska 68509 (402) 471-2186
Nevada	Nevada Revised Statutes, Chapter 459, Hazardous Waste Disposal and Solid Waste Disposal. Regulations Governing Solid Waste Management, Effective 1977.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations. Infectious waste generated by hospitals may be placed in a land disposal facility only under approval of the Department.	Division of Environmental Protection Department of Conservation and Natural Resources Capital Complex Carson City, Nevada 89710 (702) 885-4670

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
New Hampshire	New Hampshire Revised Statutes Annotated 151, 1979. Health Facilities Rules and Regulations, effective February 1984. General Requirements For all Facilities, HEP-801.	Infectious waste generated by health care facilities must be incinerated.	Bureau of Health Facilities Administration Division of Public Health Department of Health and Welfare 6 Hazen Drive Concord, New Hampshire 03301 (603) 271-4592
New Jersey	New Jersey Statues Annotated, Title 13: Conservation and Development, Chapter 1E-1. New Jersey Administrative Code, Title 7, Chapter 26, as amended. New regulations dealing with hazardous wastes expected within the year.	Infectious waste must be rendered non-infectious in accordance with the standards of the New Jersey Department of Health.	Division of Waste Management Department of Environmental Protection 33 East Hanover Street Trenton, New Jersey 08625 (609) 292-9877
	New Jersey Health Care Facilities Planning Act. New Jersey Administrative Code 8:43-B-3.6.	All infectious waste generated by hospitals must be treated before land disposal. Infectious waste that is not autoclaved or incinerated can be double-bagged for land disposal by a method approved by the Department of Environmental Protection.	New Jersey Department of Health Division of Health Facilities Evaluation CN 370 Trenton, New Jersey 08625 (609) 292-7834

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
New Mexico	Hazardous Waste Act, Section 74-4-3, as amended through 1981.	No specific regulations on infectious waste. Incineration or sterilization of infectious waste followed by land disposal is recommended.	Solid and Hazardous Waste Management Programs Health and Environment Department P.O. Box 968 Santa Fe, New Mexico 87504-0968 (505) 827-5271 or 827-0020
New York	Environmental Conservation Law, Article 27. Title 6 NCRR part 364. Collection and Transport of Industrial, Commercial, and Certain Other Wastes.	Anyone transporting a hospital waste off-site (including infectious waste) must have a waste transporter's permit.	Division of Solid and Hazardous Waste Department of Environmental Conservation 50 Wolf Road, Room 117 Albany, New York 12233 (518) 457-3254
North Carolina	North Carolina Solid and Hazardous Waste Act, as revised, July 1983. 10 NCAC 10G, Solid Waste Management, July 1, 1985	Infectious waste must be treated by an approved method prior to disposal in a landfill.	Solid and Hazardous Waste Management Branch Division of Health Services Department of Human Resources P.O. Box 2091 Raleigh, North Carolina 27602 (919) 733-2178

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
North Dakota	No governing statute or regulations.	Policy is to require autoclaving or incineration of all infectious waste generated by hospitals and nursing homes. No untreated infectious waste may be disposed of in a landfill. Every hospital and nursing home must have access to a double-chambered, approved incinerator in order to be licensed.	Division of Health Facilities Department of Health State Capitol Building Bismark, North Dakota 58505 (701) 224-2352
Ohio	Ohio Revised Code, Title 37, Chapter 34, as amended. Ohio Administrative Code, Regulations 3745-27 and 3745-37, Effective July 29, 1976.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Division of Solid and Hazardous Waste Management Ohio Environmental Protection Agency 361 East Broad Street Columbus, Ohio 43215 (614) 466-7220

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Oklahoma	Oklahoma Statutes, Title 63, 1981, Section 1-2001 et seq., Oklahoma Controlled Industrial Waste Disposal Act.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations. Current policy is based on CDC guidelines. Infectious waste regulations are being drafted.	Institutional Services, Medical Facilities Department of Health P.O. 53551 1000 N.E. 10th Street, 4th Floor Oklahoma City, Oklahoma 73152 (405) 271-6811
Oregon	Oregon Revised Statutes, Chapter 459, as amended. Oregon Administrative Rules, Chapter 340, Division 61.	Land disposal of infectious waste is controlled through the permitting process for land disposal facilities.	Hazardous and Solid Waste Division Department of Environmental Quality P.O. Box 1760 Portland, Oregon 97207 (503) 229-6266
Pennsylvania	Pennsylvania Statutes, 62 PS 901-1059, Public Welfare Code. Pennsylvania Code, Title 28, Chapter 147.74, Pennsylvania State Health Department Regulations: Disposal of Bacterial and Pathological Wastes That Are Generated in Hospitals and Medical Care Facilities.	Current policy is to allow off-site sterilization of infectious waste. New regulations are being drafted.	Bureau of Waste Management Department of Environmental Resources Fulton Building, 8th Floor P.O. Box 2063 Harrisburg, Pennsylvania 17120 (717) 787-6239

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Rhode Island	Rhode Island Hazardous Waste Management Act of 1978. Hazardous Waste Rules and Regulations Effective December 20, 1979. Rules and Regulations for Hazardous Waste Generation, Transportation, Treatment, Storage and Disposal - Effective July 18, 1984.	Infectious waste is regulated as a hazardous waste.	Division of Air and Hazardous Materials Department of Environmental Management 204 Cannon Building 75 Davis Street Providence, Rhode Island 02908 (401) 277-2797
South Carolina	Code of Laws of South Carolina, 1976, Sections 44-56-10 through 44-56-140, Hazardous Waste.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations. The state recommends that infectious hospital waste be incinerated or otherwise treated before land disposal.	Bureau of Solid and Hazardous Waste South Carolina Department of Health and Environmental Control 2600 Bull Street Columbia, South Carolina 29201 (803) 758-5681

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
South Dakota	South Dakota Codified Laws, Chapter 34A-6-2, Solid Waste Disposal Act.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Office of Air Quality and Solid Waste Department of Water and Natural Resources Joe Foss Building 523 East Capitol Avenue Pierre, South Dakota 57501 (605) 773-3153
Tennessee	Tennessee Hazardous Waste Management Act of 1977, as amended. Tennessee Solid Waste Disposal Act, as amended.	The state is initiating rulemaking action.	Division of Solid Waste Management Tennessee Department of Public Health and Environment Customs House, 4th Floor 601 Broadway St. Nashville, Tennessee 37219-5403 (615) 741-3424
	Tennessee Code Annotated, 6811-201 through 217 Minimum Standards and Regulations for Hospitals, 1974.	All infectious waste generated by hospitals must be incinerated in closed incinerators on elevated platforms.	Hospital Licensing Board 283 Plus Park Nashville, Tennessee 37210 (615) 367-6200

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Texas	Revised Civil Statutes of the State of Texas Annotated, Article 4477-7 Texas Solid Waste Disposal Act; and Article 4477-1, Texas Sanitation and Health Protection Law, as amended. Texas Administrative Code 325.136(b)(1), Texas Department of Health, Municipal Solid Waste Management Regulations, effective July 1983, as amended.	Infectious waste is regulated as a special waste. Incineration is the preferred method of treatment. Untreated waste may be double bagged and disposed of in a Type I municipal landfill.	Bureau of Solid Waste Management Texas Department of Health 1100 West 49th Street, T601A Austin, Texas 78756 - 3199 (512) 458-7271
Utah	Utah Code Annotated, Title 26, Chapter 14, Utah Solid and Hazardous Waste Act, Effective June, 1981.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Bureau of Solid and Hazardous Waste Department of Health P.O. Box 45500 Salt Lake City, Utah 84145-0501 (801) 533-4145

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Vermont	Vermont Statutes Annotated, Title 10, Chapter 159. Hazardous Waste Management Regulations, as amended September 13, 1984, Section 6602(2)(a)(14).	Infectious waste is regulated as a hazardous waste.	Hazardous and Solid Waste Management Division Department of Water Resources and Environmental Engineering Agency of Environmental Conservation State Office Building Montpelier, Vermont 05602 (802) 828-3395
Virginia	Code of Virginia, Title 32.1, Chapter 6, Article 3. Virginia Regulations Governing Disposal of Solid Waste, April, 1971.	Infectious wastes are not regulated as hazardous wastes. Waste generators must have special permission to dispose of non-municipal waste. Rules do not preclude land disposal of untreated infectious waste.	Division of Solid and Hazardous Waste Management Department of Health Monroe Building, 11th Floor 101 North 14 Street Richmond, Virginia 23219 (804) 225-2667

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Washington	Revised Code of Washington, Hazardous Waste Disposal Chapter 70.105.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Hazardous Waste Section Department of Ecology Mail Stop PV-11 Olympia, Washington 98504 - 8711 (206) 459-6322
	Revised Code of Washington, Hospital Licensing and Regulation Statute, Chapter 70.41. Washington Administrative Code, 248-18-170, Hospital Rules and Regulations.	Infectious waste generated by hospitals must be incinerated or disposed of by other approved methods. Approved methods include autoclaving, retorting, or double bagging before land disposal.	Department of Social and Health Services Facility Licensing Certification Section of the Health Services Division Mail Stop ET-31 Olympia, Washington (206) 753-7039
West Virgina	Code of West Virginia, Chapter 20, Article SE, Effective July 7, 1981.	Infectious waste regulations are being draftad.	State Health Department 1830 Washington Street East Charleston, West Virginia 25305 (304) 348-2970

APPENDIX (Continued)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Wisconsin	Wisconsin Statutes Annotated, Chapter 144, as amended.	The state has statutory authority to regulate infectious waste as a hazardous waste but has not yet promulgated regulations.	Bureau of Solid Waste Management Department of Natural Resources P.O. Box 7921 Madison, Wisconsin 53707 (608) 266-2111
	Chapter NR 181, and guidance summary "Handling and Disposal of Pathological Waste."	Policy is to recommend incineration of infectious waste. Infectious waste which has been autoclaved or sterilized may be bagged and disposed of in an engineered landfill.	
Wyoming	No regulations pertaining to infectious waste management.		Solid Waste Management Program State of Wyoming Department of Environmental Quality Herschler Building 122 West 25th Street Cheyenne, Wyoming 82002 (307) 777-7752 Department of Health and Social Services Division of Health and Medical Services 4th Floor Hathaway Bldg. Cheyenne, Wyoming 82002 (307) 777-7121

BEST AVAILABLE TECHNOLOGY AND CHAPTER 127 PLAN APPROVAL CRITERIA FOR HOSPITAL/INFECTIOUS WASTE INCINERATORS

APPLICABILITY

This document specifies the plan approval requirements for hospital/infectious waste incinerator facilities including Best Available Technology (BAT) as required by 25 Pa. Code 127.12(a)(5). This document is not intended to be a comprehensive listing of the Chapter 127 requirements. Rather, it elaborates on selective provisions of Chapter 127. The applicable capacity refers to the facility rather than the individual unit. However the emission limitations are applicable to individual units.

This criteria is not applicable to crematory incinerators or incinerators located in any hospital or in any medical care facility if the units will be used to incinerate only general refuse, provided that the applicant demonstrates that the proposed incinerator will burn only general refuse and the infectious, hazardous, and chemotherapeutic wastes will be segregated and disposed of satisfactorily. The permitting criteria for such incinerators will be determined on a case-by-case basis incorporating the requirements of this Criteria as appropriate.

This Criteria will be periodically revised as control technology improves.

In addition to these applicable permitting requirements, facilities capable of burning hospital/infectious wastes at rates greater than or equal to 50 tons per day shall also meet the permitting criteria established for municipal waste incineration and resource recovery facilities capable of burning municipal wastes at rates greater than or equal to 50 tons per day.

DEFINITIONS

INCINERATOR - Any device specifically designed to provide the controlled combustion of wastes with the products of combustion directed to a flue as defined at 25 Pa. Code Section 121.1.

HOSPITAL WASTE - Wastes generated in any hospital or any health care facility or any pathological wastes (except for human and animal remains burned in a crematory incinerator), chemotherapeutic wastes or infectious wastes generated in any facility.

INFECTIOUS WASTE - Waste that contains or may contain any disease producing microorganism or material.

Infectious wastes include, but are not limited to, the following:

(a) Those wastes that are generated by hospitalized patients who are isolated in separate rooms in order to protect others from their severe and communicable disease.

(b) All cultures and stocks of etiologic agents.

(c) All waste blood and blood products.

(d) Tissues, organs, body parts, blood and body fluids that are removed during surgery and autopsy, and other wastes generated by surgery or autopsy of septic cases or patients with infectious diseases.

(e) Wastes that were in contact with pathogens in any type of laboratory work, including collection containers, culture dishes, slides, plates and assemblies for diagnostic tests; and devices used to transfer, inoculate and mix cultures.

(f) Sharps, including hypodermic needles, suture needles, disposable razors, syringes, pasteur pipettes, broken glass and scalpel blades.

(g) Wastes that were in contact with the blood of patients undergoing hemodialysis at hospitals or independent treatment centers.

(h) Carcasses and body parts of all animals which were exposed to zoonotic pathogens.

(i) Animal bedding and other wastes that were in contact with diseased or laboratory research animals or their excretions, secretions, carcasses, or body parts.

(j) Waste biologicals (e.g., vaccines) produced by pharmaceutical companies for human or veterinary use.

(k) Food and other products that are discarded because of contamination with etiologic agents.

(l) Discarded equipment and equipment parts that are contaminated with etiologic agents and are to be discarded.

CHEMOTHERAPEUTIC WASTE - All waste resulting from the production or use of antineoplastic agents used for the purpose of stopping or reversing the growth of malignant cells. Chemotherapeutic waste shall not include any waste containing antineoplastic agents that are listed as hazardous waste under 25 Pa Code Section 75.261 (relating to criteria, identification, and listing of hazardous waste).

HOSPITAL/INFECTIOUS WASTE INCINERATOR FACILITY - Any combination of hospital/infectious waste incinerators located on one or more contiguous or adjacent properties and which is owned or operated by the same person or by persons under common control.

CREMATORY INCINERATOR - Any incinerator designed and used solely for the burning of human remains or animal remains.

BEST AVAILABLE TECHNOLOGY REQUIREMENTS

A. Emission Limitations

1. **Facilities with capacity ≤500 lbs/hr:**

   a. Particulate matter emissions shall not exceed 0.08 grain per dry standard cubic foot of exhaust gas, corrected to 7% O_2.

   b. Carbon monoxide (CO) emissions shall not exceed 100 ppmv, hourly average, corrected to 7% O_2 on a dry basis.

   c. Hydrochloric acid (HCl) emissions shall not exceed 4 lbs/hr or, shall be reduced by 90% (by weight) on an hourly basis.

   d. Visible air contaminants shall not be emitted in such a manner that the opacity of the emissions is equal to or greater than 10% for a period or periods aggregating more than 3 minutes in any one hour; or equal to or greater than 30% at any time.

2. **Facilities with capacity >500 lbs/hr and ≤2000 lbs/hr:**

   a. Particulate matter emissions shall not exceed 0.03 grain per dry standard cubic foot of exhaust gas, corrected to 7% O_2.

   b. Carbon monoxide (CO) emissions, as measured at a location upstream of the control devices, shall not exceed 100 ppmv, hourly average, corrected to 7% O_2 on a dry basis.

   c. Hydrochloric acid (HCl) emissions shall not exceed 30 ppmv, hourly average, corrected to 7% O_2 on a dry basis; or, shall be reduced by 90% by weight on an hourly basis.

   d. Sulfur dioxide (SO_2) emissions shall not exceed 30 ppmv, hourly average, corrected to 7% O_2 on a dry basis; or shall be reduced by 75% (by weight) on an eight-hour basis.

   e. Visible air contaminants shall not be emitted in such a manner that the opacity of the emissions is equal to or

greater than 10% for a period or periods aggregating more than 3 minutes in any one hour; or equal to or greater than 30% at any time.

3. Facilities with capacity >2000 lbs/hr:

a. Particulate matter emissions shall not exceed 0.015 grain per dry standard cubic foot of exhaust gas, corrected to 7% O_2.

b. Carbon monoxide (CO) emissions, as measured at a location upstream of the control devices, shall not exceed 100 ppmv, hourly average, corrected to 7% O_2 on a dry basis.

c. Hydrochloric acid (HCl) emissions shall not exceed 30 ppmv, hourly average, corrected to 7% O_2 on a dry basis; or, shall be reduced by 90% (by weight) on an hourly basis.

d. Sulfur dioxide (SO_2) emissions shall not exceed 30 ppmv, hourly average, corrected to 7% O_2 on a dry basis; or shall be reduced by 75% (by weight) on an eight-hour basis.

e. Combustion efficiency (C.E.) shall be at least 99.9 percent on a hourly basis, computed as follows:

$$C.E. = \frac{[CO_2]}{[CO_2] + [CO]} \times 100$$

$[CO_2]$ = Concentration of carbon dioxide
$[CO]$ = Concentration of carbon monoxide

f. Visible air contaminants shall not be emitted in such a manner that the opacity of the emissions is equal to or greater than 10% for a period or periods aggregating more than 3 minutes in any one hour; or equal to or greater than 30% at any time.

B. Operating Requirements

1. The secondary chamber shall be maintained at a temperature of 1800°F. The temperature of 1800°F shall be maintained for at least 2 seconds with a minimum secondary chamber residence time of 1 second. The ducting between the secondary chamber and heat recovery system or the breaching and a portion of the stack (tertiary chamber) may if desired, be included for the residence time demonstration. The temperature exiting the tertiary chamber shall be maintained at 1800°F. A thermocouple shall be appropriately located to confirm the temperature. The auxiliary (secondary and tertiary) burners of the incinerator should be designed such that without the assistance of the heat content of the waste, a minimum temperature of 2000°F can be maintained for at least 2 seconds.

2. The firing of the burners and the combustion air shall be modulated automatically to maintain a secondary chamber exit temperature of 1800°F.

3. The incinerator shall be equipped with an automatic loader except for units with capacities less than or equal to 300 lbs/hr and equipped with the interlocks specified in paragraph B.4. However, a sealed feeding device capable of preventing combustion upsets during charging will be required for the units with capacity less than 300 lbs/hr.

4. For batch fed incinerators, interlocks should be provided to prevent charging until: (1) the secondary chamber exit temperature is established and holding at 1800°F; and, (2) the combustion cycle is complete.

5. For non-batch fed incinerators, the charging of waste to the incinerator shall automatically cease through the use of an interlock system if:

   a. The incinerator's secondary temperature drops below 1800°F for a 15 minute period, or

   b. The carbon monoxide emissions are equal to or greater than 150 ppmv, corrected to 7% O_2 on a dry basis for a 15 minute period, or

   c. The flue gas oxygen level drops below 6% (wet basis) for a 15 minute period, or

   d. The opacity of the visible emissions is equal to or greater than 10% for a period of 15 minutes.

OTHER CHAPTER 127 REQUIREMENTS

C. Ambient Impact Analyses

Ambient impact analyses shall be conducted for: a) arsenic and compounds; b) beryllium and compounds; c) cadmium and compounds; d) hexavalent chromium and compounds; e) lead and compounds; f) mercury and compounds; g) nickel and compounds; h) polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) expressed as 2,3,7,8 tetrachlorinated dibenzo-p-dioxin (TCDD) equivalents using toxicity equivalents factors (TEFs) described in Appendix A. Using available emission factors, the emissions from the facility shall be estimated and the analyses shall be conducted by performing dispersion modeling using the facility's exhaust characteristics. The analyses shall be conducted in accordance with the procedures stipulated in Appendix C.

If the application is subject to "Prevention of Significant Deterioration" (PSD) requirements, the analyses shall be conducted in accordance with the "Guidelines on Air Quality Modeling" dated January, 1983 (as revised). The applicant should discuss the modeling requirements with the Department prior to starting any modeling study.

The analysis must show that predicted concentrations do not exceed the following annual ambient concentrations. Levels exceeding these concentrations have been determined by the Department to be unacceptable.

Contaminants	Ambient Concentration ($\mu g/m^3$)
Arsenic and compounds	0.23×10^{-3}
Beryllium and compounds	0.42×10^{-3}
Cadmium and compounds	0.56×10^{-3}
Hexavalent Chromium and compounds	0.83×10^{-4}
Lead and compounds	0.50
Mercury and compounds	0.08
Nickel and compounds	0.33×10^{-2}
PCDD & PCDF expressed as 2,3,7,8 TCDD equivalents	0.30×10^{-7}

Compliance shall be verified by stack sampling as described in paragraph F. Using the actual stack emission rates, the exhaust parameters from each test and the dispersion modeling techniques specified in the application as approved by the Department, the calculated maximum annual ambient concentrations shall not exceed the above levels.

D. Monitoring Requirements

The primary chamber temperature and secondary chamber exit temperature shall be continuously measured and recorded. Sensors shall be located such that flames from the burners do not impinge on the sensors.

Incinerators with a capacity larger than 500 lbs/hr shall be equipped with instruments for the continuous monitoring and recording of O_2, CO and opacity. Continuous monitoring and recording for CO_2, is also required for facilities with a capacity greater than or equal to 2000 lbs/hr.

The Department reserves the right to require the owner/operator of facilities with a capacity less than 2000 lbs/hr, to install SO_2 monitors at a time after the initial compliance tests if it is determined to be necessary. The Department also reserves the right to require facilities with a capacity greater than 2000 lbs/hr, to install HCl and SO_2 monitors at any time if it is determined to be necessary.

The O_2, CO and CO_2 monitors, when required, shall be co-located upstream of the air pollution control devices. If the applicant

chooses to comply with SO_2 and HCl emission limitations by meeting the 75% and 90% reduction requirement, the SO_2 and HCl monitors, when required, shall be located upstream and downstream from the air pollution control device. If the applicant chooses to monitor the two locations with a single detector, the two locations should be sampled at an interval acceptable to the Department.

Continuous monitoring shall be conducted in accordance with 25 Pa Code Chapter 139 and be approved by the Department.

The Department reserves the right to require, at a later date, the owner/operator to provide telemetering of continuous monitoring data to the Department.

E. Start-up and Shut-down Requirements

No waste shall be charged to the incinerator until equilibrium at the required temperature has been attained in the chambers. The control equipment shall be operational and functioning properly prior to the introduction of waste into the incinerator and until all the wastes are incinerated.

During shutdowns the required temperatures are to be maintained in the chambers using auxiliary burners until the wastes are completely combusted.

A detailed procedure for normal system start-up and shut-down shall be submitted as a part of the application for approval including the duration of preheat and burn-out cycles.

F. Testing Requirements

1. Facilities with capacity ≤500 lbs/hr:

Source tests shall be conducted for: a) particulate matter; b) HCl; c) CO; d) arsenic and compounds (expressed as arsenic); e) beryllium and compounds (expressed as beryllium); f) cadmium and compounds (expressed as cadmium); g) hexavalent chromium and compounds (expressed as chromium); h) lead and compounds (expressed as lead); i) mercury and compounds (expressed as mercury); j) nickel and compounds (expressed as nickel); and k) PCDD and PCDF (expressed as 2,3,7,8 TCDD equivalents).

The Department reserves the right to require the owner or operator to conduct further source tests at any time if it is determined to be necessary by the Department after the initial compliance tests.

2. Facilities with capacity >500 lbs/hr and ≤2000 lbs/hr:

Source tests shall be conducted for: a) particulate matter; b) HCl; c) CO; d) SO_2; e) arsenic and compounds (expressed as arsenic);

f) beryllium and compounds (expressed as beryllium); g) cadmium and compounds (expressed as cadmium); h) hexavalent chromium and compounds (expressed as chromium); i) lead and compounds (expressed as lead); j) mercury and compounds (expressed as mercury); k) nickel and compounds (expressed as nickel); and l) PCDD and PCDF (expressed as 2,3,7,8 TCDD equivalents).

The owner or operator shall conduct source tests at any time or interval of time as may be prescribed by the Department. At a minimum, source tests shall be conducted for the above specified pollutants every year. As a data base is established and the emissions consistently show compliance the schedule may be altered.

3. Facilities with capacity >2000 lbs/hr:

Source tests shall be conducted for: a) particulate matter; b) HCl; c) CO; d) SO_2; e) arsenic and compounds (expressed as arsenic); f) beryllium and compounds (expressed as beryllium) g) cadmium and compounds (expressed as cadmium); h) hexavalent chromium and compounds (expressed as chromium); i) lead and compounds (expressed as lead); j) mercury and compounds (expressed as mercury); k) nickel and compounds (expressed as nickel); and l) PCDD and PCDF (expressed as 2,3,7,8 TCDD equivalents).

The owner or operator shall conduct source tests at any time or interval of time as may be prescribed by the Department. At a minimum, source tests shall be conducted:

a. For all pollutants specified in F.1 of this criteria except PCDD and PCDF - every six months, and

b. For PCDD and PCDF - every year.

c. For HCl and SO_2 (if monitors are required) - as required by the Department for the initial certification and system performance audits of the continous monitors.

As a data base is established and the emissions consistently show compliance the schedule may be altered.

All tests are to be conducted in accordance with the Department's source testing procedures described in "Source Testing Manual, Revision No. 1" (as revised) dated January, 1983. Source testing procedures are to be approved by the Department prior to testing.

G. Record Keeping and Reporting Requirements

Continuous emission/parameter data gathered from the monitors shall be submitted to the Department quarterly. The data shall be retained for at least two (2) years following the date of record and shall be made available to the Department during facility inspections.

The Department shall be notified by telephone immediately following any failure of process equipment, failure of any air pollution control equipment, failure of any monitoring equipment, or a process operational error which results in an increase in emissions above any allowable emission rate. In addition, the Department shall be notified in writing of the problem and measures taken to correct the problem as expeditiously as possible but no later than five (5) days following such failure.

H. Operator Training Requirements

Prior to the start-up, all incinerator operators shall be trained by the equipment manufacturers' representatives and/or another qualified organization as to proper operating practices and procedures. The content of the training program shall be submitted to the Department for approval. The applicant shall submit a copy of a certificate verifying the satisfactory completion of a training program prior to issuance of the operating permit. The applicant shall not operate the incinerator without an operator who has satisfactorily completed the training program.

I. General Application Requirements

The plan approval application shall include a description of each specific waste and approximate quantity of each such wastes which will be charged to the incinerator. The application shall, as a minimum, contain the final design specifications of the incinerator and the associated air pollution control devices with dimensioned drawings indicating the locations of burners, air injection ports and monitors. The application shall also include an estimate of potential and actual emissions of the non-typical air contaminants. These contaminants shall include: a) HCl; b) PCDD and PCDF (expressed as 2,3,7,8 TCDD equivalents (estimated as potential and actual emissions)); c) arsenic; d) beryllium; e) cadmium; f) hexavalent chromium; g) nickel; h) lead; and, i) mercury. The application shall also include a set of calculations for estimating secondary chamber residence time using the procedures contained in Appendix B and the results of ambient impact analyses conducted using the modeling procedures contained in Appendix C.

Approved by: James K. Hambright, Director
Bureau of Air Quality Control

January 21, 1988

APPENDIX A
to APPENDIX C

2,3,7,8 - TCDD Toxicity Equivalence Factors (TEFs)

Homologue/Congener	TEF
Mono through trichloro dioxins and Dibenzofurans	0
2,3,7,8-TCDD	1
Other TCDDs	0.01
2,3,7,8-PeCDD	0.5
Other PeCDDs	0.005
2,3,7,8-HxCDDs	0.04
Other HxCDDs	0.0004
2,3,7,8 HpCDDs	0.001
Other HpCDDs	0.00001
OCDDs	0
2,3,7,8-TCDF	0.1
Other TCDFs	0.001
2,3,7,8 PeCDFs	0.1
Other PeCDFs	0.001
2,3,7,8-HxCDFs	0.01
Other HxCDFs	0.0001
2,3,7,8-HpCDFs	0.001
Other HpCDFs	0.00001
OCDFs	0

APPENDIX - B
to APPENDIX C

RESIDENCE TIME CALCULATION GUIDANCE

The review of all incinerators shall include verification of the residence time stated on the application. This guidance shall be followed to assure that these calculations are handled in a uniform manner.

STEP 1. Estimate the total heat input to the system:

Total system heat input (Btu/hr) = [Maximum waste firing rate (lbs/hr) x Maximum heating value (Btu/lb)] + Average primary burner heat input + Average secondary burner input.
Note: Use the average burner inputs required after the onset of waste burning.

Use a waste heating value of 8500 BTU/lb.

STEP 2. Estimate the system heat loss (prior to heat recovery):

System heat loss = Shell loss + sensible heat in ash + sensible heat in unburned carbon + latent heat.

The heat loss may be assumed to be 20% of total heat input.

STEP 3. Calculate the net heat available (Q) to raise the temperature of the products of combustion:

Q (Btu/hr) = (Total system heat input) - (system heat loss)

STEP 4. Calculate the weight of product of combustion (M)

$$M = Q/\{C_p \times (T_o - T_i)\}$$

C_p = average specific heat (Btu/lb ^oF), assume a value of 0.28.
T_o = exit temperature (^oF), use the design temperature of 2000 ^oF as T_o.
T_i = ambient air temperature (^oF), assume the ambient temperature to be 70^oF.

STEP 5. Calculate the volume of product of combustion (F):

$$F(scfs) = \frac{M}{d \times 60 \times 60}$$

d (lb/cu. ft.) = density of exhaust gases at 70°F, use a value of 0.075.

$$F'(acfs) = F \times \frac{(T_o + 460)}{530}$$

$$F' \text{ @ design temperature} = F \times \frac{2460}{530}$$

STEP 6. Calculate the volume of secondary chamber and tertiary chamber (if tertiary chamber is included for the 2 second residence time demonstration). Tertiary chamber is the area between secondary chamber and heat recovery system or breaching area/part of the stack.

STEP 7. Residence time = $\frac{\text{Chamber volume}}{F'}$

For a minimum 1 sec secondary chamber residence time,

$$\frac{\text{secondary chamber volume}}{F'} = >1$$

For a minimum 2 sec @design temperature 2000°F,

$$\frac{\text{secondary + tertiary chamber volume}}{F'} = >2$$

APPENDIX C

to APPENDIX C

DISPERSION MODELING PROCEDURES

I. PROCEDURE FOR DETERMINATION OF STACK HEIGHT ADEQUACY AND BUILDING INFLUENCES ON STACK PLUME DISPERSION

In the absence of any outside interference on the dispersion of stack plumes, the PTPLU dispersion model can be used to make a conservative screen of ground level concentration. Most of the time influences do exist, and they must be considered. First the building or buildings of potential influence must be determined. When more than one building is likely to influence the stack plume dispersion, the controlling influence needs to be determined. Except in infrequent cases the determination of potential building influence shall be made of buildings on site at the facility.

The building influence can be determined as follows:

A. DETERMINE POSSIBLE BUILDING INFLUENCE:

1. Determine the height (H) and projected width (W) of the tallest building at the facility.

2. Draw a circle with a radius of 10 H or 10 W (whichever is less) around the building.

3. Disregard any possible building influence if the stack is not within the circle, as determined in step 2, above.

4. Working closer to the stack from the distance of the tallest building, repeat steps 1, 2, and 3 above to determine which other buildings may also exert an influence on the stack.

5. If no buildings are considered significant enough to exert an influence on the stack, skip the remaining sections in this APPENDIX and use METHOD A for dispersion modeling.

B. DETERMINE BUILDING CAVITY HEIGHT:

1. Calculate the building cavity height (H_c) for all significant buildings (found by the procedure in Section A) by use of the following formula:

   $H_c = H + 0.5\ L$, where L is the lesser of the building height or projected width.

2. Select the building with the largest cavity height as the one which would exert the greatest influence.

C. CHECK STACK HEIGHT ADEQUACY:

1. Check to insure that stack design would not obstruct good dispersion of substance (i.e., no rain caps, elbows, etc.).

2. If the physical stack height is greater than Hc, and if the distance of 10 L (the building wake region) does not extend beyond the plant boundary, skip the rest of the appendix, go to page C-4 and use METHOD A.

3. Calculate the effective stack height, H_e, using the following formula:

   $H_e = H_s + H_m$ where H_s is physical stack height and H_m is momentum plume rise calculated by the following equations (Ref: Regional Workshops on Air Quality Modeling: Summary Report, EPA-450/4-82-015, Appendix C, page C-2, (Amended October 1983)):

$$H_m = \left[\frac{3\ F_m(x)}{b^2 u^2} \right]^{1/3}$$

where
- b = (1/3 + u/v_s),
- u = critical wind speed (m/s), (assume 7.5 m/s)
- x = downwind distance (m) (assume 2 building heights or projected widths downwind, whichever is less),
- F_m = momentum flux $=(T_a/T_s)\ V_s^2 \cdot d^2/4$
- T_a = ambient air temperature (^oK) (assume 293^oK),
- T_s = stack exit temperature (^oK),
- V_s = stack exit velocity (m/s); and
- d = stack inner diameter (m).

4. If H_e is greater than H_c and if the distance of 10 L (the wake region) does not extend beyond the plant boundary, skip the rest and use METHOD A found in page C-4.

5. Go to page C-4 and use METHOD B for all remaining cases.

The PTPLU-2 dispersion model (METHOD A) may be used for screening if: (1) there are no building influences predicted by the procedure in Section A above, or (2) the stack height is adequate and there are no building wake effects beyond the property line (according to Section C above).

II. DISPERSION MODELING PROCEDURES

For screening purposes, the PTPLU dispersion model may be used for evaluation of point sources in cases where no building influences are expected. Some judgement must be made, however, in cases where stack designs (rain caps, elbows, etc.) may result in poorer dispersion. Where building influences may be of concern, as determined earlier, conservative estimates of the maximum ground level annual ambient concentrations within a building cavity region or building wake effect region should be made and compare these values with the acceptable ambient concentration for the substance.

METHOD A: [PTPLU-2(Version 6 from EPA UNAMAP) Model]]

1. Use the following assumption: Ambient temperature 293°K, mixing height 1500 m, and a receptor height of 2m.

2. Enter the stack parameter data in metric units: stack temperature (°K), stack flow (m^3/sec), stack area (m^2) and the emission rate (g/sec).

3. The model will predict hourly ground level concentrations for the substance ($\mu g/m^3$) for each of six stability classes at various downwind distances from the stack.

4. Determine the maximum hourly concentration predicted and convert this value to an annual concentration by multiplying the hourly concentration by a factor of 0.15.

METHOD B (Building Influences):

1. For building cavity situations, as determined in APPENDIX C-1 calculate the maximum ground level concentration (in $\mu g/m3$) expected in the cavity by the formula:

$$X(\text{conc.}) = Q*10^6/(1.5\ U*A*0.15)$$

where X = the maximum annual concentration ($\mu g/m^3$),
Q = is the emission rate (g/sec),
U = the wind speed (m/sec),
A = the building area (height of building times its projected width) (m^2); and
1.5 is a coefficient recommended by EPA.

2. For building wake effect regions extending beyond the facility property line, as determined in APPENDIX C-1, calculate the maximum ground level ambient concentration ($\mu g/m^3$) in the wake effect region by using the ISCST model with representative "worst case" meteorological conditions [refer to Regional Workshops on Air Quality Modeling: A Summary Report, EPA-450/4-82-015, Appendix C, pages C-4 through C-6 (amended October 1983) for guidance].

3. If predicted values of "X" exceed the acceptable ambient concentration in either Step 1 or 2, the applicant shall use dispersion models approved by the Department.

END

DATE FILMED

4/08/92