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MIXED WASTE INTEGRATED PROGRAM INTERIM EVALUATION REPORT ON THERMAL TREATMENT TECHNOLOGIES

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ACRONYMS AND ABBREVIATIONS

BDAT	best demonstrated available technology
CAA	Clean Air Act
CBC	case-by-case
CCW	constituent concentration in waste
CCWE	constituent concentration in waste extract
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DRE	destruction and removal efficiency
DT&E	demonstration, test, and evaluation
EPA	U.S. Environmental Protection Agency
°F	degrees Fahrenheit
FEMP	Fernald Environmental Management Project
FY	fiscal year
g	gram
HAZWRAP	Hazardous Waste Remedial Actions Program
HCl	hydrogen chloride
INEL	Idaho National Engineering Laboratory
K	potassium
kg	kilogram
LANL	Los Alamos National Laboratory
LDR	land disposal restriction
LLW	low-level waste
m^3	cubic meter
mg	milligram
mrem	millirem
MW	mixed waste
MWIP	Mixed Waste Integrated Program
MWTP	Mixed Waste Treatment Project
Na	sodium
NAAQS	National Ambient Air Quality Standards
nCi	nanocurie
NEPA	National Environmental Policy Act
NESHAPs	National Emission Standards for Hazardous Air Pollutants
NIST	National Institute of Science and Technology
NO_x	nitrogen oxides
NRC	Nuclear Regulatory Commission
O/O	owner/operator
ORNL	Oak Ridge National Laboratory
OTD	Office of Technology Development
PCB	polychlorinated biphenyl
PIC	product of incomplete combustion
Pu	plutonium
R&D	research and development
RCRA	Resource Conservation and Recovery Act
RDDT&E	Research, Development, Demonstration, Test, and Evaluation

RFP	Rocky Flats Plant
SERI	Solar Energy Research Institute
SNL	Sandia National Laboratory
SRS	Savannah River Site
TCLP	Toxicity Characteristic Leaching Procedure
TRU	transuranic
TSCA	Toxic Substances Control Act
TSG	Technical Support Group
TTWG	Thermal Treatment Working Group
USC	United States Code
WIPP	Waste Isolation Pilot Plant
WMIS	Waste Management Information System

EXECUTIVE SUMMARY

The Mixed Waste Integrated Program (MWIP) is one of several U.S. Department of Energy (DOE) integrated programs established to organize and coordinate throughout the DOE complex the development of technologies for treatment of specific waste categories. The goal of the MWIP is to develop and deploy appropriate technologies for the treatment of DOE mixed low-level and alpha-contaminated wastes in order to bring all affected DOE installations and projects into compliance with environmental laws. Evaluation of treatment technologies by the MWIP will focus on meeting waste form performance requirements for disposal.

Thermal treatment technologies were an early emphasis for the MWIP because thermal treatment is indicated (or mandated) for many of the hazardous constituents in DOE mixed waste and because these technologies have been widely investigated for these applications. An advisory group, the Thermal Treatment Working Group (TTWG), was formed during the program's infancy to assist the MWIP in evaluating and prioritizing thermal treatment technologies suitable for development.

The TTWG is composed of personnel from DOE Headquarters and contractor, subcontractor, and independent thermal technology experts who met on a regular basis to evaluate thermal treatment technologies and recommend development strategy. DOE membership in the group includes representatives from the Office of Technology Development (OTD) Research and Development and Demonstration Test and Evaluation divisions, the Office of Waste Management Operations, and the Office of Environmental Restoration.

The initial focus of the TTWG was to identify existing industrial thermal treatment technologies that, with low risk, could be applied to DOE waste streams; assess their real stage of development; and, if the technologies met the above requirements, provide demonstrations for implementation. Focus would then shift to addressing new and innovative technologies.

The primary responsibility for MWIP thermal technology development has since shifted to one of five technical support groups (TSGs) formed by the program and now functioning. This smaller group is called the Waste Destruction and Stabilization Technical Support Group. The TTWG membership has been retained as a pool of thermal treatment experts on which the TSG can draw for specific tasks such as new technology assessments or document reviews.

The determination of the scope of DOE's mixed-waste treatment needs is made difficult by the fact that many sites are still in the process of characterizing and reporting their mixed wastes. There are several data bases on DOE waste that were generated at different times, for different purposes, and with different waste category definitions. All of these data bases and publications indicate that the mixed-waste problem at DOE sites is large and growing. The TTWG has assimilated information from these data bases along with updated information to estimate the magnitude and characteristics of the DOE mixed-waste streams.

Most of the thermal technology data utilized in this study were compiled for a report recently generated for the OTD. The extensive and diverse expertise and development experience of the members of the TTWG were invaluable in developing and verifying this list of technologies. Twenty-six technologies were examined in depth for application to DOE mixed wastes. These technologies are described in detail in Appendix A to this report. The technologies are grouped into three general categories for this study: (1) incinerators; (2) melters; and (3) miscellaneous technologies.

A technology evaluation methodology was formulated to convert the technology comparisons to a single numerical index that could be used to compare the various technologies on an equal basis. This methodology utilizes a set of criteria against which to evaluate each technology's attributes and performance to determine its potential for treating each of the waste categories identified.

The candidate technologies that were deemed currently available to meet near-term DOE needs without significant development efforts were assessed by the TTWG to determine their applicability to treating each of the six major waste stream categories. Determinations of high applicability, medium applicability, low applicability, or nonapplicability were assigned to each technology. Technologies rated highly applicable for a waste stream will be evaluated against other highly applicable technologies to establish preferred technologies to pursue for each waste stream category.

For the DOE to implement any thermal treatment technology, whether existing or emerging, it must identify any technology development needs or deficiencies that may hinder effective utilization of the technology for DOE mixed wastes. These may be known hardware or operational deficiencies, or they may be information gaps that must be filled. Deficiencies were identified for all of the technologies that were rated highly applicable to each waste type.

The results of this assessment should be viewed as a grouping of high-potential thermal technologies that DOE should investigate further for each of the waste stream categories evaluated. It should be noted that thermal technologies may not be the best solution for all waste streams (e.g., aqueous liquids), and the highly ranked thermal technologies should be compared with nonthermal processes as part of a rigorous evaluation.

The thermal technologies ranked highest by the TTWG for each waste category are summarized below:

- Aqueous liquids
  - ultraviolet photooxidation,
  - wet-air oxidation, and
  - supercritical water oxidation;
- Organic liquids
  - liquid-injection incinerator,
  - controlled-air incinerator, and
  - cyclone incinerator;
- Wet solids
  - microwave melter,
  - joule-heated melter, and
  - fluidized-bed incinerator;

- Dry homogeneous solids

  - joule-heated melter,
  - microwave melter,
  - slagging-kiln incinerator, and
  - electric-arc furnace; and

- Heterogeneous solids (large and small)

  - electric-arc melter
  - slagging-kiln incinerator, and
  - rotary-kiln incinerator.

An important consideration that is not directly included in the evaluation is technology versatility. A technology that can operate on a wide variety of waste streams, such as all six of the waste categories, presents some significant advantages to DOE. By summing the rankings of a technology on each waste stream, both versatility and effectiveness are considered. The potential weakness in this approach is that all the waste streams are assumed to be equally important.

The results of the overall evaluation scoring indicate that the four highest-rated technologies were rotary kilns, slagging kilns, electric-arc furnaces, and plasma-arc furnaces. The four highest-rated technologies were all judged to be applicable on five of the six waste streams and are the only technologies in the evaluation with this distinction. Conclusions as to the superiority of one technology over others are not valid based on this preliminary study, although some general conclusions can be drawn.

The conclusions and important points that can be drawn from the evaluation are summarized as follows:

- None of the evaluated technologies ranked highly on all of the DOE waste categories. While some technologies were applicable to five of the streams, these systems would not perform effectively on some of the streams.

- The highest-ranked technologies on the DOE mixed waste overall were rotary-kiln incinerators, slagging-kiln incinerators, electric-arc furnaces, and plasma-arc furnaces. The versatility of these technologies was the primary reason for their high ratings.

- The most effective facility (considering cost and benefit) to treat the six DOE waste categories would involve at least two of the evaluated technologies.

1. INTRODUCTION

The charter of the U.S. Department of Energy (DOE) Office of Technology Development (OTD) states that the Division of Research and Development (R&D) shall:

> . . . develop an applied research and development program at DOE sites across the nation designed to identify operational needs in the areas of environmental restoration, waste management operations, and corrective activities, to rapidly advance beyond currently available technologies, and to provide solutions to key technical issues that, if not solved in a timely manner, will adversely affect DOE's ability to meet its 30-year cleanup goal and its operational goals.

The Mixed Waste Integrated Program (MWIP) is one of several DOE integrated programs established to organize and coordinate throughout the DOE complex the development of technologies for treatment of specific waste categories. The goal of the MWIP is to develop and deploy appropriate technologies for the treatment of DOE mixed low-level and alpha-contaminated wastes to bring all affected DOE installations and projects into compliance with environmental laws. Evaluation of treatment technologies by the MWIP will focus on meeting waste form performance requirements for disposal.

1.1 THERMAL TREATMENT WORKING GROUP

Thermal treatment technologies were an early emphasis for the MWIP because thermal treatment is indicated (or mandated) for many of the hazardous constituents in DOE mixed waste and because these technologies have been widely investigated for these applications. An advisory group was formed during the program's infancy to assist the MWIP in evaluating and prioritizing thermal treatment technologies suitable for development. This group, the Thermal Treatment Working Group (TTWG), was chartered to do the following:

- develop objectives for the MWIP and success/failure criteria for thermal systems;
- develop methodologies for assessing thermal technology capabilities, development needs, and potential waste stream applicability;
- develop methodology for prioritizing thermal technology development projects;
- develop methodology for introducing new or innovative technologies from industry;
- review and evaluate technical reports, proposals, and plans; and
- assess issues and prepare recommendations as requested by OTD.

The TTWG is composed of personnel from DOE Headquarters and contractor, subcontractor, and independent thermal technology experts who met on a regular basis to pursue the activities described above. DOE membership in the group includes representatives from OTD R&D and Demonstration, Test, and Evaluation divisions, the Office of Waste Management Operations, and the Office of Environmental Restoration. All of the major DOE sites with mixed wastes are represented in the group. The U.S. Environmental Protection Agency (EPA) is also represented at the group meetings.

The overall objective of the TTWG is to identify and develop technologies for the destruction of the combustible portion of DOE mixed waste and thermal stabilization processes for mixed waste and treatment residue to produce a final waste form that will meet DOE disposal criteria and be acceptable to federal and state regulatory agencies.

The initial focus of the TTWG was to identify existing industrial thermal treatment technologies that, with low risk, could be applied to DOE waste streams; assess their real stage of development; and, if the technologies met the above requirements, provide demonstrations for implementation. Focus would then shift to addressing new and innovative technologies.

Long-term objectives of the TTWG are to select thermal treatment technologies with the potential to perform the above functions better, safer, faster, and cheaper than current practices and to accelerate the development and demonstration of these technologies. The long-term strategy will focus on robust technologies capable of treating multiple mixed-waste streams, less-developed technologies with high potential benefits, and technologies to treat waste streams generated from environmental restoration, decontamination and decommissioning activities. The program will concentrate on identifying and developing only those technologies that have a reasonable chance of being implemented in a time frame to meet regulatory milestones and DOE's 30-year cleanup goal.[1]

1.2 TECHNICAL SUPPORT GROUP

The primary responsibility for MWIP thermal technology development has since shifted to one of five Technical Support Groups (TSGs) formed by the program and now functioning. This smaller group is called the Waste Destruction and Stabilization Technical Support Group. The TTWG membership has been retained as a pool of thermal treatment experts on which the TSG can draw for specific tasks such as new technology assessments or document reviews. Organizational relationships for the MWIP, TSG and TTWG are illustrated in Fig. 1.1. As can be seen from this figure, the MWIP will be addressing technology development for all areas of waste treatment from front-end waste handling to generation of a disposable waste form.

1.3 DOE MIXED-WASTE TREATMENT NEEDS

The determination of the scope of DOE's mixed-waste treatment needs is made difficult by the fact that many sites are still in the process of characterizing and reporting their mixed wastes. There are several data bases on DOE waste that were generated at different times, for different purposes, and with different waste category definitions. All of these data bases and publications indicate that the mixed-waste problem at DOE sites is large and growing. The TTWG has assimilated information from these data bases along with updated information to estimate the magnitude and characteristics of the DOE mixed-waste streams. These estimated quantities, given in Sect. 2 of this report, include

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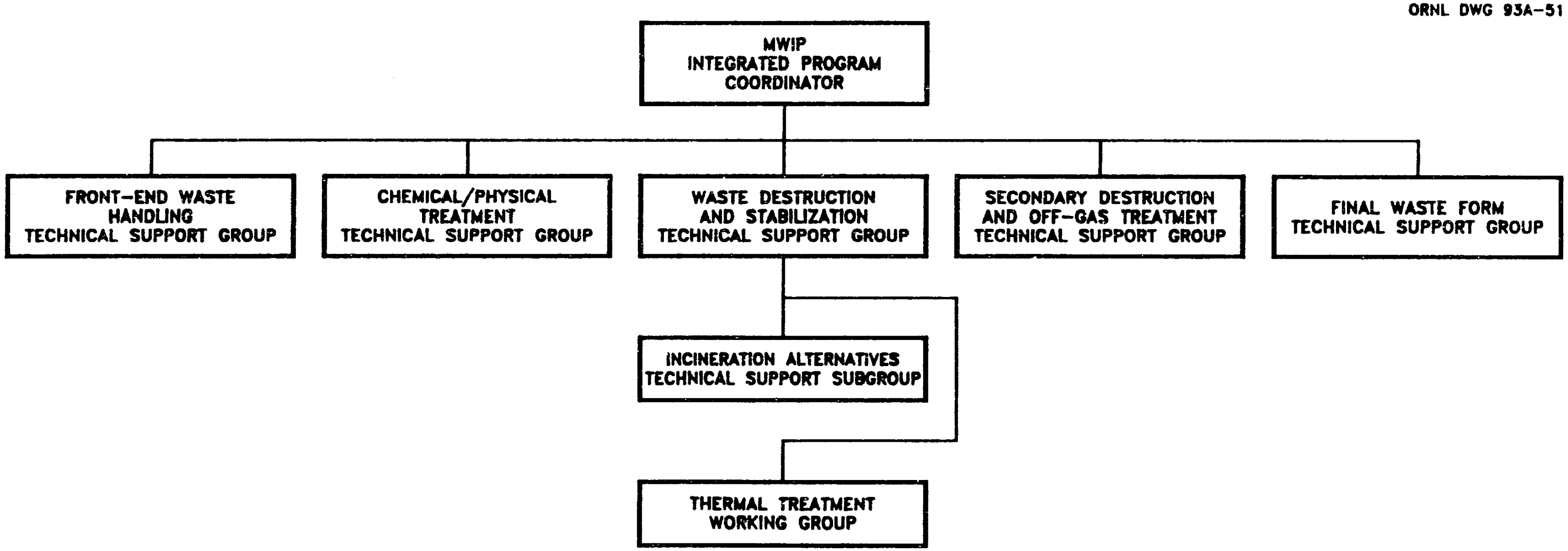

Fig. 1.1. Organization relationship of the Mixed Waste Integrated Program (MWIP), Technical Support Groups, and Thermal Treatment Working Group.

only waste currently stored or generated by DOE. Wastes generated as the result of planned environmental restoration activities or decontamination and decommissioning of facilities are generally not included.

Hazardous waste treatment and disposal are governed by the Resource Conservation and Recovery Act (RCRA). Radioactive waste management is governed by the Atomic Energy Act. Mixed waste is defined as any matrix containing both a RCRA hazardous waste and a radioactive waste subject to the Atomic Energy Act. Regardless of the type of radioactive constituents that these mixed wastes contain, they are subject to the RCRA hazardous waste regulations, including the land disposal restrictions (LDRs). Mixed wastes were lumped into the LDR Third Third waste category by EPA and are subject to the LDRs already promulgated for those hazardous wastes. EPA granted national capacity variances for all of these wastes because of a lack of national treatment capacity. This 2-year variance expired in May 1992, and although a 1-year extension has been proposed, the application of the LDRs to these wastes is a near-term problem for DOE.

Permitted storage space for mixed waste in the DOE system is limited, and there are constraints on the time it can be stored prior to disposal, depending on the expiration of the variance and the date the waste was placed into storage. To complicate the problem, there are currently no permitted mixed-waste disposal facilities in the United States. The development of permitted facilities that can dispose of mixed wastes is being pursued or investigated at a number of DOE sites. In the absence of such facilities, the available options for noncompliant waste are (1) treatment to separate the radioactive and hazardous components or to eliminate the hazardous characteristics of the final waste form or (2) pursuit of the delisting of the waste residue for listed hazardous constituents. There are significant environmental and economic incentives to utilize treatment processes that will minimize the volume of the radioactive waste form as well as the volume of hazardous waste disposed of in a RCRA-permitted disposal facility.

2. WASTE STREAM CHARACTERIZATION

Efficient thermal treatment of waste materials is dependent on knowing waste stream characteristics well so that technology attributes can be matched to treatment needs. The appropriate selection of technologies for thermal treatment of DOE wastes requires a level of characterization detail that is only just now being achieved across the system, so much of the TTWG's work has been based on waste data that have a significant level of uncertainty. In addition, the large number of streams and the extreme variability of waste constituents require that technology assessments be based on generic or representative waste characteristics.

Data on the characteristics of DOE mixed-waste streams have been accumulated over the last several years as part of several major efforts. Information on waste characteristics continues to evolve as regulations governing waste generation, storage, treatment, and disposal are better understood and as regulators and DOE sites reach agreements on the classification of some major waste streams. New waste streams are also being identified, and characteristics of the streams are still being determined. This section focuses on currently available waste information and also identifies additional data needs.

2.1 MIXED-WASTE TREATMENT PROJECT FINDINGS

Some members of the OTD TTWG also participate in DOE Waste Operations (EM-30) Mixed-Waste Treatment Project (MWTP) activities. The waste data collection efforts of the MWTP have provided a good basis on which to conduct general technology evaluations. The waste data presented in this section are a result of these efforts.

2.1.1 Waste Management Information System Data Base

The major DOE data base for hazardous wastes is maintained by the Hazardous Waste Remedial Actions Program (HAZWRAP) at the Oak Ridge site and is called the Waste Management Information System (WMIS) Data Base. This data base was first developed in 1989 for the *National Report on Prohibited Waste and Treatment Options*,[2] completed by DOE in 1989 in response to the Rocky Flats Federal Facilities Compliance Agreement with EPA. The data base continues to be modified with new information as it is received from the field. It was used for development of the document *Land Disposal Restrictions Case-by-Case Extension Application for Radioactive Mixed Wastes*[3] that was recently submitted to EPA. New information is also being input to the data base from a series of site visits coordinated by EM-30's MWTP. The updated information will be available late in calendar year 1992.

2.1.2 Sources of Data for This Report

Most of the data for this report were obtained from the WMIS data base and have been updated with additional information from Rocky Flats Plant, Los Alamos National Laboratory, Savannah River Site and the Oak Ridge Y-12 Plant. Data on site totals also include data from the case-by-case (CBC) report for Fernald, which were not included in the WMIS data records. The information on each stream is provided in two parts: the current inventory of the waste and the expected annual generation rate. It should be noted that, while a constant average annual rate is shown, the actual rate varies from year to year. The annual rate shown represents an average over the time period. For example, Hanford data compilers have noted that they will receive a large shipment of material currently stored at off-site locations in non-DOE facilities. The materials will be shipped to the receiving site as soon as Hanford is able to receive and dispose of the wastes. This anticipated spike in the generation rate is averaged out over the total time as discussed in Sect. 2.1.3.

2.1.3 Waste Volumes at DOE Sites

The WMIS, CBC, and MWTP data have been sorted by site and aggregated as total current inventory, expected total generation rate, and expected process rate. The expected process rate has been developed to combine the inventory and generation rate numbers into a single number and to provide perspective on the size of treatment facilities that will be needed at each site. The process rate is based on the following assumptions: (1) that the current inventory will be processed over 10 years, (2) that it will be about 10 years before a process facility is available, (3) that the annual generation rate will continue for the next 20 years, and (4) that the waste will be processed uniformly over time. Algebraically, this means that the expected process rate is 10% of the current inventory plus twice the current annual generation rate.

Three major waste streams have been omitted from the waste data presented herein because separate programs have been established to address treatment of these waste streams. Two of these waste streams are at the Hanford site, where much of the single-shell and double-shell tank wastes are classified as mixed waste. These two streams are the largest DOE waste streams and amount to about 218,000 m^3 of existing inventory and 13,000 m^3/year of annual generation. A grout treatment facility has been established to treat these wastes and prepare them for disposal. The third waste stream is a partially cemented sludge from the waste pond at the Oak Ridge K-25 Site. This waste stream, with a volume of about 28,000 m^3, is also large enough to be treated in a dedicated facility, which is yet to be defined.

For the remaining volume of mixed waste, it can be noted that the eight major sites are the Fernald Environmental Management Project, Idaho National Engineering Laboratory (INEL), Oak Ridge K-25 Site (K-25), Portsmouth Gaseous Diffusion Plant, Hanford Site, Rocky Flats Plant (RFP), Savannah River Site (SRS), and Oak Ridge Y-12 Plant (Y-12). Figure 2.1 graphically presents the process rates at the eight major sites. These eight sites account for about 96% of the total of the mixed-waste volumes.

2.1.4 Waste Characteristics

To develop additional information about the wastes, each of the streams has been assigned a treatment code. The first digit of the code assigns the waste stream to one of six major treatment categories: aqueous liquids (100), organic liquids (200), wet solids (300), dry homogeneous solids (400), large heterogeneous solids (500), and small heterogeneous solids (600). The division between aqueous and organic liquids is the 1% by weight organic level used in RCRA (40 CFR 268) to distinguish between wastewaters and nonwastewaters. Wet solids are those waste forms that may contain free or combined water and in particular sludges and cemented wastes. Particulate solids are those wastes

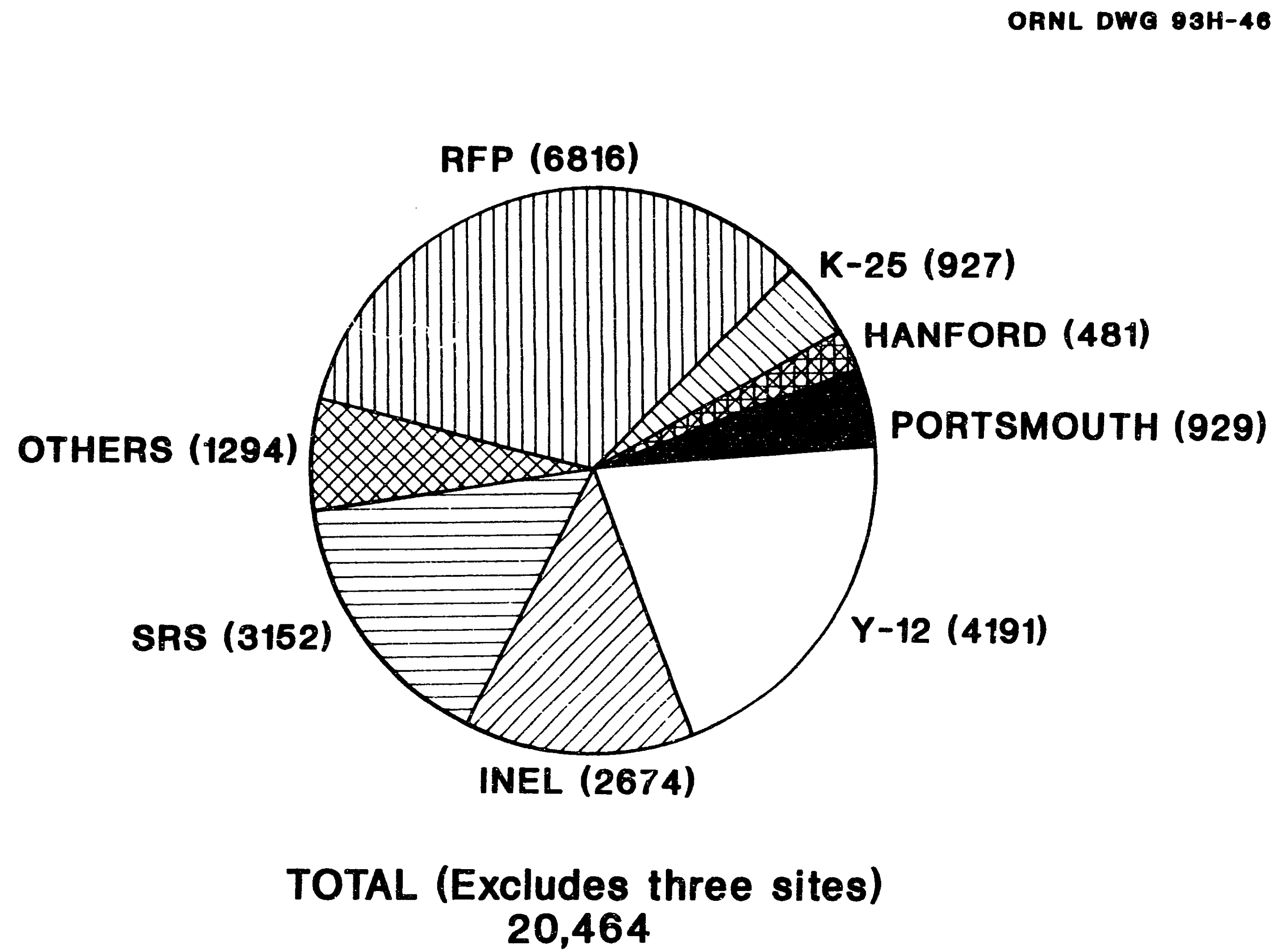

Fig. 2.1. Mixed-waste volumes at DOE sites. The process rate is expressed in cubic meters per year. INEL = Idaho National Engineering Laboratory; RFP = Rocky Flats Plant; SRS = Savannah River Site.

that can be fed as a particulate waste and are commonly ashes and soils. The heterogeneous wastes were subdivided based on the anticipation that the larger, more massive wastes streams would need special size-reduction capabilities. The distinction between the two categories is that "small wastes" will fit in a 55-gal drum. From the information available in assigning codes, the streams that could be positively identified as "large" were few in number. Modifications may be necessary in the small and large heterogeneous categories as more information is obtained about specific waste streams.

Figure 2.2 shows graphically, based on total expected processing rates, the distribution of major waste types. As the figure shows, wet solids—mainly cemented sludges—make up the largest waste type in terms of volume. The other two major waste types are aqueous liquids and heterogeneous dry solids. Heterogeneous dry solids, including miscellaneous wastes, are mixtures of metals, combustibles, and other inorganic materials. They are expected to be the most difficult wastes to treat because of the intimate combination of organic material needing destruction, potentially decontaminable materials, and other materials needing stabilization or immobilization. This may require extensive sorting of the wastes. While they are third in volume, the small heterogeneous solids represent the largest number of waste streams. Other wastes of special interest are the organic liquids (actually next to the smallest in waste volume) and the lead- and mercury-containing waste volumes (included under small heterogeneous solids), which are also relatively small.

The distribution of the waste types at each of the 11 major sites was also determined and is shown for the anticipated processing rate in Fig. 2.3. Analysis of the waste stream information from each of the sites shows that no two sites have the same distribution of wastes, and, in fact, each site is dominant in a different type of waste (e.g., wet solids at RFP and the K-25 Site, heterogeneous solids at INEL, homogeneous solids and organic liquids at Paducah, and aqueous liquids at Lawrence Livermore National Laboratory, ORNL, and SRS).

2.1.5 Planned Improvements to Waste Stream Data

The reviews of the data and the initial preparation of a reference waste flow sheet have shown that additional information is needed on the various waste streams. Environmental restoration wastes, particularly those from remediation of contaminated disposal sites and the decontamination and decommissioning of numerous DOE facilities, are anticipated to be large in volume, but data are generally not available. One of the major data needs is information on the matrix compositions of the wastes. Other data needs include improved definition of combustible and mixed combustible wastes (i.e., what fraction of material is combustible in each group) and information regarding the size of the waste packages and size of the wastes within the packages (e.g., thickness of the metal components). These data will be important in addressing handling equipment and equipment capability.

Reviews suggest that current data have several major inconsistencies with respect to classification of high-level waste, transuranic (TRU) waste, low-level waste, and polychlorinated biphenyl (PCB) waste streams. At Hanford, the estimated fraction of low-level waste in double- and single-shell tanks is included in the data base, whereas at SRS wastes in such tanks are classified as high level. With TRU waste, the opposite has occurred: SRS and INEL have included their estimated volume of <100 nCi/g TRU waste as low-level waste, whereas at Hanford, in the absence of adequate information, all suspect waste is left in the TRU category. The handling of PCB wastes may also not be

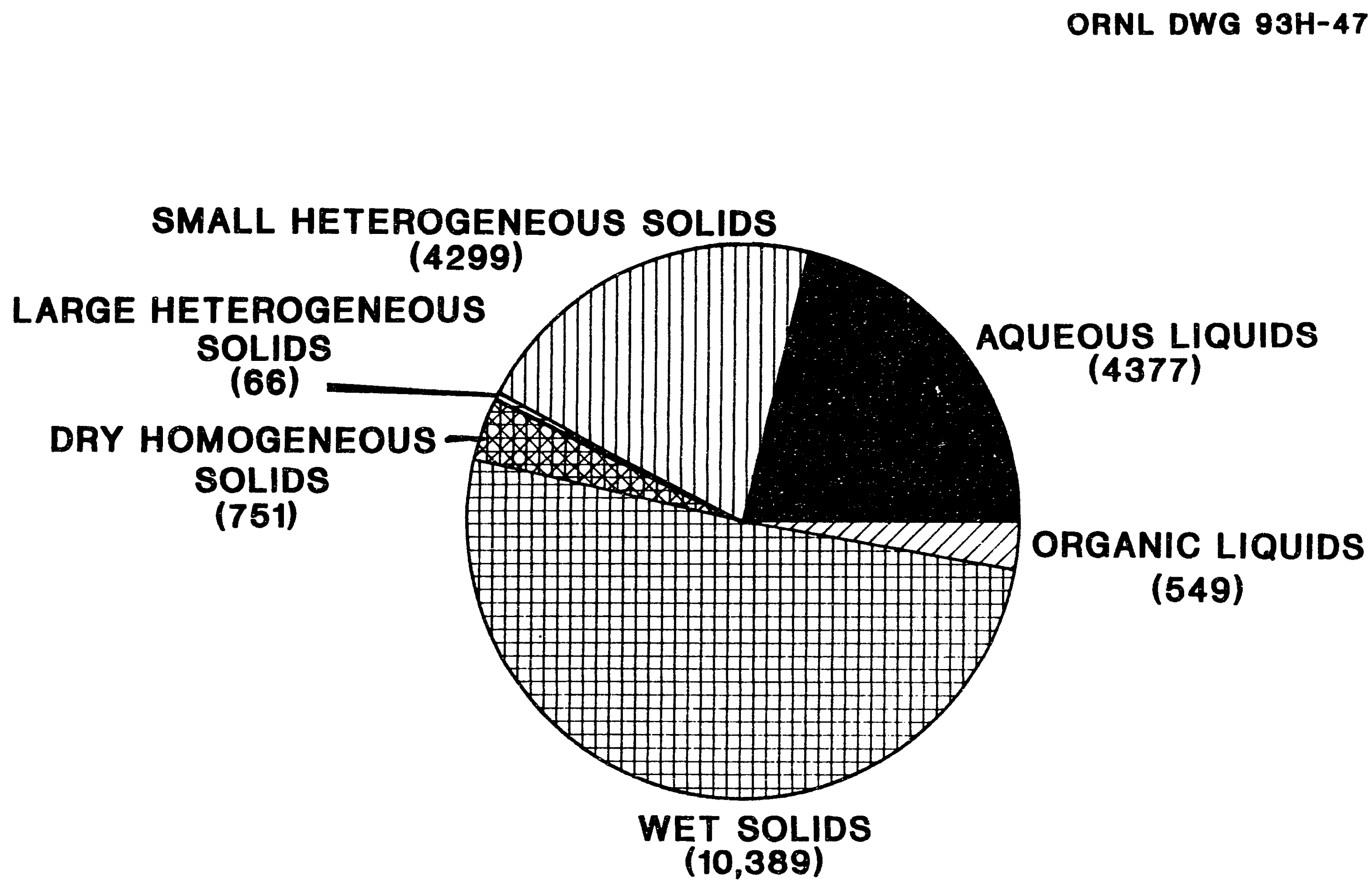

Fig. 2.2. Distribution of DOE mixed-waste types. The process rates are expressed in cubic meters per year.

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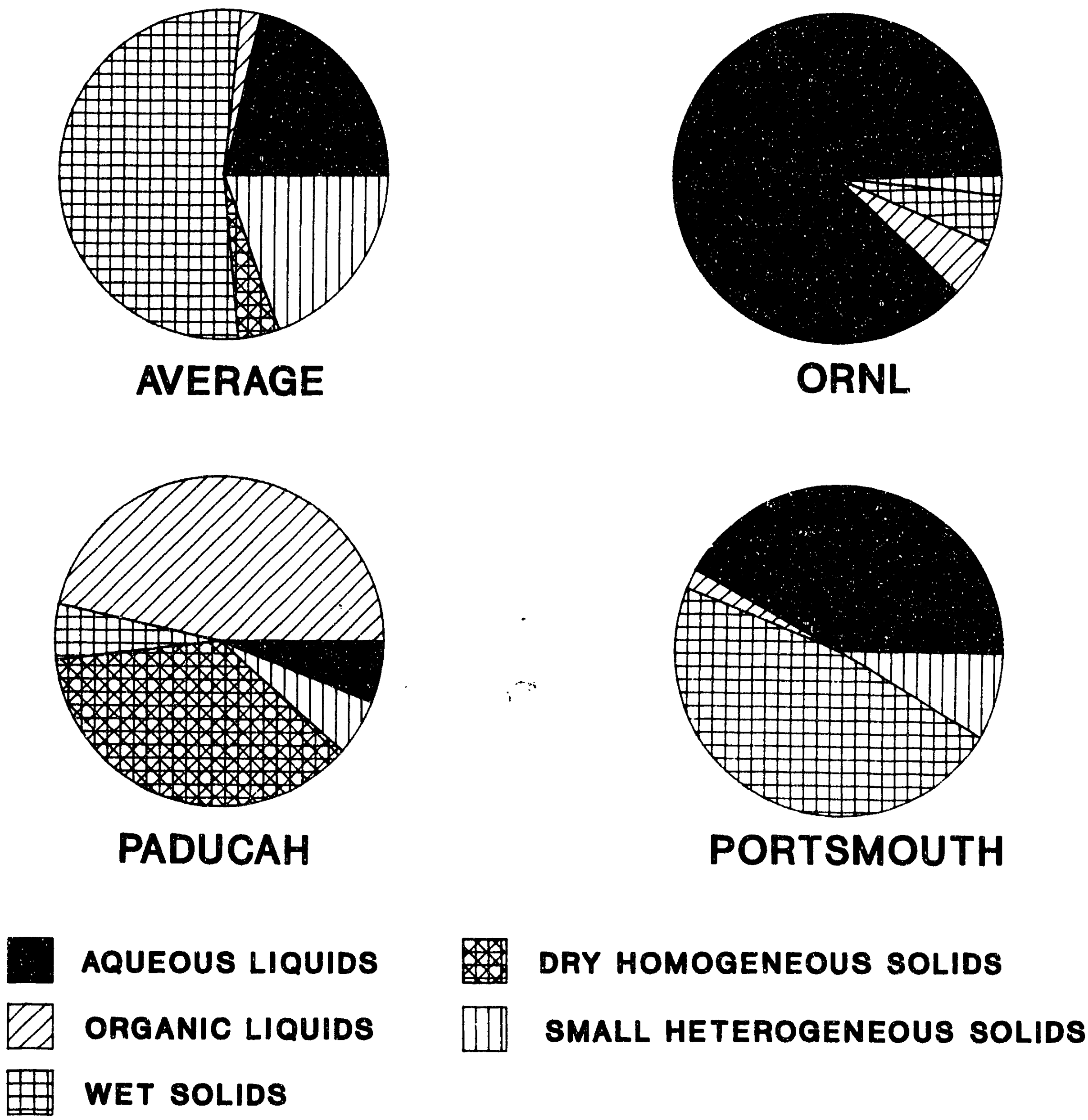

Fig. 2.3. Comparison of process rates for types of wastes at major DOE sites. Large heterogeneous solids, which make up less than 0.1% of the total process rate at one site (RFP), are not shown in this figure. INEL = Idaho National Engineering Laboratory; LANL = Los Alamos National Laboratory; LLNL = Lawrence Livermore National Laboratory; RFP = Rocky Flats Plant; SRS = Savannah River Site.

ORNL DWG 93H-49

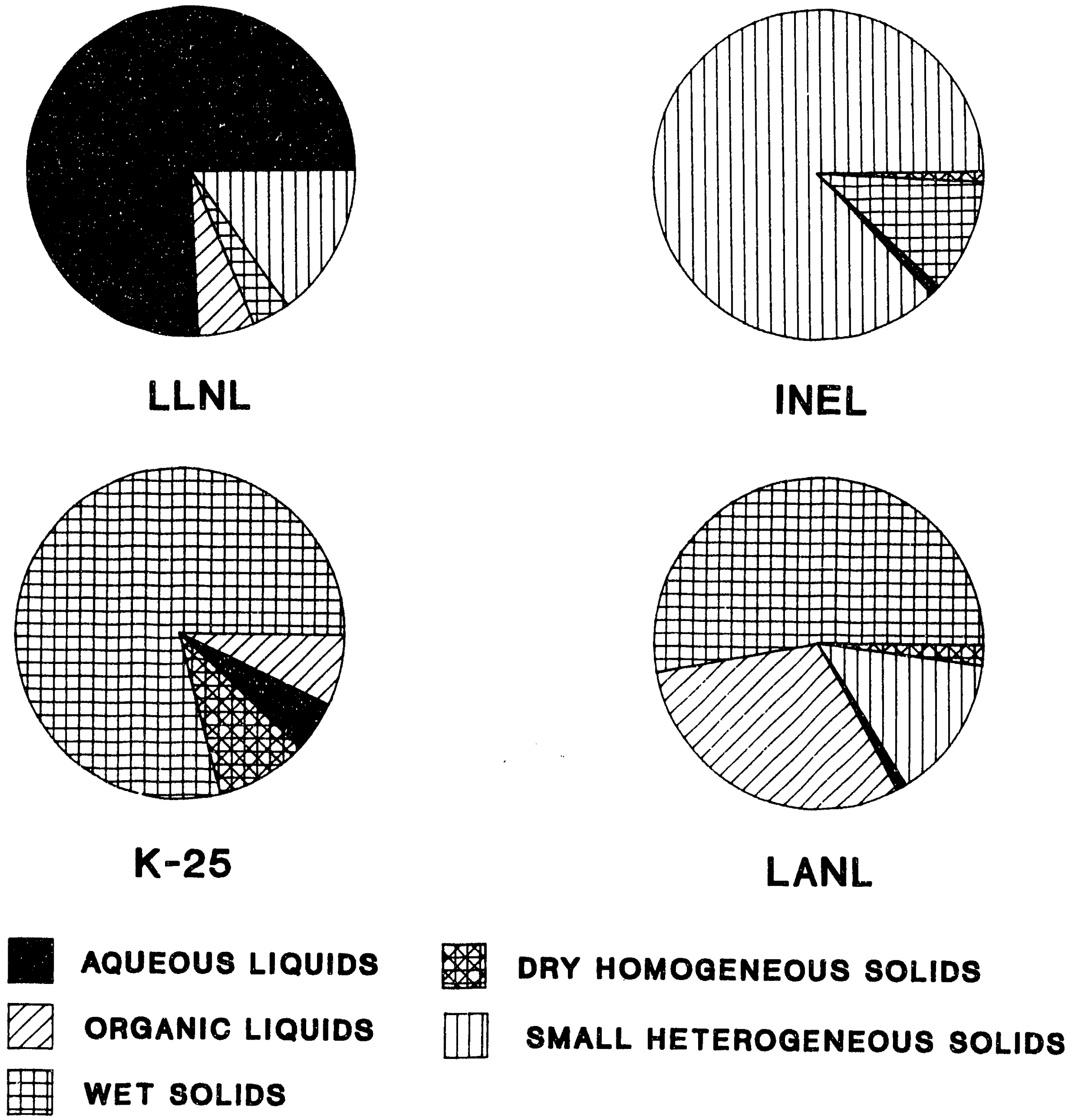

Fig. 2.3 (continued)

ORNL DWG 93H-60

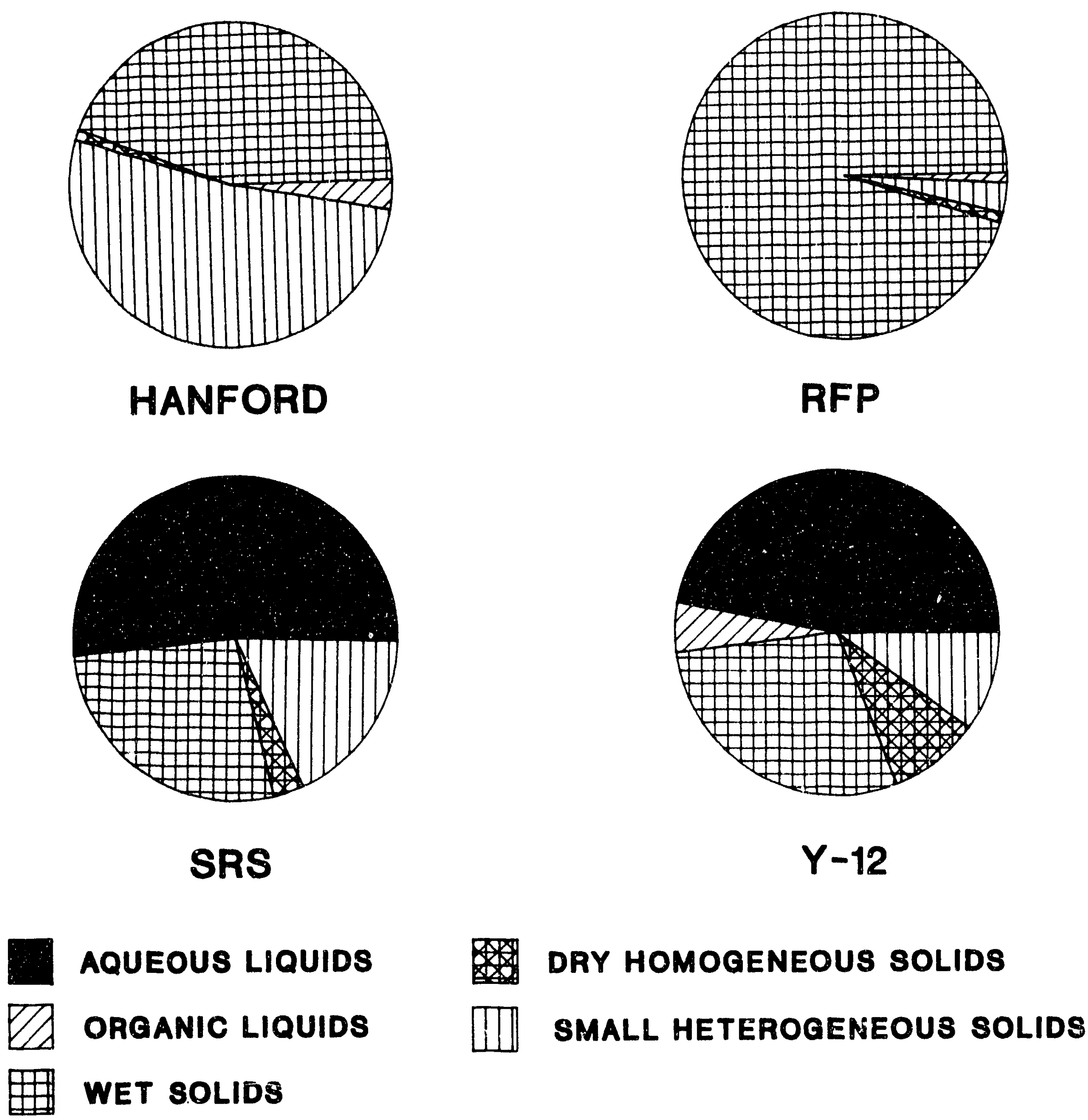

Fig. 2.3 (continued)

consistent: some sites have not included PCB wastes in their estimates because these wastes are not directly regulated by RCRA.

To obtain more information, site visits are being conducted by the MWTP with the cooperation of HAZWRAP and the sites. Information from these visits will be incorporated in the WMIS system and will be widely available. It is recognized that waste information will continue to change as operations and plans change and that these data will need periodic review and adjustment.

2.2 WASTE STREAM PRIORITIZATION

The TTWG approach to prioritization of technology development was to prioritize waste streams for relative need and then to address first the technologies applicable to high-priority waste streams. A waste stream prioritization methodology was developed and applied to DOE's highest-volume waste streams as identified by the MWTP group. Each of the largest 21 waste streams (excluding the three very large waste streams mentioned previously), representing approximately 94% of the volume of the largest 100 waste streams, was assessed against three equally weighted criteria: (1) waste process rate (volume); (2) regulatory compliance status; and (3) perceived risk (to workers, the environment, and the public).

Numerical scores were calculated for each waste stream based on the following scoring breakdown:

- Waste volume (process rate)
  - >1000 m^3/year — 3
  - 100–1000 m^3/year — 2
  - <100 m^3/year — 1

- Compliance status
  - Currently out of compliance (i.e., California List wastes and solvents) — 3
  - Approaching out of compliance (other mixed wastes) — 2
  - No immediate compliance issue (stored before effective date of LDR) — 1

- Perceived risk. Start with a score of 1 and add 1 for
  - Dispersable waste form
  - Liquid waste form
  - Proximity of groundwater
  - Proximity of population

A high score represents a high priority. The results of the waste stream prioritization, shown in Table 2.1, indicate that wet solids and aqueous liquids are perceived by the TTWG as the DOE waste streams requiring the most immediate attention, based on the above criteria. Of the 12 highest-priority waste streams, wet solids account for 6 and aqueous liquids account for 5.

It is interesting to note that the largest 21 DOE waste streams have a distribution of waste categories, illustrated in Table 2.2, roughly comparable to the distribution of total

Table 2.1. Waste stream prioritization

Description of waste	Major waste group no.	Site[a]	Criteria scores: Waste volume	Compliance status	Perceived risk	Total score
High-activity waste	100	SRS	2	3	3	8
Pondcrete	300	RFP	3	3	2	8
P&U listed rad, contaminated condensate	100	INEL	3	2[b]	2	7
Low-activity waste	100	SRS	3	2	2	7
Wastewater treatment metal sludge	300	Y-12	3	2	2	7
Saltcrete	300	RFP	2	3	2	7
DWPF benzene	200	SRS	2	3	2	7
X-701B remediation waste	300	PORTS	2	3	2	7
Aqueous acidic waste	100	Y-12	3	1	2	6
Plating-line slurry	100	SRS	2	2	2	6
Stabilized waste pond sludges	300	K-25	2	2[b]	2	6
Wastewater treatment spent carbon	300	Y-12	2	2	2	6
Solvent wastes <100 nCi/g	600	SRS	2	3	1	6
Mixed waste soil	400	Y-12	2	2	2	6
Remedial facility investigation liquids	600	PORTS	2	3	1	6
M-Area plating-line waste slurry	100	SRS	2	2	2	6
Filters–Low-level waste	600	INEL	2	1	2	5
Metals–Low-level waste	600	INEL	2	1	1	4
Combustibles–Low-level waste	600	INEL	2	1	1	4
Uncemented slugdes–Low-level waste	300	INEL	2	1	1	4
Miscellaneous low-level waste (paper, metal, etc.)	600	INEL	2	1	1	4

[a]INEL = Idaho National Engineering Laboratory; K-25 = Oak Ridge K-25 Site; PORTS = Portsmouth Gaseous Diffusion Plant; RFP = Rocky Flats Plant; SRS = Savannah River Site; Y-12 = Oak Ridge Y-12 Plant.

[b]Uncertain ranking.

DOE waste volumes, by category, found in Fig. 2.1. A conclusion that might be reached from this exercise is that technology development priorities for DOE mixed wastes would be the same whether based solely on waste category volumes or on specific waste stream priorities.

Table 2.2. Largest waste distribution by category

Waste category	No. of streams in largest 21
Wet solids	7
Aqueous liquids	6
Small heterogeneous solids	6
Organic liquids	1
Dry homogeneous solids	1

3. CANDIDATE THERMAL TECHNOLOGIES

3.1 TECHNOLOGIES IDENTIFIED

Most of the thermal technology data utilized in this study were compiled for a report recently generated for the OTD.[4] A variety of sources was consulted to identify and characterize thermal treatment technologies currently available or emerging that could conceivably be utilized to treat DOE's mixed wastes. EPA-published documents such as emerging technology summaries, operating facility and manufacturer profiles, and technology performance evaluations were especially helpful. Extensive literature searches were conducted on a variety of computerized data bases, and a large body of reference data was collected. Numerous technology developers, equipment vendors, and facility operators were contacted to obtain as much current and complete data as possible. The extensive and diverse expertise and development experience of the members of the TTWG were invaluable in developing and verifying this list of technologies. The references for each technology can be found at the end of the applicable data sheets in Appendix A.

While compiling the listing of all known technologies, a few technologies were identified that were not included in the study. In general, these were excluded because of a lack of adequate information or lack of demonstrated feasibility. Additional emerging technologies and previously unknown technologies have been identified subsequent to the OTD report and are included in this study. Although performance data for some of these technologies are limited, adequate data were available to make qualitative assessments.

Technologies that represent variations in configuration of a basic technology were grouped under a single methodology title with a description of the most representative application. Variations of the basic technology are pointed out in the technology descriptions in Appendix A. A general assessment of each technology is included in these descriptions listing advantages, disadvantages, and additional development/research needs.

This study addresses thermal technology maturity in the broad general groupings of "operational" and "emerging." Operational technologies may be conventional, in that they are a variation of historical incineration configurations employing open-flame combustion, or unique in their approach to thermal destruction, but they are all commercially available and in general use although not necessarily for waste applications. Emerging technologies are identified by their level of development and size. The three levels of emerging technology development as used in this study are defined as follows:

- Bench scale. Small-scale representation of the basic technology elements to evaluate technical feasibility, also known as laboratory scale. (Time required for full implementation is >5 years.)

- Pilot scale. Less than full-scale model of the technology with most of the required features and support systems included to evaluate engineering performance. (Time required for full implementation is on the order of 2–5 years.)

- Demonstration scale. At or near full-scale system for demonstration of production-scale operations prior to actual operational deployment. (Time required for full implementation is <2 years.)

Table 3.1 lists the technologies identified. Those technologies not further evaluated are italicized, and the reasons for omission are listed.

3.2 TECHNOLOGIES EVALUATED

Twenty-six technologies were examined in depth for application to DOE mixed wastes. These technologies are described in detail in Appendix A to this report. The technologies are grouped into three general categories for this study: (1) incinerators, (2) melters, and (3) miscellaneous technologies.

3.2.1 Incinerators

The conventional incinerators evaluated employ variations of open-flame combustion of wastes for thermal destruction. Recent data on hazardous waste incinerators indicate there are approximately 175 conventional incinerators burning hazardous wastes in the United States, processing 2 to 3 million metric tons of waste annually.[5] The conventional incinerators evaluated in this report include the following:

- agitated-hearth incinerator,
- controlled-air incinerator,
- cyclone incinerator,
- fluidized-bed incinerator,
- indirect-fired pyrolysis incinerator,
- KfK excess-air incinerator,
- liquid-injection incinerator,
- multiple-hearth incinerator, and
- rotary-kiln incinerator.

3.2.2 Melters

The melter technologies evaluated in this study are designed to destroy hazardous organics by direct exposure to molten materials or by exposure to heat radiation above the molten materials. The molten materials may be glass, metal, or mixed inert materials referred to as slag. In addition to destruction of organics, melters produce a stabilized waste matrix, such as glass, slag, or metal, which binds the toxic constituents and renders them nonleachable.

The melter technologies evaluated include two operational technologies (slagging kiln and joule melter), with the remainder at various levels of development. Some of these technologies are recent adaptations of commercial thermal processes for waste destruction. The following melters were evaluated:

- electric-arc furnace,
- fuel-fired melter,
- high-temperature joule melter,
- in-can microwave melter,
- in-can resistance melter,
- induction melter,
- joule-heated melter,
- plasma-arc furnace,

Table 3.1. Thermal technologies identified

Technologies considered[a]	Reason for omission
Incinerators	
Agitated-hearth incinerator	
Controlled-air incinerator	
Cyclone incinerator	
Fluidized-bed incinerator	
Indirect fired pyrolysis incinerator	
KfK excess-air incinerator	
Liquid-injection incinerator	
Multiple-hearth incinerator	
Rotary-kiln incinerator	
Melters	
Electric-arc furnace	
Fuel-fired melter	
High-temperature joule melter	
In-can microwave melter	
In-can resistance melter	
Induction melter	
In situ vitrification	*In situ treatment process only*
Joule-heated melter	
Plasma-arc furnace	
Stirred-joule melter	
Slagging-kiln incinerator	
Other technologies	
Calciner	*Specialty application of fluidized-bed incinerator*
Fluid-wall reactor	*No longer commercially available*
Infrared furnace	
Molten-salt furnace	
Plasma-pyrolysis reactor	
Radio-frequency heating	*In situ stripping technology only, no destruction*
Radio-frequency plasma	*Not a primary destruction process, better suited to secondary destruction applications*
Steam gasification detoxifier	
Supercritical water oxidation	
Low-temperature thermal separator	*No waste destruction, pretreatment process only*
Ultraviolet photooxidation	
Wet-air oxidation	

[a]Italics indicate technologies excluded from further evaluation.

- stirred-joule melter, and
- slagging-kiln incinerator.

3.2.3 Miscellaneous Technologies

Other thermal technologies, listed below, that did not fit into either the conventional open-flame incinerator or melter technology categories were also evaluated. In general, these technologies are somewhat limited in versatility, but offer some specific advantages for certain waste categories. One technology, ultraviolet photooxidation, was included as a thermal technology even though it is unclear if destruction is by thermal means or by some other mechanism. The following seven technologies were evaluated:

- infrared furnace,
- molten-salt furnace,
- plasma-pyrolysis reactor,
- steam-gasification detoxifier,
- supercritical water oxidation,
- ultraviolet photooxidation, and
- wet-air oxidation.

4. TECHNOLOGY EVALUATION METHODOLOGY

4.1 METHODOLOGY

A technology evaluation methodology was formulated to convert the technology comparisons to a single numerical index that could be used to compare the various technologies on an equal basis. This methodology utilizes a set of criteria against which to evaluate each technology's attributes and performance to determine its potential for treating each of the waste categories identified. These criteria represent important aspects to be considered in determining each technology's potential to treat DOE mixed waste streams.

Numerical scores from 0 to 10 were awarded according to how the technology met the criteria. To make the evaluation as objective as possible, the elements necessary to justify awarding the numeric scores were clearly defined, thereby minimizing any preconceived notions or other biases of the evaluators. The elements necessary to award a numeric score under each of the criteria are presented in the following sections. The criteria scores are added to give the final technology score.

4.2 TECHNOLOGY EVALUATION CRITERIA

The following criteria were utilized to rate currently available operational technologies for consideration in meeting immediate DOE needs. To be considered in the evaluation, a technology must be currently successful in a fully integrated system at demonstration scale, but not necessarily applied to the specific waste stream in question.

4.2.1 Maintainability

This criterion assesses the maintenance requirements of a technology. Technologies that require low component maintenance or are easy to maintain in an alpha and/or a beta/gamma hot cell environment rate higher than those technologies that have frequent maintenance needs or are difficult to maintain. From a possible score of 10, three points were deducted for each of the following maintenance issues:

- above-normal number of moving parts,
- poor component accessibility for maintenance, and
- questionable component reliability.

4.2.2 Safety Risk

This criterion assesses the ability of a technology to operate within the range of acceptable risk exposure to the operators and general public. From a possible score of 10, three points were deducted for each of the following hazardous operations:

- high temperature (>2000°F),
- high pressure,

- dispersible residues, and
- downgrade for high electrical energy hazards (one additional point deducted for this condition).

4.2.3 Operability

This criterion assesses the ease of operation. Technologies that are easier to operate and control were rated higher than ones that are difficult to operate or control. Two points were deducted from a high score of 10 for each of the following difficult operations:

- complex feed requirements,
- above-normal support system requirements,
- frequent hands-on operational needs, and
- high-manpower requirements.

4.2.4 Flexibility

This criterion assesses the capability of the technology to accept a wide variety of waste stream types. Technologies capable of accepting a wide variety of waste stream types rate higher than technologies that require major changes or perhaps cannot be changed to meet new requirements or waste streams variations. A technology that requires minimal sorting compared with the other technologies rates a 10. One that requires a high level of waste sorting as compared with the others rates a 5.

4.2.5 Effluent

This criterion assesses the ability of a technology to entrain the radioactive component into the processed-waste residual rather than the off-gas system and to reduce effluent. Technologies that are known to emit high levels of priority pollutants or products of incomplete combustion (PICs), to produce particulate carryover, or to entrain radioactive constituents in the off-gas system are downrated. From a possible score of 10, the points indicated were deducted for the following above-normal conditions:

- particulate carryover (-1),
- metal volatilization (-2),
- NO_x formation (>2000°F or high combustion air rates) (-1), and
- secondary discharge treatment required (-3).

4.2.6 Maturity

This criterion assesses the relative availability of a technology for use by DOE in the near term to treat mixed wastes. From a possible score of 10, three points were deducted for technologies not meeting each of the following requirements:

- time proven (>5 years of operation),
- commercially applied to waste treatment, and
- demonstrated on this type of waste.

5. TECHNOLOGY/WASTE STREAM APPLICABILITY

The candidate technologies that were deemed currently available to meet near-term DOE needs without significant development efforts were assessed by the TTWG to determine their applicability to treatment of each of the six major waste stream categories. Determinations of high applicability, medium applicability, low applicability, or nonapplicability were assigned to each technology. Table 5.1 presents the results of the applicability determinations. Technologies rated highly applicable for a waste stream will be evaluated against other highly applicable technologies to establish preferred technologies to pursue for each waste stream category.

Because of the diverse nature of the specific waste streams included in some of the waste stream types, determinations of applicability were not always straightforward. For example, the two heterogeneous solid waste categories have combustible components as well as noncombustible components. Some technologies can process both combustibles and noncombustibles, while others are suited for processing only one or the other. In the case of the organic liquid wastes, some of the technologies could process such wastes well only if the wastes were diluted to low concentrations. In the case of wet solids, cemented sludges are included in this category and will present feed problems for some technologies normally considered as sludge processors. In such instances, the limitations are addressed in footnotes.

Waste stream applicability for each technology is discussed in more detail in Appendix A. Table 5.1 was used to prepare the functional process diagrams included in Appendix A for each of the technologies, specifically the waste stream sort/feed blocks.

Table 5.1. Technology applicability/waste stream matrix

Technologies[a]	Aqueous liquid	Organic liquid	Wet solids	Dry solids	Small heterogeneous	Large heterogeneous
	Waste streams					
Incinerators						
Agitated hearth	Low	High	High[b]	Medium	High[d]	N/A[c]
Controlled air	Low	High	Medium	Low	High[d]	N/A[c]
Fluidized bed	Low	High	High[b]	Medium	Medium[d]	N/A[c]
Cyclone	Low	High	Medium	Low	Medium[d]	N/A[c]
Indirect fired pyrolysis	Low	High[e]	High	Low	High[f]	High[f]
KfK excess air	Low	High	High	Medium	High[d]	N/A[c]
Liquid injection	Low	High	N/A	N/A	N/A	N/A
Multiple hearth	Low	High	High[b]	Medium	Medium[d]	N/A[c]
Rotary kiln	Low	High	High	High	High	High
Melters						
Electric-arc furnace	Medium	High	High	High	High	High
Fuel-fired melter	Medium	High	High	High	Low	Low
High-temp. joule melter	Medium	High	High	High	High	High
Microwave melter	Medium	Medium[e]	High	High	N/A	N/A
In-can resistance melter	Low	Low[e]	Medium	Medium	Low	N/A
Induction melter	Low	Low	Low	Low	Medium	Medium
Joule-heated melter	Medium[g]	High	High	High	N/A	N/A
Plasma-arc furnace	Medium	High	High	High	High	High
Stirred-joule melter	Low	High	High	High	N/A	N/A
Slagging-kiln incinerator	Medium	High	High	High	High	High
Miscellaneous						
Infrared furnace	N/A	N/A	Low	High	N/A	N/A
Molten-salt furnace	Low	High	N/A	N/A	High[d]	N/A
Plasma-pyrolysis reactor	Low	High	N/A	N/A	N/A	N/A
Steam gasification detoxifier	Medium	High	Low	N/A	Medium[d]	N/A
Supercritical water oxidation	High	High[h]	N/A	N/A	N/A	N/A
Ultraviolet photooxidation	High	High[h]	N/A	N/A	N/A	N/A
Wet-air oxidation	High	High[h]	N/A	N/A	N/A	N/A

[a]Includes all technologies evaluated—operational and emerging.
[b]Applicability rating with exception to cemented sludges.
[c]Technology rating higher for wood waste fraction; however, no wood waste volume is predicted.
[d]Combustible waste fraction only.
[e]Organic sludge waste fraction only.
[f]Organic decontamination of noncombustible waste fraction only.
[g]High for high-level waste slurry only.
[h]With <10% organics.

6. TECHNOLOGY-RANKING EVALUATIONS

The initial focus of the TTWG was to identify existing industrial thermal treatment technologies that, with low risk, could be applied to DOE waste streams; assess their real stage of development; and, if the technologies met the above requirements, perform assessments to guide decisions on technology demonstrations to pursue. Focus would then shift to addressing new and innovative technologies. Technologies that are currently available (termed "operational") were identified and are included in Table 6.1.

These technologies were then evaluated, by waste stream, using the criteria from Sect. 4.2. Technology ranking scores from the evaluations are contained in Table 6.2.

Table 6.1. Operational technology/waste stream matrix

Technologies[a]	Applicability to waste stream type[b]					
	Aqueous liquids	Organic liquids	Wet solids	Dry solids	Small heterogeneous	Large heterogeneous
Incinerators						
Agitated hearth		X	X		*c*	
Controlled air		X			*c*	
Cyclone		X				
Fluidized bed		X	X		*c*	
Indirect pyrolysis		*d*	X		*e*	*e*
KfK excess air		X	X		*c*	
Liquid injection		X				
Multiple hearth		X	X			
Rotary kiln		X	X	X	X	X
Melters						
Electric-arc furnace		X	X	X	X	X
Microwave melter			X	X		
Joule-heated melter	*f*	X	X	X		
Plasma-arc furnace		X	X	X	X	X
Slagging-kiln incinerator		X	X	X	X	X
Miscellaneous						
Infrared furnace				X		
Molten-salt furnace		X			*c*	
Steam gasifier detoxifier		X				
Supercritical water oxidation	X	*g*				
Ultraviolet photooxidation	X	*g*				
Wet-air oxidation	X	*g*				

[a]Does not include emerging technologies.
[b]An X denotes high applicability; shading denotes lower applicability.
[c]Combustibles only.
[d]Sludges only.
[e]Organic decontamination of noncombustibles only.
[f]High-level waste slurry only.
[g]Made up of <10% organics.

Table 6.2. Operational technology rankings/waste stream type

Technologies[a]	Ranking by waste stream type[b]						Composite score
	Aqueous liquids	Organic liquids	Wet solids	Dry solids	Small heterogeneous	Large heterogeneous	
Incinerators							
Agitated hearth		50	34		24		108
Controlled air		56			46		102
Cyclone		56					56
Fluidized bed		54	49		44		147
Indirect pyrolysis		47	47		38	44	176
KfK excess air		53	37		40		130
Liquid injection		56					56
Multiple hearth		50	40				90
Rotary kiln		53	47	47	47	47	241
Melters							
Electric-arc furnace		50	45	48	48	48	239
Microwave melter			52	52			104
Joule-heated melter	*c*	50	50	52			152
Plasma-arc furnace		50	43	46	43	43	225
Slagging-kiln incinerator		50	48	48	48	48	242
Miscellaneous							
Infrared furnace				38			38
Molten-salt furnace		41			36		81
Steam gasifier detoxifier		52					52
Supercritical water oxidation	48	43					91
Ultraviolet photooxidation	52	52					104
Wet-air oxidation	49	49					98

[a]Does not include emerging technologies.
[b]Shading denotes less than high applicability.
[c]High-level waste slurry only, not ranked for low-level waste.

7. TECHNOLOGY DEVELOPMENT NEEDS

7.1 THERMAL TECHNOLOGY DEVELOPMENT NEEDS

For DOE to implement any thermal treatment technology, whether existing or emerging, it must identify any technology development needs or deficiencies that may hinder effective utilization of the technology for DOE mixed wastes. These may be known hardware or operational deficiencies, or they may be information gaps that must be filled. Addressing and resolving these deficiencies in the development of technologies are the charter of the OTD.

Deficiencies were identified for all of the technologies that were rated as highly applicable to each waste type. Table 7.1 lists all of the highly applicable technologies for each waste stream category and also presents a list of development needs and lists of industry developers and DOE sites involved in the technology. This list attempts to identify known technology development needs.

7.2 OFF-GAS SYSTEM TECHNOLOGY DEVELOPMENT NEEDS

A companion OTD document to the OTD/HAZWRAP/SAIC thermal technology study[4] discusses off-gas treatment technologies.[6] These data were utilized by the TTWG in evaluating thermal treatment technologies because all thermal treatment technologies will require off-gas treatment. The data from the report will be used to evaluate complete thermal treatment systems.

Table 7.1. Development needs for high-potential technologies

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
Aqueous liquids			
Incinerator technologies			
No incinerator technology rated as high or medium applicability for aqueous waste streams			
Miscellaneous technologies			
Wet-air oxidation	Ash content limits, corrosion and corrosion monitoring, oxyhydroxide formation with actinides, radioactive applications	Oxidyne; Ver Tech; Zimpro/Passavant, Inc.	None
Supercritical water oxidation	Ash content limits, corrosion and corrosion monitoring, phase behavior—precipitation and solids management, high-pressure pump design, pressure letdown valve design, oxyhydroxide formation with actinides, steam flash and release potential, radioactive applications	Modar, Inc; ABB Lummus Crest; Modell Development Corp.; Ecowaste; Genesyst, Inc.; R. H. Halff Associates	LANL, SNL, NIST, INEL
Ultraviolet photooxidation	Light-source efficiency with respect to bandwidth, catalyst degration, pH dependency of reaction rate, competing reactions of organics, scale-up effects	Kerr McGee, ECOVA, DeGussa	LLNL, ORNL, SERI, SNL
Melter technologies			
Joule-heated melter[b]	Demonstration of effectiveness as hazardous waste treatment, studies on partitioning of radionuclides and heavy metals in glass	American Environmental Management Corp.; Penberthy Electromelt International, Inc.; Recomp, Inc.; Sorg Engineering; Frazier-Simplex, Inc.; Toledo Engineering Co., Inc.	Mound, RFP, SRS, Hanford, West Valley

Table 7.1 (continued)

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
Organic liquids			
Incinerator technologies			
Rotary kiln	Improved refractory seals design, improved ash removal, advanced off-gas system for improved nuclide removal	ABB Raymond; ABB Environmental Services; Allis Chalmers; AMETEK Process Systems; Anderson 2000, Inc.; Aqua-Guard Technologies; Bigelow-Liptak; Brule CE&E; Cleansoils; Cleever-Brooks Div.; College Research Corp.; Combustion Engineering; Conservtherm System; Combustion Technologies; DRE Technologies; Ford-Bacon-Davis; Fuller Power; Harper Electric Furnace; International Waste Energy Systems; John Zink; Joy Energy Systems; Kennedy Van Saun Corp.; Lurgi Corp.; M&S Engineering & Manufacturing Co.; McGill Pollution Control Systems; Soil Purification, Inc.; Surface Combustion; Texcel Environmental Systems; Thermal, Inc.; Thermal Process Construction; Trofe, Inc.; Von Roll; Vulcan Waste Systems; Westinghouse Resource Energy Systems; Williams Environmental Services	ORNL, SRS

Table 7.1 (continued)

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
Fluidized-bed incinerator	Optimization of process, advanced off-gas system for higher radionuclide removal	ARI Technologies; AWT Systems; Aerojet Energy Conversion; Anderson 2000, Inc.; Combustion Power Co.; Conversion Technologies; Copeland Associates; Fuller Company; GA Technologies; Hankin Environmental Systems, Inc.; Keeler/Dorr Oliver; Lurgi Corp.; Niro Atomizer; Process Combustion Corp.; Texcel Environmental Systems Co.; Waste Tech Services; Zimpro/Passavant, Inc.	RFP
Controlled-air incinerator	Improved ash removal, advanced off-gas system for higher radionuclide removal	AER; Aerojet Energy Conversion; American Energy Waste System; Anderson 2000, Inc.; Basic Environmental Engineering; Besser-Wasteco Corp.; Burney the Burner; Oil Incineration Systems; Cleever-Brooks Div.; Consumat Systems; Econo-Therm Energy Systems Corp.; International Waste Energy Systems; Joy Energy Systems, Inc; Kennedy Van Saun Corp.; Koch Process Systems, Inc.; Simonds Manufacturing Corp.; Stock Equipment Co.; Thermal, Inc.; Thermal Process Construction Co.; Trecan Combustion, Ltd.; Vent-O-Matic Incinerator Corp.; Vulcan Waste Systems, Inc.; John Zink Co.	Brook-haven, INEL, Y-12, K-25, SRS, RFP, LLNL, Pantex
Multiple-hearth incinerator	Adaptation to radiological service, advanced off-gas system for higher radionuclide removal	Bethlehem Corp.; BSP Thermal Systems; Hankin Environmental Systems, Inc.; Kennedy Van Saun Corp.; Texcel Environmental Systems Co.; Thermal Process Construction; Zimpro/Passavant, Inc.	None

Table 7.1 (continued)

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
KfK excess air	Off-gas system, secondary combustion	Fahrhold (Denmark), NGC (Japan), NUKEM (Germany)	None
Liquid injection	Advanced off-gas system for higher radionuclide removal	Anderson 2000, Inc.; Bayco Industries; Bedford Industries, Inc.; Bigelow-Liptak; Brule CE&E; Burn-Zol; Combustion Technologies; Copen; Durr Engineering & Management; Energy Development Association; Entech; Epscon Industrial Systems, Inc.; Fuel & Combustion Technology, Inc.; Hirt Combustion Engineers; John Zink; Kelly Liquid Injection; Lotepro Corp.; Lurgi Corp.; McGill Pollution Systems, Inc.; Met-Pro; NOA, Inc.; North American Manufacturing Co.; Peabody; Prenco; Process Combustion; Product Recovery & Energy Co.; Pyro Industries, Inc.; Selas Fluid Processing Corp.; Smith Engineering & Environmental; Surface Combustion, Inc.	SRS
Cyclone incinerator	Destruction and removal efficiency determination studies	Babcock and Wilcox; Institute of Gas Technology; York Shipley, Inc.; Environmental Technology	Mound
Agitated hearth	No specific needs identified		RFP
Indirect-fired pyrolysis[c]	Adaptation to radioactive service	Bryant Incinerators, Midland-Ross Corp.	None
Miscellaneous technologies			
Molten-salt furnace	Materials of construction (corrosion), maintenance requirements, continuous flow operations (vs batch), chemical stability of melt	Rockwell International	Hanford, LANL, LLNL

Table 7.1 (continued)

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
Steam gasification detoxifier	Demonstration of continuous feed, off-gas catalyst improvement, oxyhydroxide formation with actinides, hydrogen gas buildup, radioactive contamination/exposure provisions	Synthetica Technologies, Inc.	Hanford, SRS
Wet-air oxidation[d]	Ash content limits, corrosion and corrosion monitoring, oxyhydroxide formation with actinides, radioactive applications	Zimpro/Passavant, Inc.; Oxidyne; Ver Tech	None
Supercritical water oxidation[d]	Ash content limits, corrosion and corrosion monitoring, phase behavior—precipitation and solids management, high-pressure pump design, pressure letdown valve design, oxyhydroxide formation with actinides, steam flash and release potential, radioactive applications	Modar, Inc.; ABB Lummus Crest; Modell Development Corp.; Ecowaste; Genesyst, Inc.; R. H. Halff Associates	LANL, SNL, NIST, INEL
Plasma-pyrolysis reactor	Heating value limitations, torch electrode life, power requirements vs feed properties	Westinghouse; Pyrolysis Systems, Inc.	None
Ultraviolet photooxidation[d]	Light-source efficiency with respect to bandwidth, catalyst degradation, scale-up effects, pH dependency of reaction rate, competing reactions of organics	Kerr McGee, ECOVA, DeGussa	LLNL, ORNL, SERI, SNL
Melter technologies			
Joule-heated melter	Demonstration of effectiveness for hazardous waste treatment, partitioning of radionuclides and heavy metals in glass	See above list	Mound, RFP, SRS, Hanford, West Valley

Table 7.1 (continued)

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
High-temperature joule melter	Safety assessment (heterogeneous solids), metal tapping, metal oxidation	American Environmental Management Corp.; Penberthy Electromelt International, Inc.; Recomp, Inc.; Sorg Engineering; Frazier-Simplex, Inc.; Toledo Engineering Co., Inc.	Hanford
Plasma-arc furnace	Safety assessment (heterogeneous), NO_x reduction, electrode wear, optimization of slag chemistries	French, Retech, Westinghouse, ABB, PEC, Canadians	INEL
Fuel-fired melter	Oxygen enrichment studies	Glass industry	None
Stirred melter	Improved high-temperature metals	Glasstech	SRS
Electric-arc melter	No specific needs identified	Mannesmann Demag, Lectromelt Corp.	None
Slagging kiln	No specific needs identified	Allis Chalmers; Combustion Engineering Co.; Ford, Bacon and Davis; Rollins Environmental Services; Von Roll, Ltd. (Switzerland); John Zink Co.	None
Wet solids			
Incineration technologies			
Rotary kiln	Improved refractory seals design, improved ash removal	See above list	RFP, K-25, SRS, INEL
Fluidized bed[e]	Optimization of process, advanced off-gas system	See above list	RFP
Indirect-fired pyrolysis	Adaptation to radiological service	Bryant Incinerators	None
KfK (excess air)	Off-gas system, secondary combustion	Fahrold (Denmark), NGC (Japan), NUKEM (Germany	None
Multiple hearth[e]	Adaptation to radioactive service	See above list	None

Table 7.1 (continued)

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
Agitate hearth[c]	No needs specified	None identified	RFP
Miscellaneous technologies			
No miscellaneous technology identified as highly applicable to wet solids			
Melter technologies			
Joule-heated melter	Demonstration of effectiveness for hazardous waste treatment, studies on partitioning of radionuclides and heavy metals	See above list	Mound, RFP, SRS, Hanford, West Valley
In-can microwave melter	Develop dielectric property models, study container corrosion problems, volatility studies, control heat profiles, understanding of microwave effects	Japanese	RFP, ORNL, K-25
High-temperature joule melter	Safety assessment (heterogeneous) refractory, metal tapping, metal oxidation	See above list	Hanford
Plasma-arc furnace	Safety assessment (heterogeneous), NO_x reduction, electrode wear	ABB Environmental Services; Retech, Inc.; PEC; Westinghouse; Canadian and French	INEL, ORNL
Fuel-fired melter	Oxygen enrichment studies	Glass industry	None
Stirred melter	Improved high-temperature metals	Glasstech	SRS
Electric-arc melter	No specific needs identified	Mannesmann Demag, Lectromelt Corp.	None
Slagging kiln	No specific needs identified	See above list	None

Table 7.1 (continued)

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
Homogenous dry solids			
Incinerator technologies			
Rotary kiln	Improved refractory seals design, improved ash removal	See above list	RFP, K-25, SRS, INEL
Miscellaneous technologies			
Infrared furnace	Feed preparation, feed transport, mesh furnace belt life, waste stirring for maximum exposure	ECOVA; Westinghouse Haz Tech; OHM; Harper Electric Furnace; National Applied Science; Systems, Inc.; Shirco Infrared Systems, Inc.	SRS
Vitrification technologies			
Joule-heated melter	Demonstration of effectiveness for hazardous waste treatment, studies on partitioning of radionuclides and heavy metals	See above list	Mound, RFP, SRS, Hanford, West Valley
Plasma-arc furnace	Safety assessment (heterogeneous), NO_x reduction, electrode wear	ABB Environmental Services; Retech, Inc; PEC; Westinghouse; Canadian and French	INEL, ORNL
Fuel-fired melter	Oxygen enrichment studies	Glass industries	None
Stirred melter	Improved high-temperature melts	Glasstech	SRS
Electric-arc melter	No needs specified	Mannesmann Demag, Lectromelt Corp.	None
Slagging kiln	No specific needs identified	See above list	None
In-can microwave melter	Develop dielectric property models, study container corrosion problems, volatility studies, control heat profiles	Japanese	RFP, ORNL, K-25

Table 7.1 (continued)

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
High-temperature joule melter	Safety assessment (heterogeneous) refractory, metal tapping, metal oxidation	See above list	Hanford
Small heterogeneous solids			
Incinerator technologies			
Indirect-fired pyrolysis[f]	Adaptation to radioactive service	Bryant Incinerators, Midland-Ross Corp.	None
KfK (excess air)[g]	Off-gas system, secondary combustion	Fahrold (Denmark), NGC (Japan), NUKEM (Germany)	None
Rotary kiln	Refractory seals, ash removal	See above list	RFP, K-25, SRS, INEL
Controlled air[g]	See above	See above list	See above
Agitated hearth[g]	No needs specified	None identified	RFP
Fluidized bed[g]	Optimization of process	See above list	RFP
Miscellaneous technologies			
No miscellaneous technology identified as highly applicable for large heterogeneous solids			
Melter technologies			
High-temperature joule melter	Safety assessment (heterogeneous) refractory, metal tapping, metal oxidation	See above list	Hanford
Plasma-arc furnace	Safety assessment (heterogeneous), NO_x reduction, electrode wear	ABB Environmental Services; Retech, Inc.; PEC; Westinghouse; Canadian and French	INEL, ORNL
Electric-arc melter	No needs specified	Mannesmann Demag, Lectromelt Corp.	None
Slagging kiln	No specific needs identified	No industries identified	None

Table 7.1 (continued)

Applicable technology by waste stream type	Development needs	Developers: Industry	Developers: DOE facilities
Large heterogeneous solids			
Incinerator technologies			
Rotary kiln	Refractory seals, ash removal	See above list	RFP, K25, SRS, INEL
Indirect-fired pyrolysis[f]	Adaptation to radiological service	Bryant Incinerators	None
Miscellaneous technologies			
Molten-salt furnace[g]	Materials of construction (corrosion), maintenance requirements, continuous flow operations (vs batch), chemical stability of melt	Rockwell International	Hanford, LANL, LLNL
Melter technologies			
High-temperature joule melter	Safety assessment (heterogeneous) refractory, metal tapping, metal oxidation	See above list	Hanford
Plasma-arc furnace	Safety assessment (heterogeneous), NO_x reduction, electrode wear	ABB Environmental Services; Retech, Inc.; PEC; Westinghouse; Canadian and French	INEL, ORNL
Electric-arc melter	No needs specified	Mannesmann Demag, Lectromelt Corp.	None
Slagging kiln	No specific needs identified	See above list	None

[a]INEL = Idaho National Engineering Laboratory; K-25 = Oak Ridge K-25 Site; LANL = Los Alamos National Laboratory; LLNL = Lawrence Livermore National Laboratory; NIST = National Institute of Standards and Technology; ORNL = Oak Ridge National Laboratory; RFP = Rocky Flats Plant; SERI = Solar Energy Research Institute; SNL = Sandia National Laboratory; Y-12 = Oak Ridge Y-12 Plant.

[b]High-level waste slurry only.

[c]Organic sludge fraction only.

[d]Organic liquids with <10% organics.

[e]Wet solids except for cemented sludges.

[f]Organic decontaminations of noncombustible waste fraction only.

[g]Combustible waste fraction only.

7.3 RADIOACTIVE WASTE TREATMENT EXPERIENCE

Two recent studies funded by DOE[7,8] identified, on a limited scale, thermal technologies that have been or are currently being employed in the DOE system and in the commercial sector for treatment of radioactive wastes. The objective of these studies was to compile the experiences and examine the lessons that could be learned from them (to aid planners and designers of future systems) and to avoid the pitfalls already experienced. These data augment the list of technology deficiencies identified by the TTWG. The TTWG recommends an expansion of this effort because, even though the information gleaned in the initial cursory look will be very valuable to thermal technology developers throughout the system, a more detailed look is viewed as a cost-effective way to prevent recurrence of the same problems experienced previously. There is no known existing repository for such information.

8. CONCLUSIONS

The results of this assessment should be utilized to indicate a grouping of technologies at which DOE should be directing its attention for each of the waste stream categories evaluated. Thermal technologies may not be the best solution for all wastes streams (e.g., aqueous liquids), and the highly ranked thermal technologies should be compared with nonthermal processes as part of a rigorous evaluation.

8.1 TECHNOLOGY RANKING BY WASTE STREAM

The thermal technologies ranked highest by the TTWG for each waste category are summarized below:

- Aqueous liquids
  - ultraviolet photooxidation,
  - wet-air oxidation, and
  - supercritical water oxidation;
- Organic liquids
  - liquid-injection incinerator,
  - controlled-air incinerator, and
  - cyclone incinerator;
- Wet solids
  - microwave melter,
  - joule-heated melter, and
  - fluidized-bed incinerator;
- Dry homogeneous solids
  - joule-heated melter,
  - microwave melter,
  - slagging-kiln incinerator, and
  - electric-arc furnace; and
- Heterogeneous solids (large and small)
  - electric-arc melter,
  - slagging-kiln incinerator, and
  - rotary-kiln incinerator.

The variation in ranking score among the top-ranked technologies for a given waste category was very small, ranging from 2 to 7%. A more comprehensive assessment is indicated for refinement of these results, utilizing criteria that are more differentiating so that the results will be more conclusive. In general, any of the highly ranked technologies in a given waste category would be a good technology candidate.

8.2 TECHNOLOGY VERSATILITY

An important consideration that is not directly included in the evaluation is technology versatility. A technology that can operate on a wide variety of waste streams such as all six of the waste categories presents some significant advantages to DOE. The advantages include decreased capital cost, localized risk, streamlined permitting (over permitting several less versatile technologies), and quicker implementation. The disadvantages, however, can include reduced treatment effectiveness on some waste streams. By summing the rankings of a technology on each waste stream, both versatility and effectiveness are considered. The potential weakness in this approach is that all the waste streams are assumed to be equally important. In some cases, it may be most important for a technology to be capable of processing one or two of the waste stream categories used in this study because of relative volumes or other factors. When this is the case, weighting factors could be applied to the overall evaluation to skew it in the favor of those technologies that rate highly on the most important waste streams. No attempt was made to weight the relative importance of the waste streams used in this study because of the general nature of the scope of this project (DOE mixed waste).

The results of the overall evaluation scoring are shown in Fig. 8.1. The four highest-rated technologies were rotary kilns, slagging kilns, electric-arc furnaces, and plasma-arc furnaces. The four highest-rated technologies were all judged to be applicable to five of the six waste streams and are the only technologies in the evaluation with this distinction.

An analysis that optimized overall treatment benefit while also considering capital expenditure (by carefully choosing two or three technologies) may be the best overall means of making treatment facility decisions. A good example of this type of facility would be one that uses a controlled-air incinerator on organic liquids and solid combustible waste and an electric-arc furnace on solid inert (including the controlled-air incinerator ash) and sludge wastes. This facility would have capital expenditures for only two technologies that could perhaps share an off-gas system and very effective treatment benefit.

8.3 CONCLUSIONS

Conclusions as to the superiority of one technology over others are not valid based on this study alone, although some general conclusions can be drawn. The conclusions and important points that can be drawn from the evaluation are summarized as follows:

- None of the evaluated technologies ranked highly on all of the DOE waste categories. While some technologies were applicable to five of the streams, these systems would not perform effectively on some of the streams.

- The highest-ranked technologies on the DOE mixed waste overall were rotary-kiln incinerators, slagging-kiln incinerators, electric-arc furnaces, and plasma-arc furnaces. The versatility of these technologies was the biggest reason for their high ratings.

- The most effective facility (considering cost and benefit) to treat the six DOE waste categories would involve at least two of the evaluated technologies based on this study.

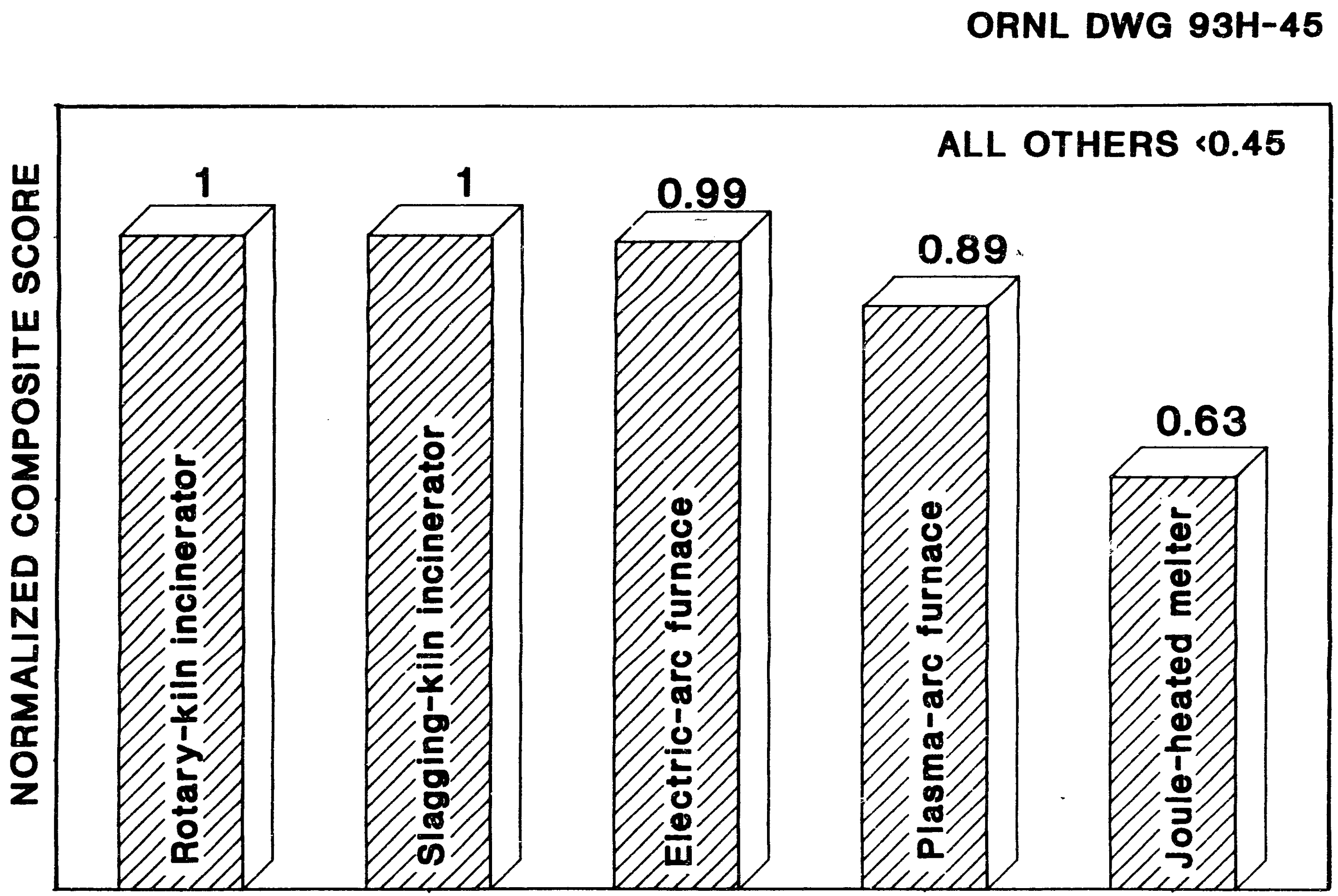

Fig. 8.1. Technology versatility comparisons.

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Appendix A. THERMAL TECHNOLOGY DATA

PREFACE

Appendix A presents additional information on each technology discussed in the text of this report. This appendix is divided into three parts: A.1—Incinerator Technologies, A.2—Miscellaneous Technologies, and A.3—Melter Technologies. Descriptions, waste applicability, advantages, disadvantages, and development needs are given for each technology. In addition, U.S. Department of Energy laboratories involved in the technologies are listed, as well as commercial vendors. References used to assemble information for each technology are also listed.

A functional process diagram is provided for each technology, which gives a general illustration of the waste sort/processing/treatment train. Additional clarifications to be considered when reviewing the functional process diagrams are discussed below. The portion of each functional process diagram listing nontreatable waste categories should not be taken as absolute information; rather, it should be reviewed along with the attached waste applicability section, as well as Tables 4.2 and 7.1. Waste streams with low applicability to a given technology were listed in the nontreatable category since they are, in general, ineffectively treated by that technology. In most cases, there are exceptions within each waste stream which are applicable to a given technology.

INCINERATOR TECHNOLOGIES

In general, incinerator technologies are not applicable to aqueous liquids, noncombustibles, or solids that are large in size. However, some incinerators are amenable to limited amounts of these waste types.

Most incinerators would be equipped with a shredder for large dry waste types. Incinerators, in general, produce an ash or ash-like residue that would require further treatment if produced from mixed-waste processing. Therefore, an ash treatment step is included. Many of the incinerator processes will also produce an off-gas residue resulting from off-gas scrubbing, which would also require treatment.

MISCELLANEOUS TECHNOLOGIES

Most of the technologies in this category are highly applicable to one or two waste types rather than to a variety of waste types. For example, five of the technologies are applicable only to aqueous liquids, two are highly applicable to dry homogeneous solids, and one is highly applicable to combustible liquids or solids only.

The high-temperature reactor/furnace technologies produce ash residues which would require a treatment step to stabilize the leachable species. The three technologies that serve to oxidize organics from aqueous solutions produce not only an ash-like precipitate but also the treated water stream that would require conversion to a solid form, in most cases before disposal.

MELTER TECHNOLOGIES

These technologies are applicable to a wide variety of waste streams. However, most of them require a shredder for some of the larger solids because they do not have the capability to accept, for a variety of reasons, large waste constituents. Generally, melters are not amenable to large heterogeneous solids because of the metal content, with the exception of those melters that are operated at very high temperatures, such as the electric-arc furnace, plasma-arc furnace, high-temperature joule melter, and slagging-kiln technologies. Because the melter technologies produce a molten slag which then solidifies to a glassy matrix, it will not be necessary, in most cases, to include an additional treatment step. However, if the glass matrix does not pass leach tests, the matrix will require further treatment, most likely including remelting.

A.1. INCINERATOR TECHNOLOGIES

Technology Name: Rotary-Kiln Incinerator

Maturity: Operational–Conventional

Description:

The rotary kiln is a cylindrical refractory-lined shell mounted on a slight incline. Rotation of the kiln provides for movement of waste through the kiln as well as for enhancement of waste mixing. Rotary kilns normally require a secondary combustion chamber to ensure complete destruction of hazardous constituents. The primary chamber functions to pyrolyze or combust solid waste to gases. The gas-phase combustion reaction is completed in the secondary chamber. Both the primary and the secondary chamber are generally supplied with auxiliary fuel systems. An extensive off-gas system is generally required to control the high volume of emissions. A functional process diagram of the rotary-kiln incinerator is shown in Fig. A.1.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	High applicability to both sludge and pumpable organic liquid waste streams.
Wet Solids:	High applicability to all subcategories of wet solids.
Dry Homogeneous Solids:	High applicability to dry solids especially soils.
Dry Heterogeneous Solids (Small):	High applicability to both the combustible and noncombustible fractions of heterogeneous solid wastes.
Dry Heterogeneous Solids (Large):	High applicability to large wood items and low applicability to noncombustibles such as equipment and glove boxes.

Advantages:

The rotary-kiln incinerator is the most versatile type of conventional incinerator. It can handle a wide variety of solid and liquid waste types and is capable of a wide range of physical waste feed configurations. Ash is removed continuously and does not interfere with waste oxidation. A rotary-kiln incinerator can be operated at very high temperatures to handle difficult-to-destroy constituents and has a good turndown ratio.

Disadvantages:

Rotary-kiln incinerators generally have high capital costs for installation. High particulate loadings are often experienced. Drying of some aqueous sludge waste or melting of some solid wastes can result in clinker or ring formation on refractory walls. Spherical or cylindrical objects may roll through the kiln before complete combustion. Rotary-kiln incinerators are not very thermally efficient and cannot be thermally cycled often (shutdown/startup cycle). The large volumes of air required for combustion give rise to large, costly off-gas treatment systems.

Development Needs:

Better kiln seal design, advanced off-gas systems, better stack monitoring and other real-time performance assurance capabilities, control of heavy metal emissions, combustion by-product formation, submicron particulate emissions.

Vendor List:

ABB Raymon
ABB Environmental Services
AMETEK Process Systems
Allis Chalmers
Anderson 2000, Inc.
Aqua-Guard Technologies
Bigelow-Liptak
Brule CE&E, Inc.
Cleansoils
Cleever Brooks Div.
College Research Corp.
Combustion Engineering
Combustion Technologies
Conservtherm Systems
DRE Technologies
Ford-Bacon-Davis
Fuller Power
Harper Electric Furnace
International Waste Energy Systems
International Energy System
Joy Energy Systems
Kennedy Van Saun Corp.
Lurgi Corp.
M&S Engineering & Manufacturing Co.
McGill Pollution Control Systems
Soil Purification, Inc.
Surface Combustion
Texcel Environmental Systems
Thermall, Inc.
Thermal Process Construction
Trofe, Inc.
Von Roll
Vulcan Waste Systems
Westinghouse Resource Energy Systems
Williams Environmental Services
John Zink Co.

DOE Laboratories Involved in Technology:

Rocky Flats Plant
Oak Ridge K-25 Plant
Savannah River Site
Idaho National Engineering Laboratory

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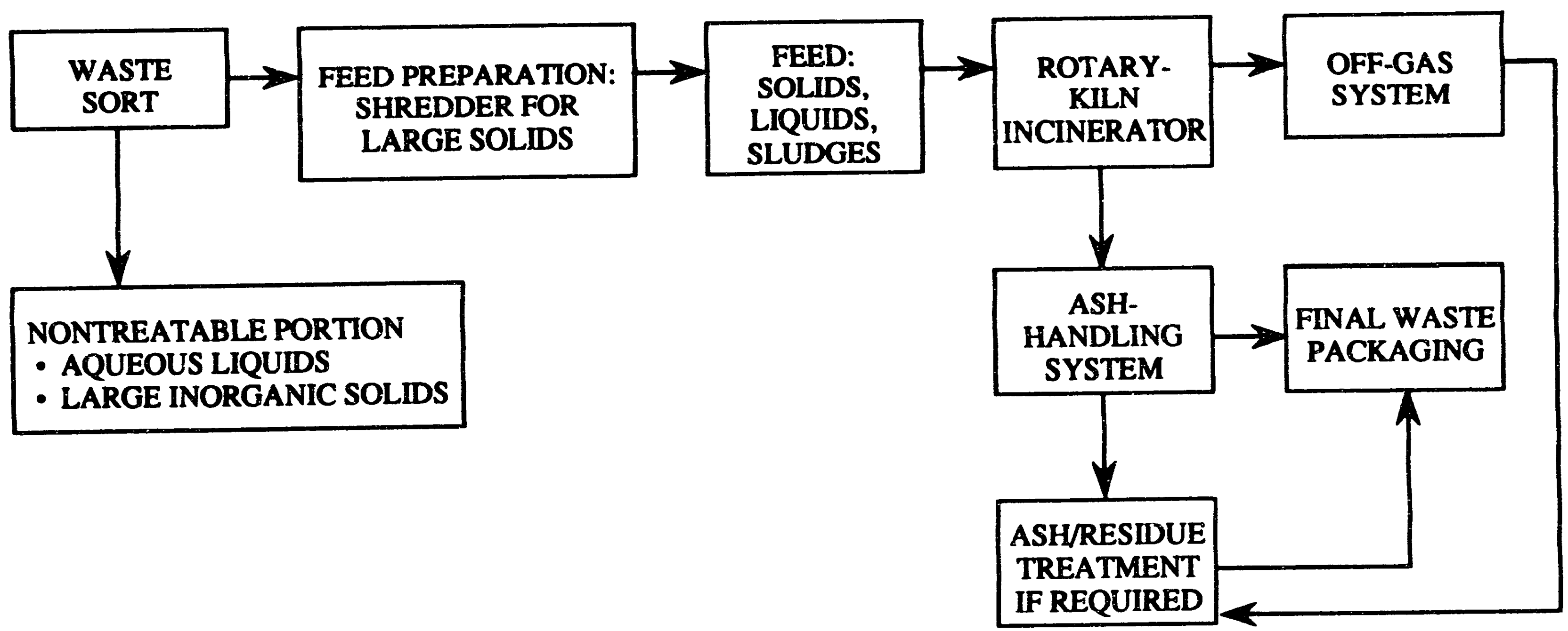

Fig. A.1. Functional process diagram of the rotary-kiln incinerator.

Technology Name: Fluidized-Bed Incinerator

Maturity: Operational-Conventional

Description:

A vertical refractory-lined vessel containing a bed of an inert granular material. The bed is "fluidized" by passing air, which serves as combustion air, through a perforated plate at the bottom of the vessel. Waste is fed to the hot bed for combustion, where the high thermal mass and turbulent mixing action of the bed material rapidly transfer the heat to the waste. Auxiliary fuel is often used to maintain bed temperature. A secondary chamber may be required to ensure complete combustion for hazardous wastes. Limestone is usually added to the bed to provide capability for in-bed acid-gas scrubbing capability (no scrubber required). Off-gas particulate removal is required. A variation of fluidized-bed technology is a circulating-bed system where higher air velocities cause high carryover rates. The carryover material is recovered and returned to the system. A functional process diagram of the fluidized-bed incinerator is shown in Fig. A.2.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	Medium applicability to organic liquid sludges and high applicability to pumpable organic liquids.
Wet Solids:	High applicability to resins, with only moderate to low applicability to sludges, absorbed liquids, and cemented sludges respectively.
Dry Homogeneous Solids:	Medium applicability to homogeneous dry solids.
Dry Heterogeneous Solids (Small):	High applicability to combustible wastes within this category and low applicability to noncombustible wastes.
Dry Heterogeneous Solids (Large):	Medium applicability to wood waste (with size reduction).

Advantages:

The fluidized-bed incinerator is relatively simple in design, as it has few moving parts. Its capital and maintenance costs are relatively low, and the incinerator is long-lived. A fluidized-bed incinerator is simple to operate and has ease of process control and high thermal efficiency. Lower operating temperatures lead to lower NO_x formation and metal emission rates, and the capability for in-bed scrubbing eliminates the need for an off-gas scrubber system. Fluidized-bed incinerators are versatile in that they can accept solids, liquids, sludges, and gases.

Disadvantages:

Fluidized-bed incinerators have a relatively low throughput capacity, and it is difficult to remove residuals from the bed. Operating costs of fluidized-bed incinerators are relatively high. Solid wastes will likely have to be pretreated (shredded or sized) prior to introduction. Residence times are nonuniform, and particulate entrainment rates are high. The vessel and related components are subject to erosion. Low melting point materials in the bed may cause the bed material to fuse.

Development Needs:

Advanced off-gas systems capable of removing higher percentages of the radioactive constituents, better stack monitoring and other real-time performance assurance capabilities, control of heavy metal emissions, combustion by-product formation, submicron particulate emissions.

Vendor List:

ARI Technologies
AWT Systems
Aerojet Energy Conversion
Anderson 2000, Inc.
Combustion Power Company
Conversion Technologies
Copeland Associates
Fuller Company
GA Technologies
Hankin Environmental Systems, Inc.
Keeler/Dorr Oliver
Lurgi Corp.
Niro Atomizer, Inc.
Process Combustion Corp.
Texcel Environmental Systems Co.
Waste Tech Services, Inc.
Zimpro/Passavant, Inc.

DOE Laboratories Involved in Technology:

Rocky Flats Plant

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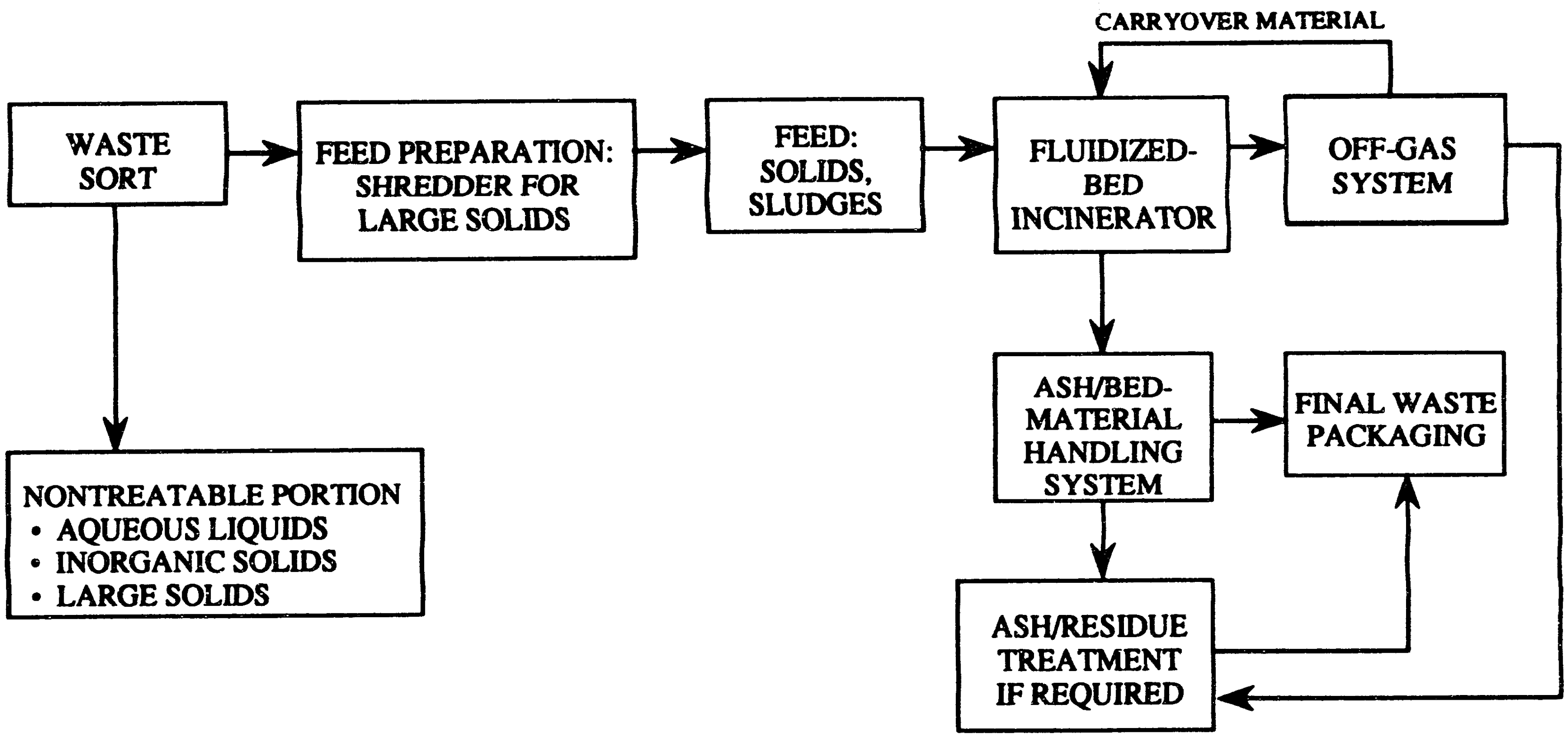

Fig. A.2. Functional process diagram of the fluidized-bed incinerator.

Technology Name: Agitated-Hearth Incinerator

Maturity: Operational-Unique

Description:

The agitated-hearth incinerator is a vertical, cylindrical chamber with a rabble arm that is rotated around the incinerator hearth to slowly agitate the waste pile, spreading out the waste material and exposing unburned material to the combustion air supply. The shaft for the rabble arm penetrates up through the bottom of the incinerator in the center of the hearth. Solid waste is fed in from the side through a ram feeder. Multiple burners are located at approximately midheight in the cylindrical walls for startup and auxiliary heat input. These burners could also be used foı liquid waste disposal. Combustion gases pass from the primary chamber to the secondary chamber for extended residence time. In operation, waste is slowly fed into the chamber over a period of time. During this period, the rabble arm continually mixes the burning waste. Eventually, the waste pile builds up, and waste feeding is stopped. The incinerator goes through a burnout cycle where the rabble arm continues to mix the waste and stir the ashes until all combustible material is consumed. As the heat input from the burning waste begins to fall, the burners are ignited to maintain the temperature in the primary chamber at approximately 800° C. When the waste is completely consumed, an ash discharge door in the floor of the hearth is opened and the ash is raked out of the chamber by the rabble arm. When the ashes have been removed, the ash discharge door is closed, the feeding cycle begins, and the process is repeated. A functional process diagram of the agitated-hearth incinerator is shown in Fig. A.3.

Waste Applicability:

Aqueous Liquids:	Low applicability.
Organic Liquids:	High applicability.
Wet Solids:	High applicability.
Dry Homogeneous Solids:	Medium applicability.
Dry Heterogeneous Solids (Small):	High applicability for combustible waste components.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

This is a simple system that can achieve an excellent burnout of combustible matter because of the long solids retention time and the mixing of the waste. The process is easy to monitor and control and can incinerate a wide range of combustible waste types including solids, liquids, and sludges.

Disadvantages:

Proper operation depends on movement of the rabble arm, which is subject to mechanical, chemical, and thermal stresses. Operation is also limited by the size of waste constituents that are too heavy to be moved by the rabble arm or that could jam the rabble arm.

Development Needs:

Conversion and long-term operation tests on radioactive waste. Characterization of off-gas, especially in terms of toxic metals and fine particulate. Better stack monitoring and other real-time performance assurance capabilities.

Vendor List:

Environmental Tech (it is unknown if this company still exists)

DOE Laboratories Involved in Technology:

Rocky Flats Plant

Bibliography:

Ziegler, D. L., "Incineration Process Fire and Explosion Protection," presented at the 13th AEC Air Cleaning Conference, San Francisco, Calif., August 1974.

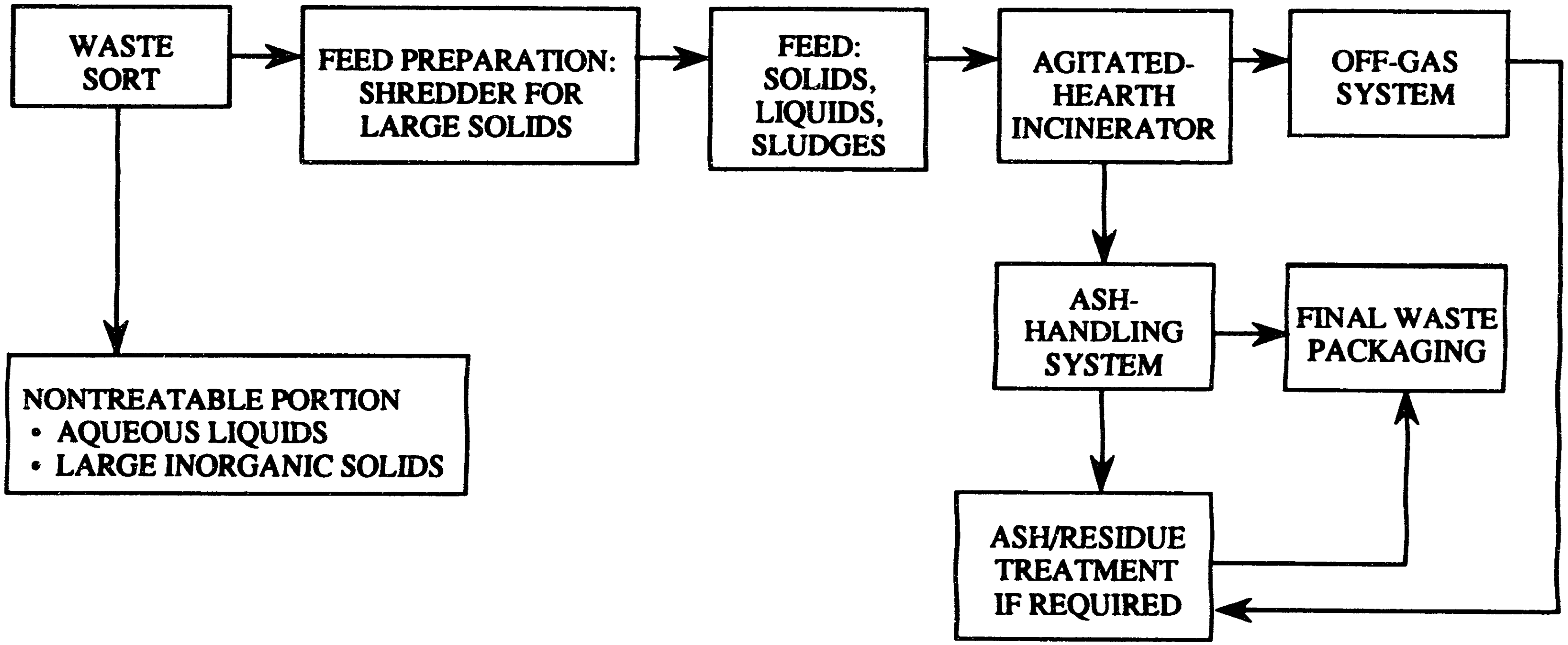

Fig. A.3. Functional process diagram of the agitated-hearth incinerator.

Technology Name: Multiple-Hearth Incinerator

Maturity: Operational-Conventional

Description:

A multiple-hearth incinerator consists of a refractory-lined steel shell with a series of circular hearths arranged in a vertical design. A series of rotating, air-cooled rabble arms conveys the solid waste from upper to lower hearths. As the waste is conveyed down through the incinerator, the successive hearths are used for drying, heating, combustion, burnout, and cooling of the waste. Fuel burners are mounted on the side of the vessel in the hearths where combustion and burnout occur. These burners can be used for high-heat-value hazardous liquids if desired. A secondary chamber may be required for complete destruction of hazardous wastes. Some form of air pollution control equipment will be required and will vary with the waste being processed. This type of incinerator has been used principally for sludges, tars, or other low-heat-value solids requiring long solids retention times and has been commonly used for disposal of dewatered activated wastewater treatment sludges. Use of this type of incinerator has been largely abandoned. A functional process diagram of the multiple-hearth incinerator is shown in Fig. A.4.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	Medium applicability to organic liquid sludges and high applicability to pumpable organic liquids.
Wet Solids:	High applicability to all subcategories of wet solids waste with the exception of medium applicability to cemented sludges.
Dry Homogeneous Solids:	Low to medium applicability to homogeneous dry solids and soils respectively.
Dry Heterogeneous Solids (Small):	Medium applicability to combustible wastes within this category and low applicability to noncombustible wastes.
Dry Heterogeneous Solids (Large):	Low applicability to wood waste only, not applicable to remainder of category.

Advantages:

The long solids retention times achieved in multiple-hearth incinerators increase the complete destruction of waste materials. Multiple-hearth incinerators can handle a wide range of wastes, including solids, sludges, liquids, and gases and are capable of evaporating large amounts of water. A wide range of fuels may be utilized to operate multiple-hearth incinerators.

Disadvantages:

Multiple-hearth incinerators cannot handle wastes that fuse into large chunks during incineration and are not good for wastes requiring high destruction temperatures. The incinerators are susceptibile to thermal shock. The large volumes of air required for combustion give rise to large, costly, and difficult-to-operate off-gas treatment systems. Solid wastes may have to be pretreated (shredded) before processing.

Development Needs:

Advanced off-gas systems adapted to remove high percentages of radioactive constituents, better stack monitoring and other real-time performance assurance capabilities, control of heavy metal emissions, combustion by-product formation, submicron particulate emissions.

Vendor List:

Bethleham Corp.
BSP Thermal Systems
Hankin Environmental Systems, Inc.
Kennedy Van Saun Corp.
Texcel Environmental Systems Co.
Thermal Process Construction
Zimpro/Passavant, Inc.

DOE Laboratories Involved in Technology:

None

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Cudahy, J., and Eicher, T. "Hazardous Waste Incineration Course," prepared by IT Corporation, August 1988.

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Modres, C. W., *Waste-to-Energy '87: Exploring the Total Market*, Badger Engineers, Inc., 1987.

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Sweet, W. E., Ross, R. D., and Velde, G. V., "Hazardous Waste Incineration: A Progress Report," *J. Air Pollut. Control Assoc.* 35 (2) (February 1985).

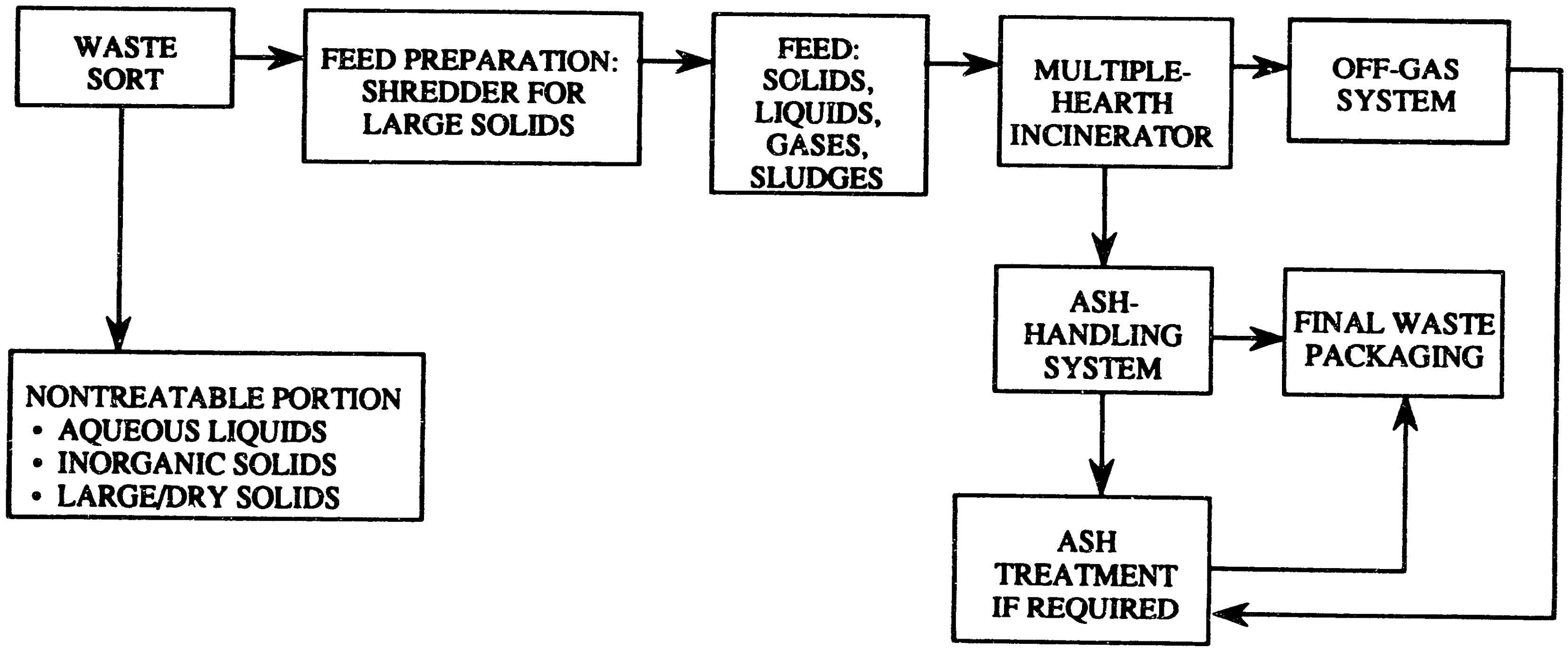

Fig. A.4. Functional process diagram of the multiple-hearth incinerator.

Technology Name: KfK Excess-Air Incinerator

Maturity: Operational-Conventional

Description:

The KfK incinerator is a vertical-shaft excess-air incinerator. The incinerator consists of a cylindrical shaft furnace with a refractory lining. The bottom section of the furnace is constructed in a cone shape. An afterburning chamber, two hot gas filters, and a two-stage flue-gas scrubbing system are located downstream of the furnace. The scrubbing system consists of a jet scrubber, a venturi scrubber, a HEPA filter, and an exhaust fan. Charging of the waste takes place via a feeding system which is accommodated in glove boxes. The furnace is charged automatically, depending on the O_2 content as well as on the furnace temperature. A double closure serves to ensure the contamination-free supply of waste from the drums. The cylindrical shaft furnace is operated at a temperature of at least 850°C. The minimum temperature is attained by means of a propane burner. For incineration, air is supplied in a controlled manner via several inlets oriented tangentially to the furnace walls. The temperature of the ash bed in the cone-shaped bottom part of the furnace is maintained at ≤800°C by means of steam addition. As a result, heat is removed from the ash bed, and the slag is prevented from adhering to the furnace. Ash discharge also takes place within a glovebox system, which is equipped with a double closure to avoid contamination. A functional process diagram of the KfK excess-air incinerator is shown in Fig. A.5.

Waste Applicability:

Aqueous Liquids:	Low applicability.
Organic Liquids:	High applicability.
Wet Solids:	High applicability, except possibly for resin wastes.
Dry Homogeneous Solids:	Low to medium applicability to homogeneous dry solids and soils respectively.
Dry Heterogeneous Solids (Small):	High applicability to combustible wastes in this category, low applicability to noncombustible wastes.
Dry Heterogeneous Solids (Large):	Low applicability to wood waste only.

Advantages:

This technology has over 20 years operating experience in Germany and Japan, incinerating both beta- and alpha-contaminated wastes (liquid wastes since 1988).

Disadvantages:

Large volumes of combustion air result in complex, costly off-gas treatment systems. High particulate carryover will entrain radioactive components into downstream components.

Development Needs:

Advanced off-gas systems, combustion by-product formation, and determination of optimal secondary chamber operating points.

Vendor List:

Fahrholf (Denmark)
NGC (Japan)
NUKEM (Germany)

DOE Laboratories Involved in Technology:

None identified

Bibliography:

Dirks, F., Hempelmann, W., Pfeifer, W., and Steinhaus, G., "Incineration of Radioactive Residues: Further Development of KfK Incineration Plants, Plant Performance and Test Results," presented at the 1991 Incineration Conference, May 1991.

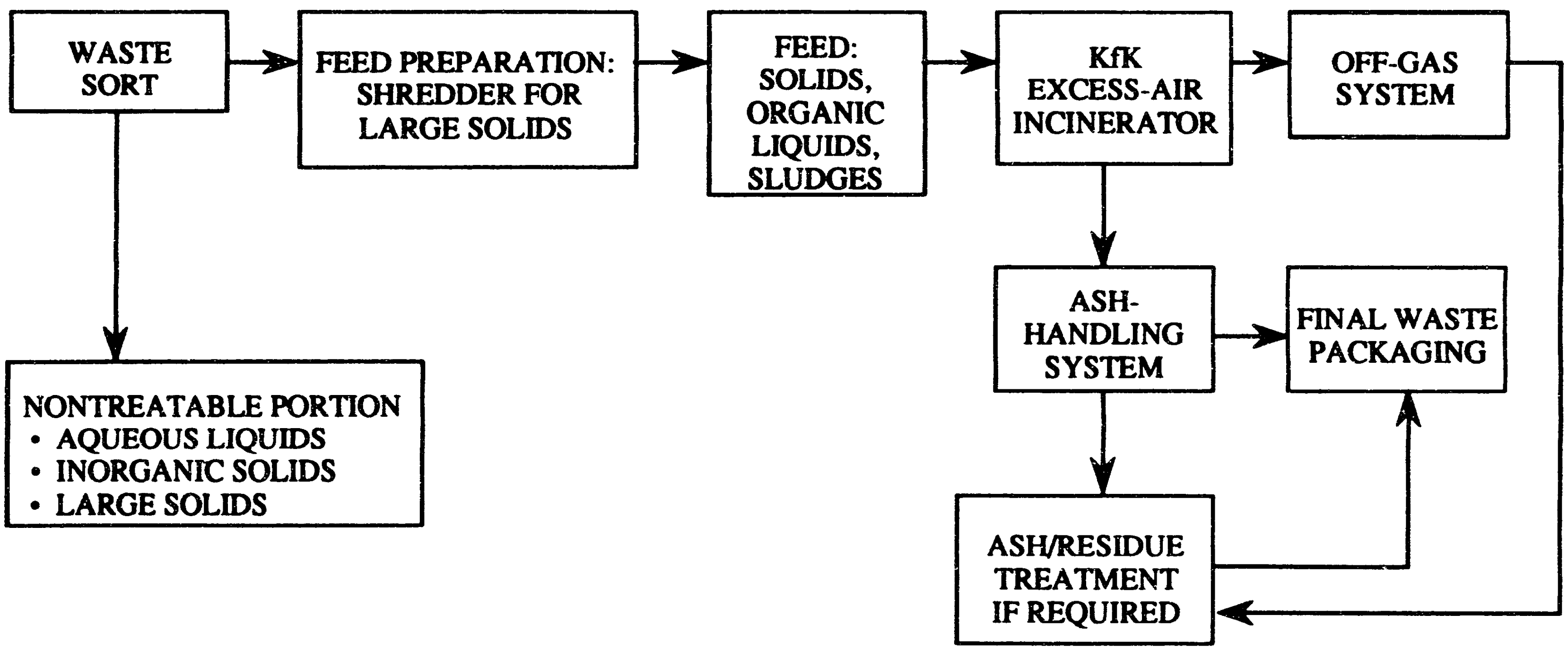

Fig. A.5. Functional process diagram of the KfK excess-air incinerator.

Technology Name: Liquid-Injection Incinerator

Maturity: Operational-Conventional

Description:

Liquid-injection incinerators are designed to process liquid wastes only. They are usually simple, refractory-lined cylinders equipped with one or more waste burners. Only one combustion chamber is generally used (secondary chamber not necessary for proper destruction). An off-gas treatment system may be required depending on the application and will vary in design based on the types of waste being processed. Most commercial liquid-injection incinerators do not use off-gas equipment; however, a liquid-injection incinerator for radioactive waste will likely require some type of off-gas particulate filter. The liquid-injection incinerator is sometimes used as a secondary chamber for other incinerator types. A functional process diagram of the liquid-injection incinerator is shown in Fig. A.6.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids that are pumpable only.
Wet Solids:	Not applicable to any wet solid subcategories with the exception of low applicability to resin wastes.
Dry Homogeneous Solids:	Not applicable.
Dry Heterogeneous Solids (Small):	Not applicable.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

No secondary combustion chamber is needed if the primary combustor has enough residence time. Liquid-injection incinerators can incinerate a wide range of liquid hazardous waste. No continuous ash-removal system is required other than for downstream air pollution control systems. Their simple design is thermally efficient, entails virtually no moving parts, and enables fairly high turndown ratios. Maintenance costs for liquid-injection incinerators are low.

Disadvantages:

Wastes which can be accepted in a liquid injection incinerator are restricted to only those that can be atomized through a burner nozzle (liquids with low or no solids content, and no sludges or solids). The incinerator system is sensitive to waste composition changes. The incinerator burners may be susceptible to plugging. The off-gas systems necessary for a liquid-injection incinerator generate secondary by-product wastes that are often difficult to handle.

Development Needs:

Advanced off-gas systems capable of removing a higher percentage of radioactive constituents, better stack monitoring and other real-time performance assurance capabilities, control of heavy metal emissions, combustion by-product formation, submicron particulate emissions.

Vendor List:

Anderson 2000, Inc.
Bayco Industries
Bedford Industries, Inc.
Bigelow-Liptak
Brule CE&E
Burn-Zol
B&W
Combustion Technologies
Copen
Durr Engineering & Management
Entech
Energy Development Assoc.
Epscon Industrial Systems Inc.
Fuel & Combustion Technology Inc.
Hirt Combustion Engineers
John Zink Co.
Kelly
Liquid Injection
Lotepro Corp.
Lurgi Corp.
McGill Pollution Control Sys.
Met-Pro
NOA, Inc.
North American Manufact. Co.
Peabody
Prenco
Process Combustion
Product Recovery and Energy Co.
Pyro Industries, Inc.
Texcel Env. Systems, Inc.
T-Thermal, Inc.
Trecan Combustion Inc.
Selas Fluid Processing Corp.
Smith Eng. & Environmental
Sure-Life
Surface Combustion, Inc.
United
UPO Solid Waste Systems

DOE Laboratories Involved in Technology:

Savannah River Site

Bibliography:

Frankel, I., et al., *Profile of the Hazardous Waste Incinerator Manufacturing Industry*, MITRE Corporation, 1982.

Lee, C. C., Huffman, G. L., and Oberacker, P. A., "An Overview of Hazardous Waste—A State-of-the-Art Review," *J. Hazard. Mater.* 14, 103–117 (1987).

McCormick, R. J., et al., *Costs for Hazardous Waste Incineration*, Noyes Publications, Park Ridge, N.J., 1985.

Rich, G., and Cherry, K., *Hazardous Waste Treatment Technologies*, Pudvan Publishing Co., 1987.

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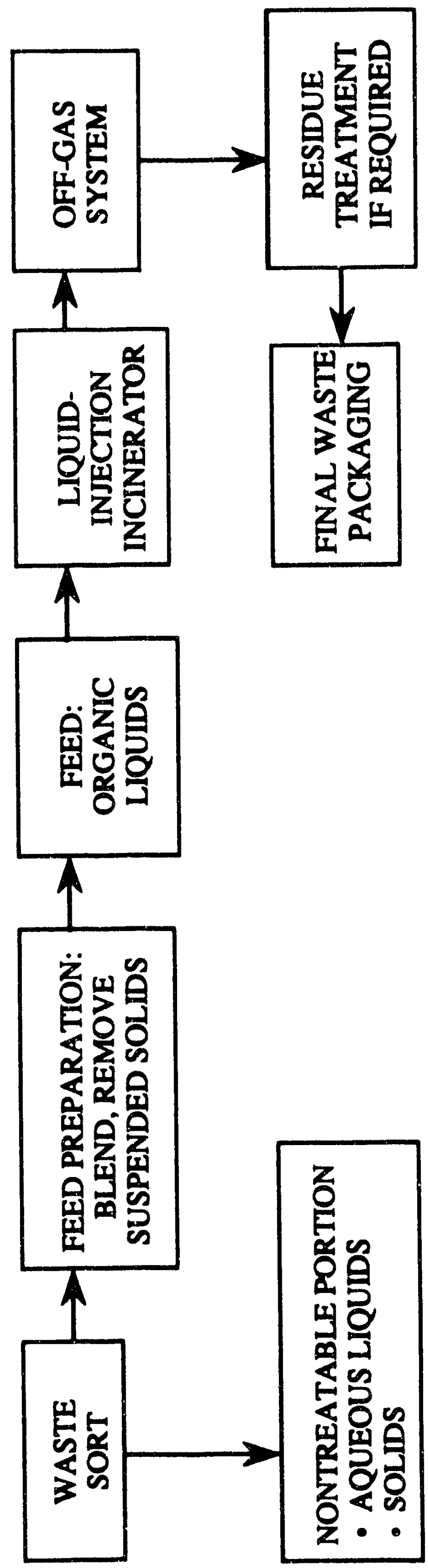

Fig. A.6. Functional process diagram of the liquid-injection incinerator.

Technology Name: Controlled-Air Incinerator

Maturity: Operational-Conventional

Description:

A controlled-air incinerator is the name often used for the stationary-hearth class of incinerator. This type of incinerator is usually designed as a two-stage combustion process with some systems using three chambers. Solid waste is fed into the primary chamber and burned at roughly 50 to 80% of the stoichiometric air requirement (starved-air condition). This pyrolyzes the waste, thus emitting a volatile fraction with the required heat supplied by partial combustion and oxidation of the fixed carbon. The resultant smoke and pyrolytic products, consisting primarily of volatile hydrocarbons and carbon monoxide along with some combustion products, pass to the secondary chamber. Excess air is provided in the secondary chamber to ensure complete combustion. Liquid waste can be incinerated in either the primary or secondary chambers. An off-gas treatment system is required to provide emission control, dependent on the application and waste type. A functional process diagram of the controlled-air incinerator is shown in Fig. A.7.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids that are pumpable and medium applicability to sludges.
Wet Solids:	Low applicability to sludges and medium applicability to the remaining wet solids subcategories.
Dry Homogeneous Solids:	Low applicability.
Dry Heterogeneous Solids (Small):	High applicability to combustible heterogeneous solids and low applicability to noncombustible solids.
Dry Heterogeneous Solids (Large):	Medium applicability to wood waste and not applicable to noncombustible equipment and metal type wastes.

Advantages:

The starved-air condition in the primary chamber leads to a lower air velocity, thus minimizing particulate entrainment and carryover. Controlled air incinerators can be used to process a wide variety of wastes including solids, liquids, and sludges and can handle wastes with high water content. These incinerators have a low-cost modular design, can utilize a wide range of supplementary fuels, and are easy to control.

Disadvantages:

Solid wastes generally have to be pretreated or packaged in some fashion before they can be fed to the incinerator. Controlled air incinerators are not well suited for wastes containing fusible ash, large bulky solid wastes, or large quantities of essentially noncombustible materials (i.e., metal and glass). Batch feeding of waste can lead to pressure spikes in the primary chamber. The large volumes of air required for secondary combustion give rise to large, costly, and difficult-to-operate off-gas treatment systems. Off-gas systems generate secondary by-product wastes that are often difficult to handle.

Development Needs:

Advanced off-gas systems capable of retaining a higher percentage of radioactive constituents, better stack monitoring and other real-time performance assurance capabilities, control of heavy metal emissions, combustion by-product formation, submicron particulate emissions.

Vendor List:

AER
Aerojet Energy Conversion
American Energy Waste System
Anderson 2000, Inc.
Basic Environmental Engineering
Besser-Wasteco Corp.
Burney The Burner
Cil Incineration Systems
Cleever-Brooks Div.
Consumat Systems
Econo-Therm Energy Systems Corp.
International Waste Energy Systems
Fuller Company
Joy Energy Systems, Inc.
Kennedy Van Saun Corp.
Koch Process Systems, Inc.
Simonds Manufacturing Corp.
Stock Equipment Co.
Thermall, Inc.
Thermal Process Constr. Co.
Trecan Combustion Ltd.
Vent-O-Matic Incineration Corp.
Vulcan Waste Systems, Inc.
John Zink Co.

DOE Laboratories Involved in Technology:

Brookhaven National Laboratory
Idaho National Engineering Laboratory
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Oak Ridge Y-12 Plant
Oak Ridge K-25 Site
Rocky Flats Plant
PANTEX
Savannah River Site

Bibliography:

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Lee, C. C., Huffman, G. L., and Oberacker, D. A., "An Overview of Hazardous/Toxic Waste Incineration," *Hazard. Waste Manage.* 36(8), 922–931 (August 1986).

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McRee, R. E., "Operation of Controlled Air Incinerators and Design Considerations for Controlled Air Incinerators Treating Radioactive Wastes," presented to the Conference on Incineration of LLRW, Tucson, Ariz., March 1985.

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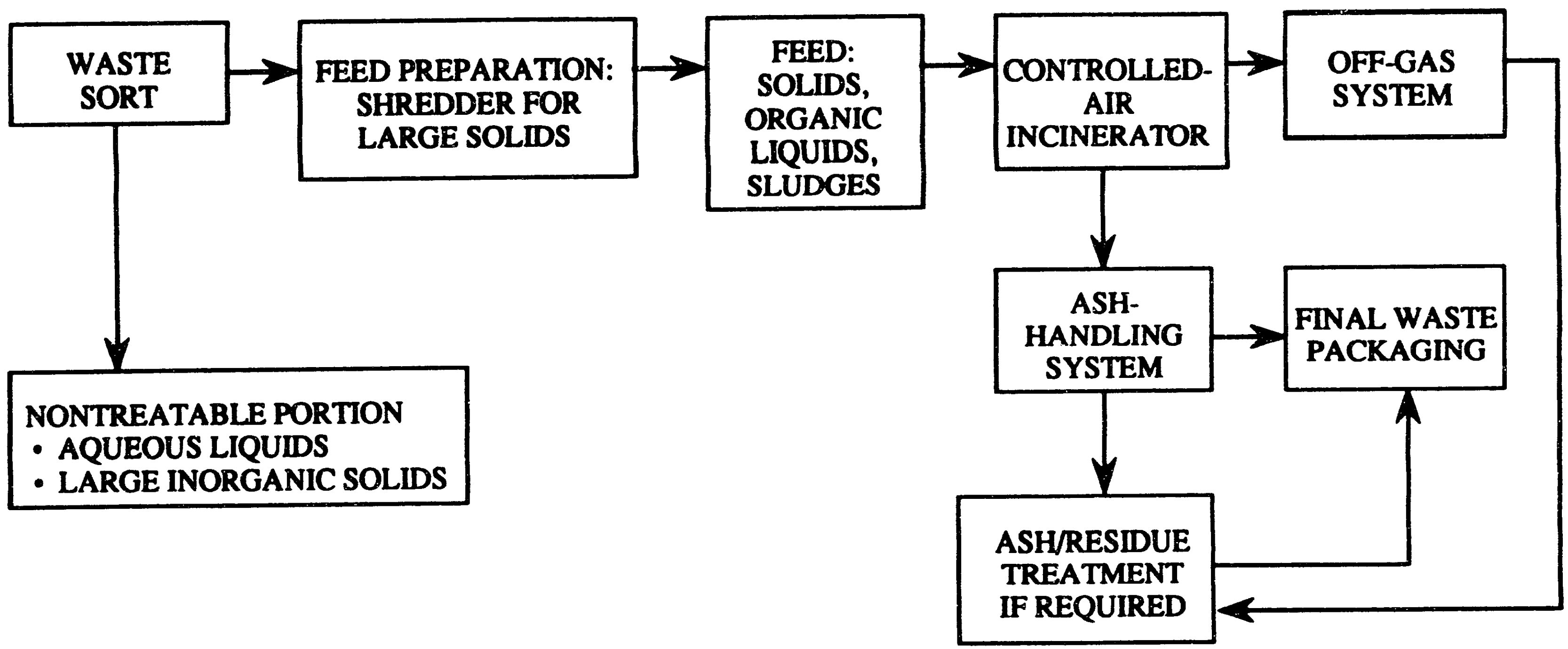

Fig. A.7. Functional process diagram of the controlled-air incinerator.

Technology Name: Cyclone Incinerator

Maturity: Operational-Unique

Description:

The cyclone incinerator is a single-hearth, vertical cylindrical vessel in which cyclonic flow is induced through the tangential introduction of fuel and air. The high-shear cyclonic flow provides intense mixing and complete combustion. Cyclone incinerators are primarily used for solid fines and dried sludges, but special furnaces have also been designed for gases or liquids. Typically, the hearth rotates with stationary rabble teeth for moving ash to a center discharge. Horizontal cyclone furnaces without hearths are also employed. These units carry the ash away with the off-gas for downstream collection. A functional process diagram of the cyclone incinerator is shown in Fig. A.8.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids that are pumpable and medium applicability to sludges.
Wet Solids:	Medium applicability to sludges, absorbed liquids, and resins and low applicability to cemented sludges.
Dry Homogeneous Solids:	Low applicability to soils and not applicable to other dry solids waste such as concrete, bricks, and salts.
Dry Heterogeneous Solids (Small):	Medium applicability to combustible heterogeneous solids and low applicability to noncombustible solids.
Dry Heterogeneous Solids (Large):	Medium applicability to wood waste (size reduced) and not applicable to noncombustible equipment and metal type wastes.

Advantages:

Cyclone incinerators are inexpensive and mechanically simple. The low temperature requirements allow for fast startup and cool down. The combustion in cyclone incinerators is stable and efficient, and the combustion volume is small. The refractory is long-lived. The off-gas and particulate loading are separated centrifugally. The high-energy density of the process results in high destruction efficiencies at moderate temperatures.

Disadvantages:

Cyclone incinerators are limited to processing gaseous, liquid, and sludge wastes.

Development Needs:

Destruction and removal efficiency determination.

Vendor List:

Babcock & Wilcox
International Gas Technology
York-Shipley, Inc.

DOE Laboratories Involved in Technology:

Mound

Bibliography:

Batdorf, J., Gillins, R., and Anderson, G. L., *Assessment of Selected Furnace Technologies for RWMC Waste*, EGG-WTD-10036, March 1992.

Brunner, C. R., *Incineration Systems*, Incinerator Consultants, Inc., Reston, Va., 1988.

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Contact: Institute of Gas Technology (Headquarters), 3424 South State Street, Chicago, Illinois 60616, (312) 567-3650.

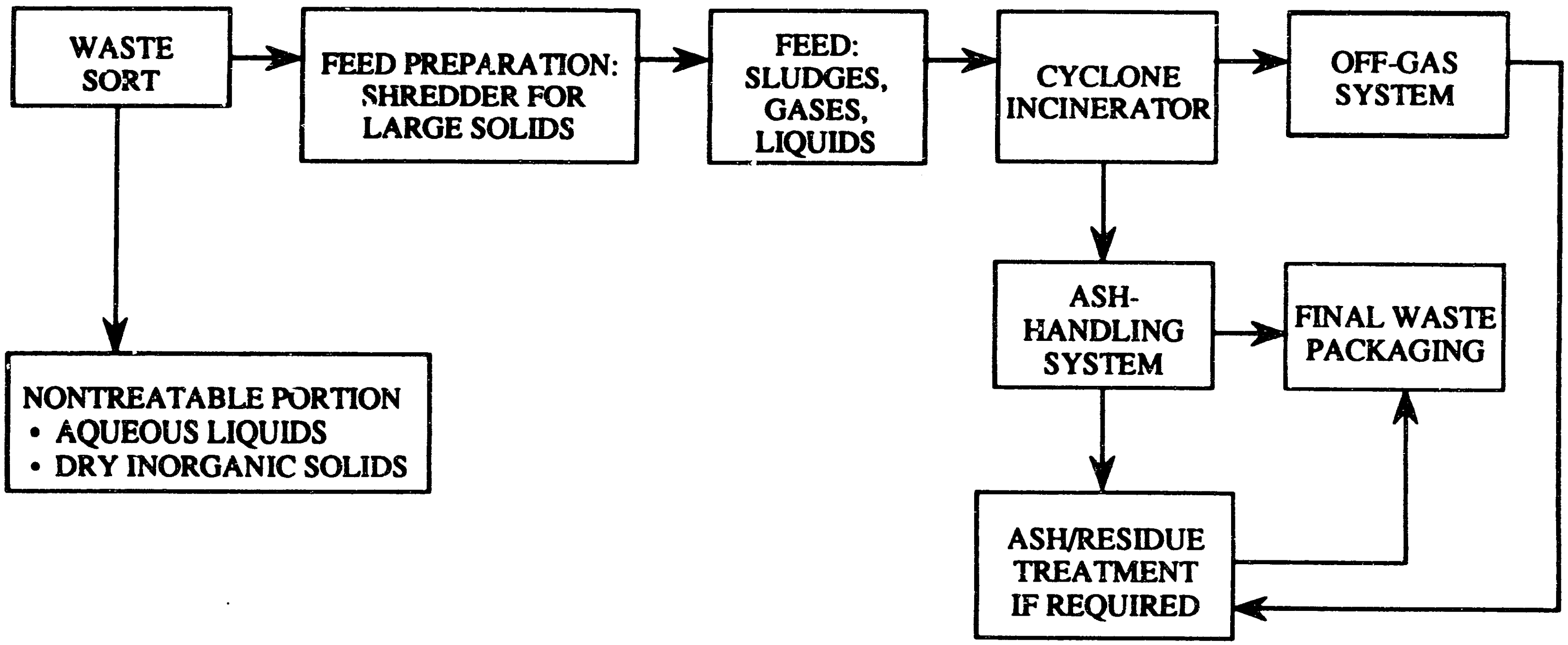

Fig. A.8. Functional process diagram of the cyclone incinerator.

Technology Name:	Indirect-Fired Pyrolysis Incinerator
Maturity:	Operational-Unique

Description:

A thermal treatment process consisting of a low temperature, indirect-fired furnace for pyrolyzing waste followed by a rich fume reactor to complete combustion and destruction. The pyrolysis process achieves chemical decomposition of waste materials by applying heat in the absence of oxygen, resulting in high destruction and removal efficiencies and low NO_x levels and particulate carryover. The process is available in continuous feed for granular or liquid materials or batch feed for liquids, solids, or sludges in open containers. Wastes are pyrolyzed at relatively low temperatures (1000–1600°F) for 15–30 min for the continuous system and 4–6 h for the batch system. The resulting fumes are then completely combusted in a rich-fume reactor chamber at 1800–2200°F for 1–2 s. Heating in the pyrolyzing chamber is provided by natural gas or fuel oil. A widely used commercial application is the destruction of organic contamination on metals and equipment. One application would collect the pyrolysis fumes for utilization as a fuel gas. A functional process diagram of the indirect-fired pyrolysis incinerator is shown in Fig. A.9.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquid sludges and low applicability to pumpable liquids.
Wet Solids:	Medium applicability to sludges and absorbed liquids, high applicability to resins, and low applicability to cemented sludges.
Dry Homogeneous Solids:	Low applicability to soils and other dry solids waste such as concrete, bricks, and salts.
Dry Heterogeneous Solids (Small):	Medium applicability to combustible heterogeneous solids and high applicability to noncombustible solids (removal of organic contamination).
Dry Heterogeneous Solids (Large):	High applicability to noncombustible equipment and metal type wastes (removal of organic contamination).

Advantages:

Inert materials are not melted or vaporized. The indirect heating and pyrolyzing mode of indirect-fired pyrolysis incinerators minimizes particulate carryover. These incinerators produce low volumes of off-gas with low NO_x concentrations. Excellent control of thermal rates can be achieved.

Disadvantages:

Indirect-fired pyrolysis incinerators are inefficient for processing high-Btu liquid wastes, and the process is not applicable for inert solids, except to remove organic contamination. Batch system process rates are low. Removal of waste containers from batch system presents high contamination risk when processing radioactive wastes.

Development Needs:

Adaptation to radioactive service

Vendor List:

Bryant Incinerator
Midland-Ross Corporation

DOE Laboratories Involved in Technology:

None

Bibliography:

"A Background Paper on Pyrolytic Incineration, Surface Combustion," Surface Combustion, Inc., Maumee, Ohio, August 1988.

Breton, M., et al., *Technical Resource Document: Treatment Technologies for Solvent Containing Wastes*, EPA/600/2-86/095, U.S. Environmental Protection Agency, October 1986.

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Schultz, T. J., et al., "Pyrolytic Incineration of Hazardous and Toxic Wastes," American Institute of Chemical Engineers, Houston, Tex., March 1989.

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Treatment Technology Briefs: Alternatives to Hazardous Waste Landfills, EPA/600/8-86/017, U.S. Environmental Protection Agency, July 1986.

Contact: Tom Schultz, Surface Combustion, Inc., 1700 Indian Wood Circle, Maumee, Ohio 43537-0428, (419) 891-7150.

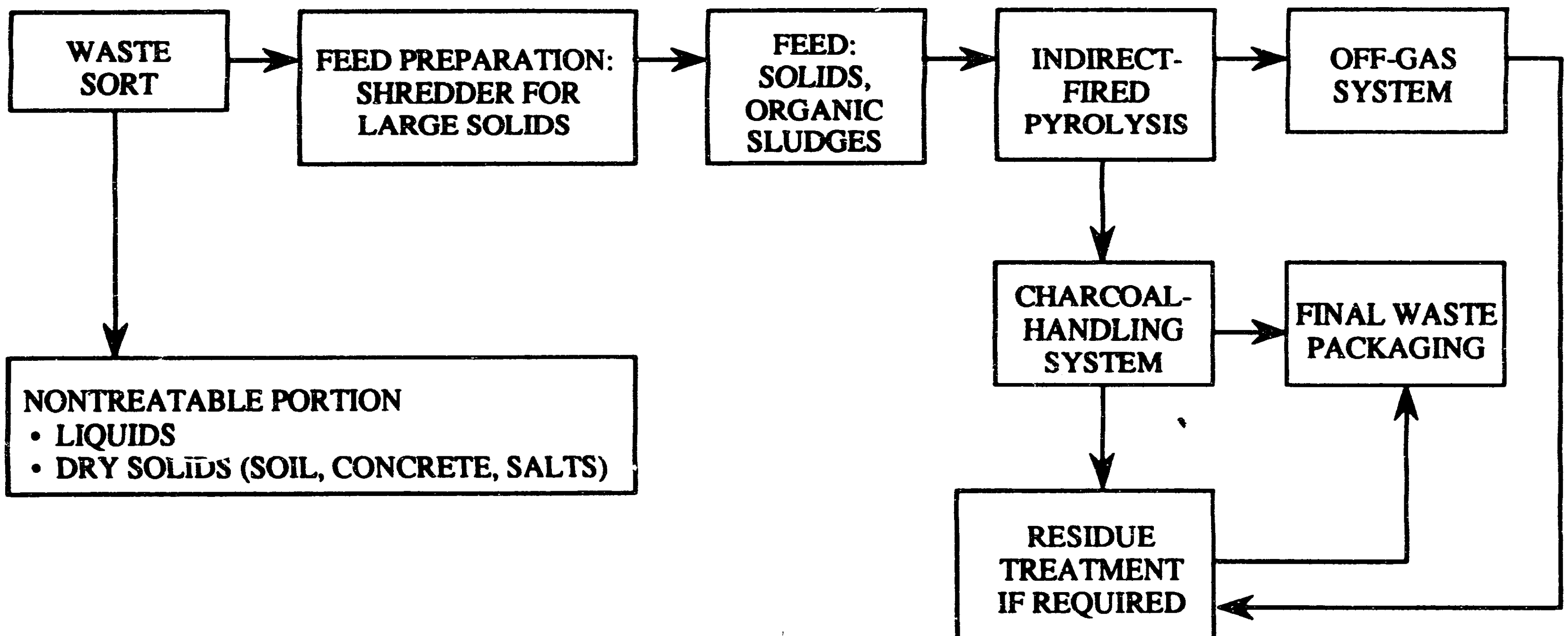

Fig. A.9. Functional process diagram of the indirect-fired pyrolysis incinerator.

A.2. MISCELLANEOUS TECHNOLOGIES

Technology Name: Infrared Furnace

Maturity: Operational-Unique

Description:

A thermal waste processing unit employing direct radiant (infrared) heat in a primary chamber to desorb organics from soils followed by fossil fuel-fired secondary combustion chamber. The primary chamber has several heating zones with increasing temperatures to initially dry and finally combust the waste passing through. The primary chamber can be operated in a pyrolysis or combustion mode. Waste is transported through the primary chamber on a mesh metal-alloy conveyor belt. Variable residence time is provided by adjusting the belt speed. The process is designed to treat organically contaminated soils and sludges. Most solid wastes require size reduction to ensure maximum exposure to the radiant energy. Sludges require pretreatment drying before feeding to the incinerator. The waste is stirred by rotary rakes to ensure adequate exposure. The ash is quenched by water sprays. Available in stationary and mobile applications. A functional process diagram of the infrared furnace is shown in Fig. A.10.

Waste Applicability:

Aqueous Liquids:	Not applicable to aqueous liquids.
Organic Liquids:	Not applicable to organic liquids.
Wet Solids:	Low applicability to wet sludges, absorbed liquids, resins, and cemented sludges.
Dry Homogeneous Solids:	High applicability to soils and other fine dry solid waste.
Dry Heterogeneous Solids (Small):	Not applicable to combustible solids or noncombustible wastes.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

Infrared furnaces have high throughput capacities. They operate with nonflame combustion and therefore have low NO_x and PIC generation rates. Off-gas requirements for such furnaces are minimal. Infrared furnaces are easy to operate and can be purchased as mobile units (six trailers).

Disadvantages:

Wastes which can be processed with an infrared furnace are limited to solid fines and sludges, and drying and other pretreatment are usually required for sludges. Feed-handling equipment is prone to clogging. Infrared furnaces are expensive. Sticky ash clinging to the conveyer belt can become a problem when the furnace is operated at high combustion temperatures.

Development Needs:

Optimization, effect of treatment on the leachability of metals in matrix, improved transport method through furnace (belt), and improved mixing mechanism.

Vendor List:

ECOVA
Harper Electric Furnace
National Applied Science Systems, Inc.
OHM
Shirco Infrared Systems, Inc.
Westinghouse HazTech

DOE Laboratories Involved in Technology:

Savannah River Site

Bibliography:

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Wall, H. O., et al., "The SITE Demonstration of the Shirco Electric Infrared Incinerator," *J. Air Pollut. Control Assoc.* 39(6) (June 1989).

Contact: Shirco Infrared Systems, Inc., 1195 Empire Central, Dallas, Texas 75247, (214) 630-7511.

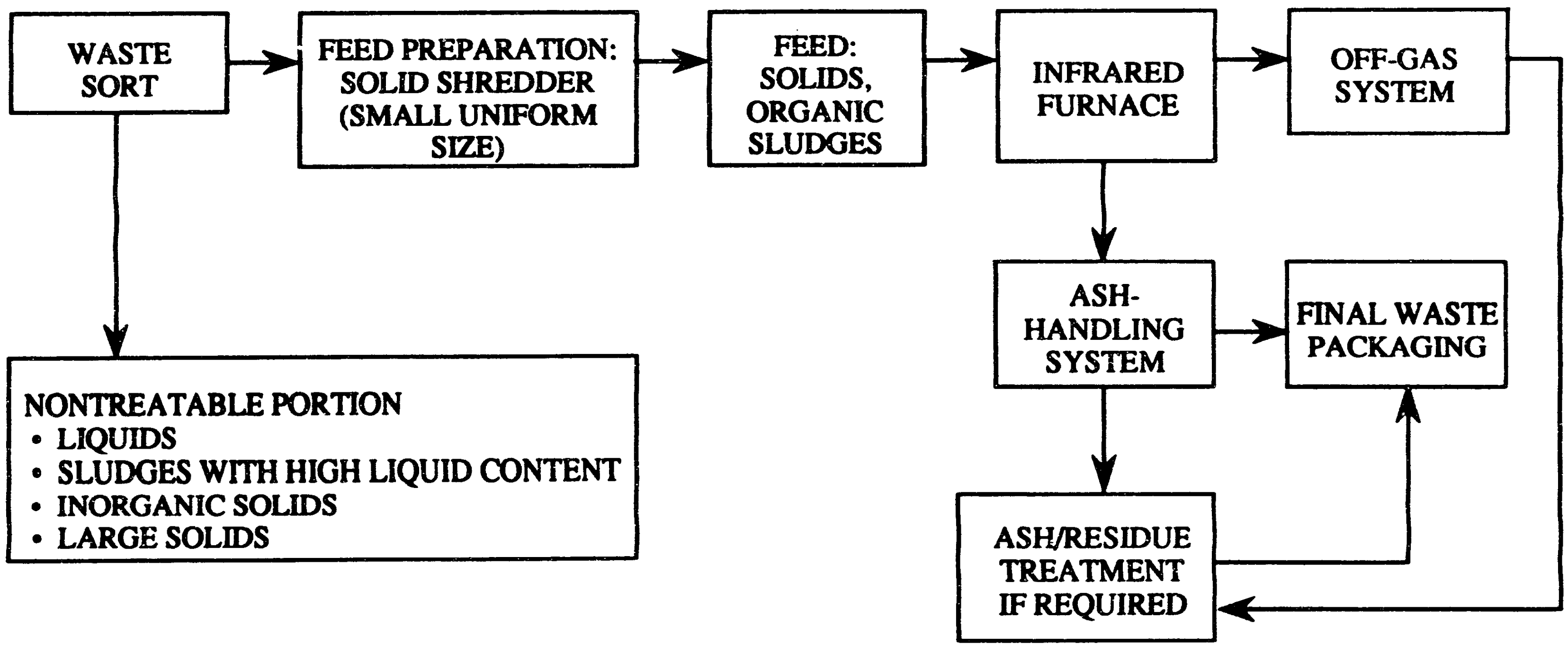

Fig. A.10. Functional process diagram of the infrared furnace.

Technology Name:	Wet-Air Oxidation
Maturity:	Operational-Unique

Description:

The aqueous-phase oxidation of dissolved or suspended organic substances at elevated temperatures and pressures. Oxygen (air) and a dilute organic/water mixture are introduced into a reactor vessel at subcritical conditions (350–650°F and 20–200 atm), where oxidation of the organics occurs. The process, once started, is thermally self-sustaining and is maintained above the vapor pressure of water to minimize evaporation. The process reduces the organics to H_2O, CO_2, and various biodegradable acids. Reaction times of 60 min are typical. A functional process diagram of the wet-air oxidation procedure is shown in Fig. A.11.

Waste Applicability:

Aqueous Liquids:	High applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids with <10% organics.
Wet Solids:	Not applicable to solids.
Dry Homogeneous Solids:	Not applicable.
Dry Heterogeneous Solids (Small):	Not applicable.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

The wet-air oxidation process is thermally self-sustaining. It is suited for nonincinerable dilute wastes and requires small equipment volumes. Its low off-gas volumes are free of NO_x, SO_x, PICs, and particulate.

Disadvantages:

Since wet-air oxidation does not generally meet EPA treatment standards, the process is predominantly used for pretreatment. The wet oxidation process is not highly predictable. Existing full-scale units are largely tailored to bench-scale results on specific compounds. Wastes which can be processed using wet-air oxidation are limited to weak aqueous organic solutions. High-pressure system hardware is required. Off-gas scrubbing is required. The wet-air oxidation process is not effective on halogenated species.

Development Needs:

Improved systems corrosion and corrosion monitoring, evaluation of oxyhydroxide formation with actinides, evaluation of ash content limits, and adaptation to radioactive applications.

Vendor List:

Zimpro/Passavant, Inc.
Oxidyne
Ver Tech

DOE Laboratories Involved in Technology:

None

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Breton, M., et al., *Technical Resource Document: Treatment Technologies for Solvent Containing Wastes*, EPA/600/2-86/095, U.S. Environmental Protection Agency, October 1986.

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Rich, G., and Cherry, K., *Hazardous Waste Treatment Technologies*, Pudvan Publishing, Northbrook, Ill., 1987.

Science Applications International Corporation, *An Assessment of Thermal Destruction Technologies for Application to Department of Energy Mixed Wastes, Volume 1: Technology Assessment*, DOE/HWP-106, August 1991.

Wilks, J. P., et al., "Wet Oxidation of Mixed Organic and Inorganic Radioactive Sludge Wastes from Water Reactors," presented at the 1989 Incineration Conference, Knoxville, Tenn., May 1989.

Contact: William Copa, ZIMPRO, Inc., Military Road, Rothschild, Wisconsin 54474, (715) 359-7211.

Contact: Gerald C. Rappe, Vertech Treatment Systems, 12000 Pecos, Third Floor, Denver, Colorado 80234, (303) 452-8800.

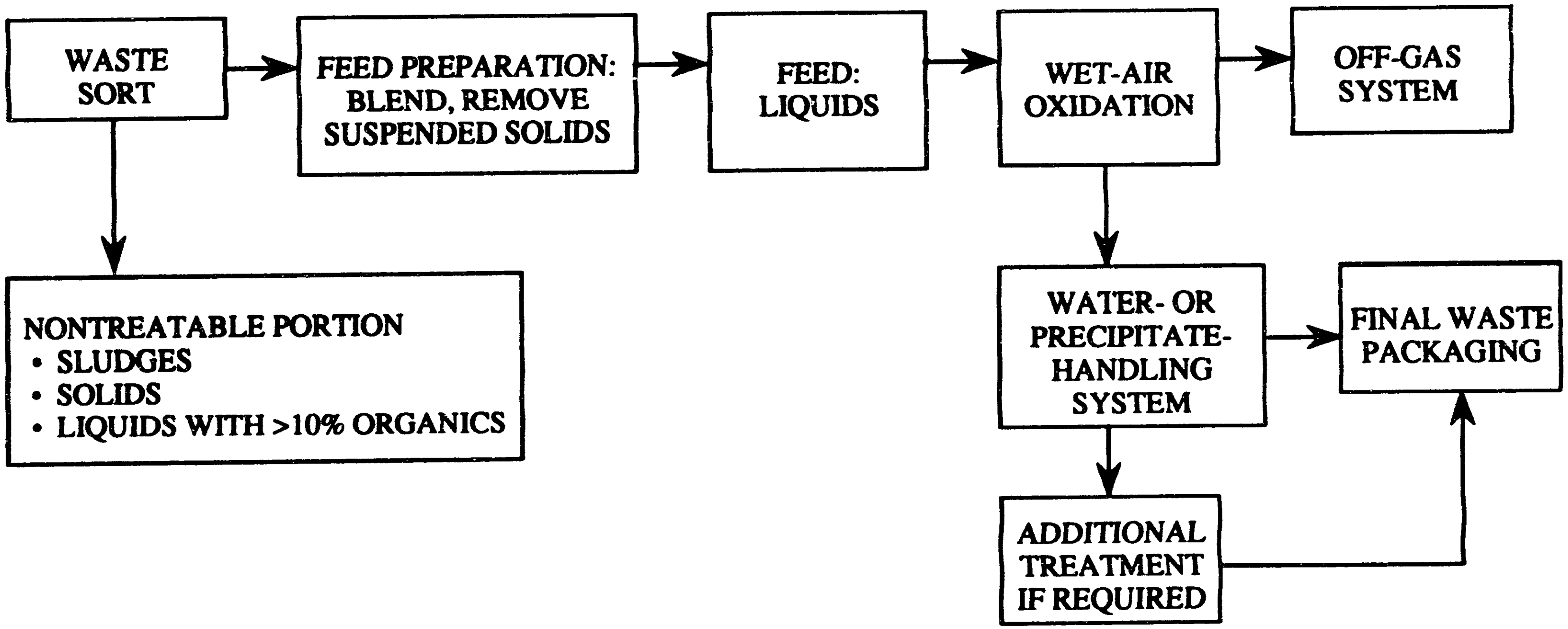

Fig. A.11. Functional process diagram of the wet-air oxidation procedure.

Technology Name: Steam Gasification Detoxifier

Maturity: Operational-Unique

Description:

A two-stage thermal process in which hydrocarbons are vaporized at 700–1100°F in an autoclave and then injected into a reaction chamber (detoxifier) with superheated steam where the organics are decomposed via steam hydrocarbon reforming chemistry. Typical detoxifier operating conditions are 2100–3000°F at a slightly negative pressure. Organics can be vaporized in-drum, minimizing waste handling requirements, or by pumping from large tanks. Nonvolatiles remain behind in the drum for subsequent disposal. The system consists of two boxes, evaporator and gasifier, which are small enough (4 × 6 × 7 ft) to be located inside many existing building spaces. All process monitors and controls are located inside these boxes, and the system is designed for automatic, hands-off operation. The off-gas is processed through halogen absorbers, carbon absorbers, and catalytic carbon monoxide converters to remove metals, methane, carbon monoxide, hydrogen, and HCl, which are normal exhaust gas constituents from this process. The off-gas from this process has potential value as a fuel gas. Process rates are 1–5 drums per 24-h day. A number of these units were manufactured and sold. A functional process diagram of the steam gasification detoxifier is shown in Fig. A.12.

Waste Applicability:

Aqueous Liquids:	Medium applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids.
Wet Solids:	Low applicability to sludges.
Dry Homogeneous Solids:	Not applicable.
Dry Heterogeneous Solids (Small):	Medium applicability to combustible solids and not applicable to noncombustibles.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

Steam gasification detoxifiers can achieve a high destruction and removal efficiency. Their low off-gas volumes are free of NO_x, SO_x, PICs, and particulate. Extremely small process equipment is required; remote and automatic operations are possible; and waste handling requirements are low.

Disadvantages:

Steam reforming detoxifiers are best for organic liquid wastes, but application for organically contaminated solids has also been demonstrated. The batch processing rate is 1-3 drums/day.

Development Needs:

Demonstration of continuous feed, off-gas–catalyst improvement, oxyhydroxide formation with actinides, hydrogen gas buildup, radioactive contamination/exposure provisions.

Vendor List:

Synthetica Technologies, Inc.

DOE Laboratories Involved in Technology:

Hanford
Savannah River Site
Sandia National Laboratory

Bibliography:

Galloway, T. R., "Achieving Reduced Risk—The Thermolytica Detoxifier Destroying Hazardous Waste On-Site," presented at the International Conference on Incineration of Hazardous/Radioactive Wastes, San Francisco, Calif., May 3–6, 1988.

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Galloway, T. R., "The Destruction of Infectious Waste in the Thermolytica Detoxifier," in *Proceedings of the HazMat West 89 Conference and Exhibition, Long Beach, November 7–9, 1989.*

Galloway, T. R., "Economical On-Site Waste Detoxification: An Exercise in Heat Recovery," *Am. Inst. Chem. Eng. Symp. Ser.*, 83 (257), 418–424 (1987); presented at 1987 National Heat Transfer Conference, Pittsburgh, Pa., August 9-12, 1987.

Galloway, T. R., "The Need for New Technical Approaches to Environmental Control & Management," pp. 13–16 in *Proceedings of the Annual Chemical Marketing Research Association Meeting, San Francisco*, February 5–7, 1990.

Galloway, T. R., "Renew Carbon On-site by Steam Reforming," *Chem. Eng.*, p. 11 (December 1991).

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Galloway, T. R., "Thermal Treatment with the Thermolytica Detoxifier," Chap. 8, pp. 77–93, in *Thermal Processes, Volume 1: Innovative Thermal Processes for Treating Hazardous Waste*, Technomic Publishing Co., Lancaster, Pa., 1990.

Galloway, T. R., "Thermolytica Detoxifier," The Hazardous Waste Consultant, McCoy & Associates, Colorado, May/June 1988.

Galloway, T. R., and Howard, F. S., "On-site Reactivation of Granular Carbon with the Synthetica Detoxifier," presented at the Annual AIChE Meeting, Los Angeles, November 17–22, 1991.

Galloway, T. R., and Sprung, J. L., "Waste Destruction by Very High Temperature Steam Reforming," National Academy of Sciences/National Research Council, Committee on Potential Applications of Concentrated Solor Photons, Solar Energy Research Institute, November 7–8, 1990, Golden, Colorado.

Science Applications International Corporation, *An Assessment of Thermal Destruction Technologies for Application to Department of Energy Mixed Wastes, Volume 1: Technology Assessment*, DOE/HWP-106, August 1991.

Wentz, C. A., and Galloway, T. R., "Public Impact on Technical Research: The Dissimilar Fates of Two Waste Gasification Projects," *Environ. Prog.* 8(3), 186–189 (August 1989).

Contact: Terry R. Gallaway, Thermolytica Corporation, 5327 Jacuzzi Street, Richmond, California 94804, (415) 528-0850.

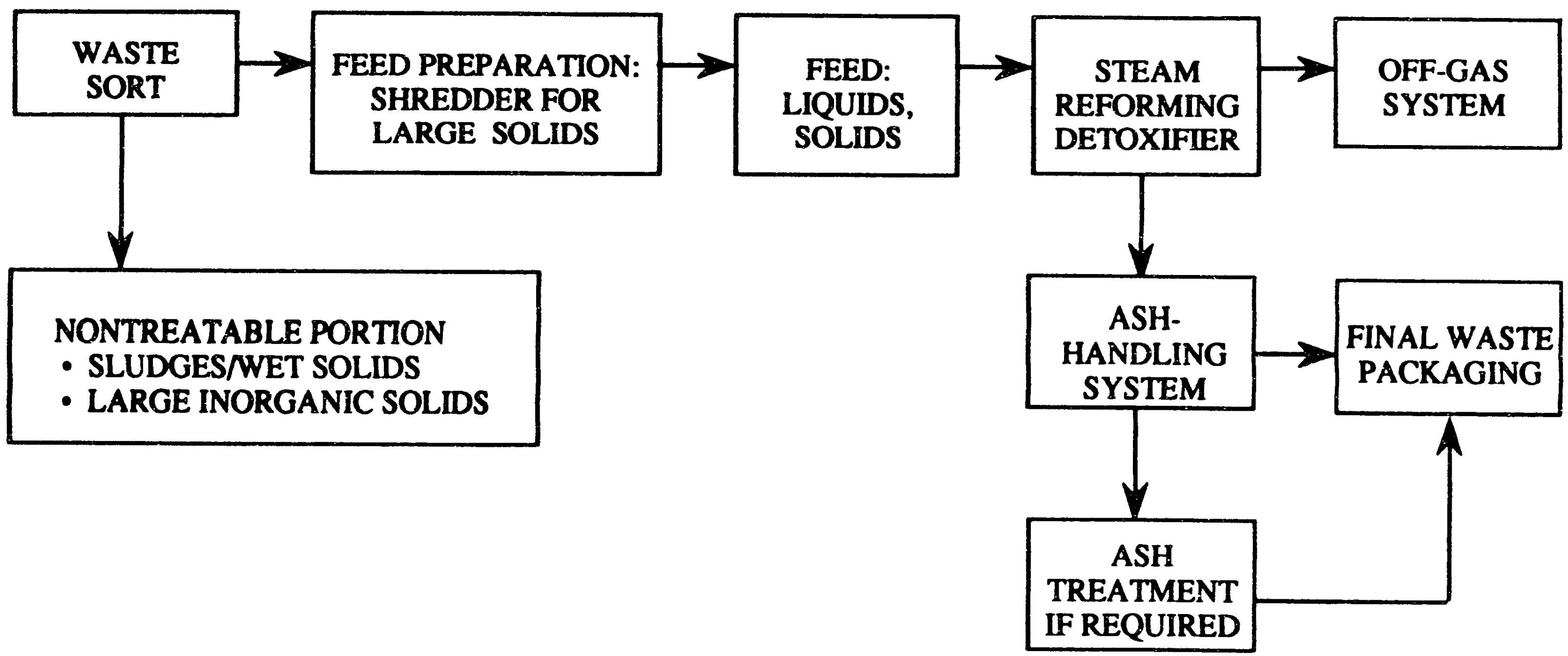

Fig. A.12. Functional process diagram of the steam gasification detoxifier.

Technology Name: Supercritical Water Oxidation

Maturity: Emerging-Demonstration

Description:

The aqueous-phase oxidation of dissolved or suspended organic contaminants at temperature and pressure conditions that are supercritical for water (above 705°F and 218 atm). Oxygen (air) and a dilute organic/water mixture are introduced into a reactor vessel where oxidation of the organics occurs. In supercritical water, oxygen and organics are totally miscible, and oxidation proceeds rapidly and completely. Inorganic compounds are nearly insoluble and precipitate out. The process reduces the organics to H_2O, CO_2, and various biodegradable acids. Reaction times of less than 1 min are required. The process, once started, is thermally self-sustaining, as well as provides a source of high-temperature process heat. One application employs a deep well and static head to generate supercritical pressures. A functional process diagram of the supercritical water oxidation procedure is shown in Fig. A.13.

Waste Applicability:

Aqueous Liquids:	High applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids with <10% organics.
Wet Solids:	Not applicable to solids.
Dry Homogeneous Solids:	Not applicable to soils or other solids.
Dry Heterogeneous Solids (Small):	Not applicable.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

The supercritical water oxidation process is thermally self-sustaining. It is suited for processing nonincinerable dilute wastes. Its low off-gas volumes are free of NO_x, SO_x, PICs, and particulate. The supercritical water oxidation process can achieve complete oxidation of organics and has a high destruction and removal efficiency. Short (1-min) residence times allow a smaller reactor; hence, small equipment volumes are required. The process provides efficient precipitation of inorganics. Off-gas scrubbing is not required. Process provides a source of high-temperature process heat.

Disadvantages:

This technology has high cost and potential equipment limitations due to stringent temperature and pressure requirements. The technology is limited to weak aqueous organic solutions. There may be equipment fouling problems, especially with pumps fouling from particulate matter. Precipitated salts are difficult to remove. The supercritical water oxidation technology has not been demonstrated for solid content wastes.

Development Needs:

Materials of construction for high-temperature/pressure conditions and abrasion problems, high-pressure pumps that are not susceptible to fouling, corrosion control and monitoring, scale-up, solid effluent handling, investigate phase behavior precipitation.

Vendor List:

ABB Lummus Crest
A. H. Halff Associates
Ecowaste
Genesyst, Inc.
Modar, Inc.
Modell Development Corp.

DOE Laboratories Involved in Technology:

Los Alamos National Laboratory
Sandia National Laboratory
NIST
Idaho National Engineering Laboratory
Rocky Flats Plant

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Tester, J. W., Holgate, H. R., Armellini, F. J., Welbey, P. A., Killilea, W. R., Hong, G. T., and Barner, H. E., "Supercritical Water Oxidation Technology: A Review of Process Development and Fundamental Research," 1991 ACS Symposium Series, Emerging Technologies for Hazardous Waste Management, Atlanta, Ga., October 1991.

Contact: Professor Jeff Tester, Energy Laboratory, MIT, 77 Massachusetts Ave., Room E40-45, Cambridge, Massachusetts 02139-4307, (617) 253-3401.

Contact: Dr. Michael Modell, MODEC, 39 Loring Drive, Framingham, Massachusetts 01701, (508) 820-09213.

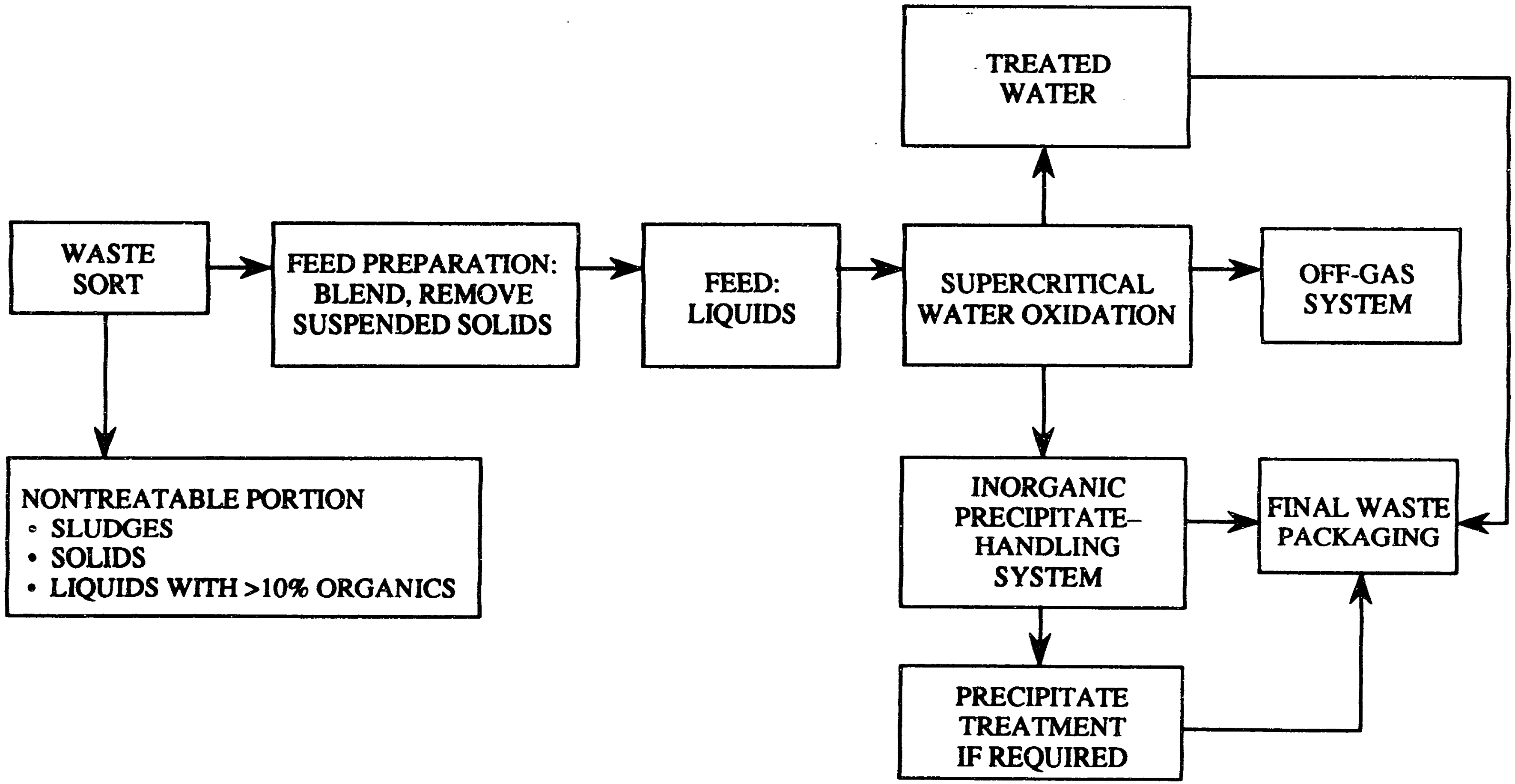

Fig. A.13. Functional process diagram of the supercritical water oxidation procedure.

Technology Name: Ultraviolet Photooxidation

Maturity: Operational-Unique

Description:

Ultraviolet photooxidation (UVP) is a process that destroys or detoxifies hazardous chemicals in aqueous solutions utilizing UV radiation from various sources. UV radiation, ozone, and hydrogen peroxide combine to oxidize organic compounds including chlorinated hydrocarbons and aromatic compounds.

The UVP unit consists of a reactor module, air compressor/ozone generator module, and a hydrogen peroxide feed system. Off-gas from the reactor passes through an ozone destruction (Decompozon) unit. The Decompozon unit destroys all gaseous volatile organic compounds stripped off in the reactor. UVP operation is based on the theory that adsorption of energy in the UV spectrum results in a molecule's elevation to a higher energy state, thus increasing the ease of bond cleavage and subsequent oxidation of the molecule. A functional process diagram of the ultraviolet photooxidation procedure is shown in Fig. A.14.

Waste Applicability:

Aqueous Liquids:	High applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids with <10% organics.
Wet Solids:	Not applicable to solids.
Dry Homogeneous Solids:	Not applicable to solids.
Dry Heterogeneous Solids (Small):	Not applicable to solids.
Dry Heterogeneous Solids (Large):	Not applicable to solids.

Advantages:

UVP is skid mounted, portable, and permits on-site treatment of a wide variety of liquid wastes. UVP is not a thermal technology; therefore, it does not pose the risks or perception problems normally associated with thermal treatment. While UVP is effective at all concentrations, it does so without giving off any air emissions. The unit can be used as a stand-alone or combined with other treatment units in a system.

Disadvantages:

UVP is not a very versatile technology. The inability of UV light to penetrate and destroy pollutants in soil or in turbid or opaque solutions is a limitation to this approach.

UVP is capable only of treating clear liquid wastes, and the reaction rate is dependent upon the pH of the input solution. During the process, the catalyst is susceptible to degradation, and some harmless organics can produce competing reactions. Maintenance of UVP units is required on a routine basis.

Development Needs:

UVP is a fully developed technology and is widely available in the commercial market. There has been some history of failure in the heater element of the Decompozon unit; however, this was a minor problem. Other areas in need of development include improved efficiency of the light source with respect to bandwidth, decreased catalyst degradation, decreased competing organic reaction, less dependency on pH with respect to reaction rate, and a more in-depth look at large-scale operations/economics.

Vendor List:

Artech Incorporated
DeGussa
ECOVA
Kerr McGee
Peroxidation Systems
Syntex Chemicals
Ultrox International

DOE Laboratories Involved in Technology:

Sandia National Laboratory
Lawrence Livermore National Laboratory
DOE Kansas City Plant

Bibliography:

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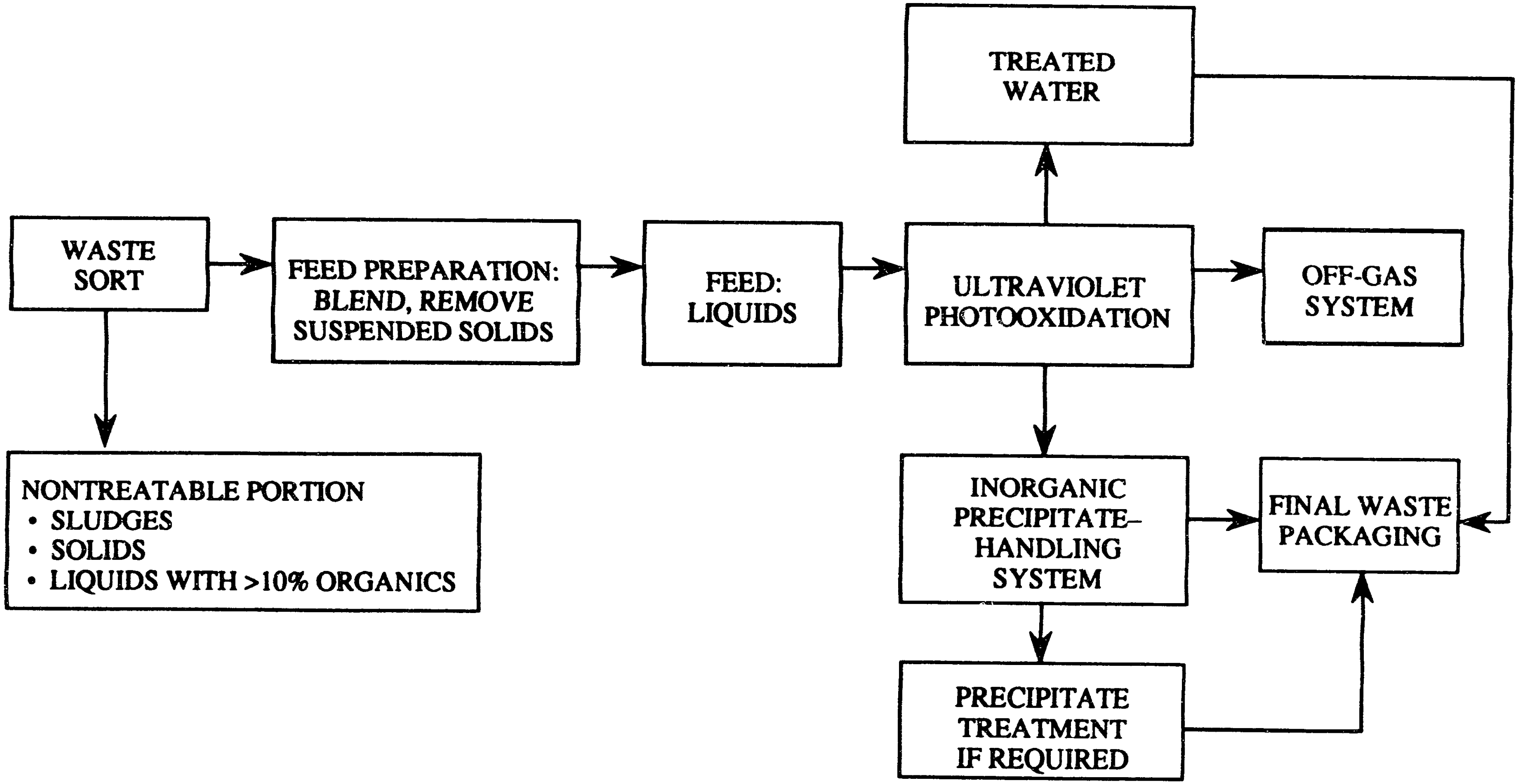

Fig. A.14. Functional process diagram of the ultraviolet photooxidation procedure.

Technology Name: Plasma-Pyrolysis Reactor

Maturity: Emerging-Demonstration

Description:

A horizontal reactor chamber in which liquid waste molecules are pyrolyzed by passing through a thermal plasma plume. The plume is generated by passing an electric charge through an atmospheric airstream which ionizes the gas molecules and generates temperatures up to 18,000°F. The collinear electrodes of the plasma device act as a plug-flow atomization zone for the liquid waste feed, and the pyrolysis chamber serves as a mixing zone where the atoms recombine to form H_2, CO, HCl, and particulate carbon. Residence times in the residence zone and recombination zone are 500 μs and 1 s respectively. Temperature in the recombination zone is maintained at 1200-2400°C. After off-gas scrubbing, the residual gases are electrically ignited in a flare stack. A functional process diagram of the plasma-pyrolysis reactor is shown in Fig. A.15.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids.
Wet Solids:	Not applicable to absorbed liquids or sludges with organics.
Dry Homogeneous Solids:	Not applicable to solids.
Dry Heterogeneous Solids (Small):	Not applicable.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

The small equipment size required for this technology allows for portability; minimal setup is required after delivery to new site. The plasma-pyrolysis reactor technology has a high throughput and can process highly toxic and refractory compounds, as well as wastes with low heating values. The technology has rapid on/off cycle times, high destruction and removal efficiencies, and high destruction temperatures; it produces a fuel gas for energy recovery.

Disadvantages:

The technology can treat only liquids with light particulate loading. Plasma-pyrolysis reactors are energy intensive to operate.

Development Needs:

Limited long-term operational data, electrode life uncertainties, significant effect on peak electrical use (peak charge may increase), heating value limits of waste streams, power needs vs feed properties.

Vendor List:

Pyrolysis Systems Inc.
Westinghouse

DOE Laboratories Involved in Technology:

None

Bibliography:

Breton, M., et al., *Technical Resource Document: Treatment Technologies for Solvent Containing Wastes*, EPA/600/2-86/90, U.S. Environmental Protection Agency, October 1986.

Freeman, H., "Innovative Thermal Hazardous Organic Waste Treatment," Noyes Publications, Park Ridge, N.J., 1985.

Geimer, R., Hertzler, T., Gillins, R., and Anderson, G. L., *Assessment of Incineration and Melting Treatment Technologies for RWMC Buried Waste*, EGG-WTD-10035, February 1992.

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Joseph, M. F., and Barton, T. G., "Waste Destruction by Plasma Arc Pyrolysis," Pyrolysis Systems, Inc., Kingston, Ontario, Canada.

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Contact: E. S. Fox, Jr., Pyrolysis Systems, Inc., 61 Thorold Road, Welland, Ontario, L3B 5PI, Canada, (416) 735-2401.

Contact: Westinghouse Plasma Systems, P.O. Box 350, Madison, Pennsylvania 15663, (412) 722-5275.

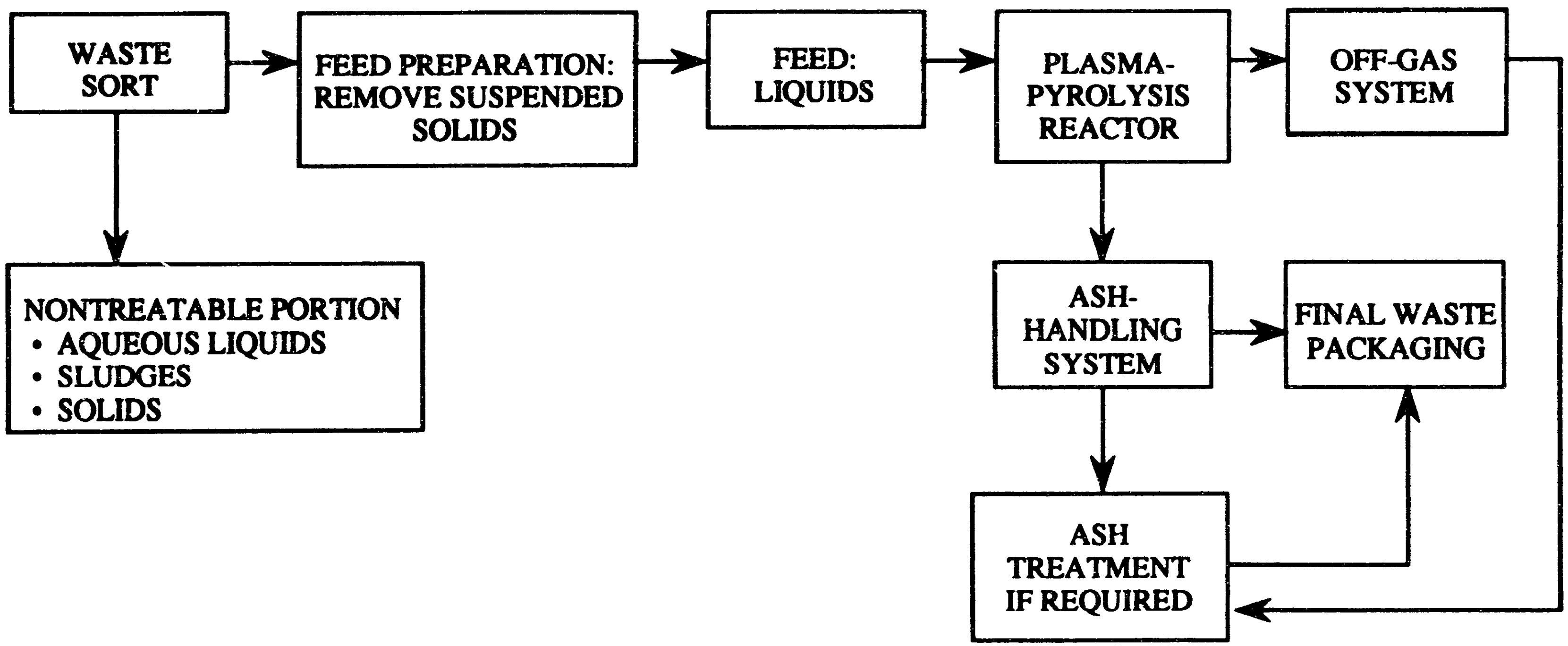

Fig. A.15. Functional process diagram of the plasma-pyrolysis reactor.

A.3. MELTER TECHNOLOGIES

Technology Name: Molten-Salt Furnace

Maturity: Emerging-Pilot/Emerging-Demonstration

Description:

In the molten-salt process, waste and air are continuously introduced beneath the surface of a sodium carbonate (Na_2CO_3) melt at a temperature of 750 to 1000°C. Supplemental fuel may be required if the waste is not sufficiently combustible. Rapid destruction of the waste results from the catalytic effect of the salt and from the intimate contact of the waste with air and the hot molten salt, which provides rapid transfer of heat to the waste. The molten salt forms chemical complexes with toxic metals and radionuclides which reduces their thermodynamic activity and thus retains them in the salt. Sodium carbonate is used because it prevents emission of acidic gasses, such as HCl (ordinarily produced from organic chloride compounds) and SO_2 (from organic sulfur compounds). Also, it is stable, nonvolatile, inexpensive, and nontoxic. The carbon and hydrogen of the waste are converted to CO_2 and steam; halogens form their corresponding sodium halide salts; P, S, As, and Si (from glass or ash in waste) form oxygenated salts; and the iron from metal containers forms iron oxide. The ash is trapped in the melt. The melt is removed periodically or for each batch to prevent excessive buildup of halide salts or ash. The ash can be separated from the salt in an aqueous separations process with the sulfates and chlorides scrubbed out and the carbonates recycled to the melt. The CO_2 and water can be captured and stored in liquid form to be analyzed prior to release. A functional process diagram of the molten-salt furnace is shown in Fig. A.16.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids.
Wet Solids:	Not applicable to solids.
Dry Homogeneous Solids:	Not applicable.
Dry Heterogeneous Solids (Small):	High applicability to combustible dry solids only.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

High waste destruction efficiency and high heat transfer rates. Liquid waste effluent is not produced. The molten-salt combustor is versatile, handling a wide variety of wastes.

Excellent temperature control may be maintained due to the thermal inertia of melt bed. Acid gases are not produced, nor are they emitted. The radioactive elements of heavy metals are retained in the salt. Public acceptance is potentially good.

Disadvantages:

High ash waste requires greater salt makeup than liquid wastes (e.g., solvents), and salt/ash separation is difficult. Feedstock must be size reduced, as large forms (e.g., 55-gal drum) cannot be accepted. The molten salt is corrosive to most metals. The system complexity is high because of salt-recycling needs to make the process cost-effective.

Development Needs:

Performance of materials of construction over range of salt chemical compositions and temperatures. Need to develop process for treatment of spent melt (e.g., process to separate ash from salt) and develop process to recover radioactive elements or heavy metals from salt.

Vendor List:

Rockwell International

DOE Laboratories Involved in Technology:

Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Hanford (using zinc chloride salts)

Bibliography:

Batdorf, J., Gillins, R., and Anderson, G. L., *Assessment of Selected Furnace Technologies for RWMC Waste*, EGG-WTD-10036, March 1992.

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Gay, R. L., et al., "Destruction of Toxic Wastes Using Molten Salts," presented at the Technical Meeting of the American Institute of Chemical Engineers, Anaheim, Calif., April 1981.

Johanson, J. G., et al., "Destruction of Hazardous Wastes by the Molten Salt Destruction Process," presented at the Seminar of the American Society of Testing and Materials, Committee D-27, Nashville, Tenn., March 1982.

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Contact: Richard L. Gay, Rocketdyne Division, Rockwell International Corporation, 6633 Canoga Ave., Canoga Park, California 91303, (818) 700-3505.

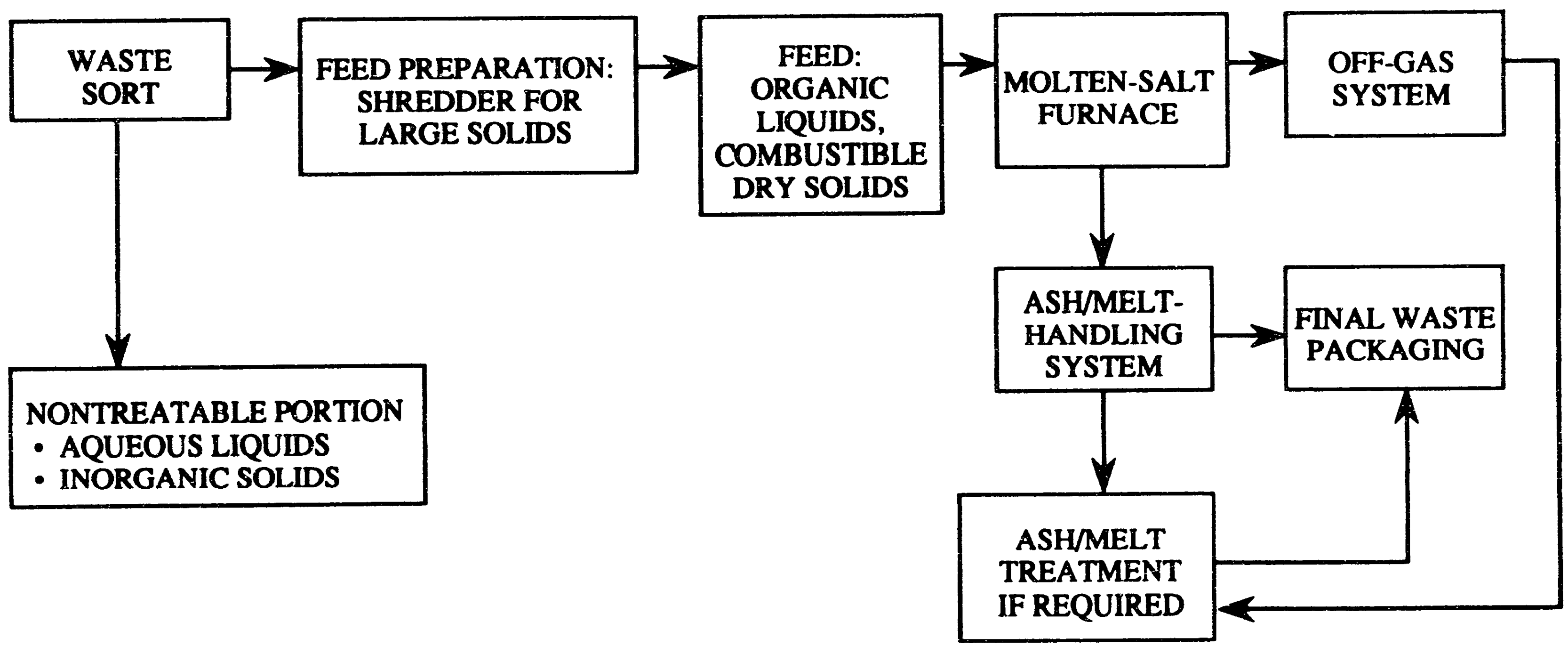

Fig. A.16. Functional process diagram of the molten-salt furnace.

Technology Name: Joule-Heated Melter

Maturity: Operational on Mixed High-Level Radioactive Waste

Description:

A refractory-lined reactor in which a pool of glass is initially melted by auxiliary heating, then maintained in a molten state by joule heating. (Alternating electric current passing through the glass between submerged electrodes dissipates energy due to bulk glass resistivity.) The technology described here is distinguished from the high-temperature joule melter described later by its nominal operating temperature of 1200°C or less. This class of process equipment includes a broad range of designs. It is the base technology for vitrifying high-level radioactive waste at Savannah River's Defense Waste Processing Facility, the West Valley Vitrification Facility, and the Hanford Waste Vitrification Plant. This general technology has been deployed internationally and operated under remote radioactive conditions for over 6 years (1985 to 1991) in the PAMELA plant at Mol, Belgium. High-level mixed wastes are typically fed in a slurry form to facilitate transfer of waste to the process. Glass formers or premelted glass is mixed in with the waste to provide the silica and fluxes needed to melt at the operating temperature limit of 1200°C.

For nonslurried waste applications, waste is introduced into the furnace above the molten glass pool along with the combustion air. Combustion is achieved by exposure to the radiant heat above the pool or by contact with the molten glass. Exhaust gases flow out the opposite end of the furnace. Solid products of combustion and noncombustible materials are encapsulated in the glass, which can be continuously removed or batch discharged to solidify into a nonleachable matrix. A feeding variation by one developer introduces the waste and air under the surface of the molten glass via a drop tube to confine most of the combustion below the surface of the pool, enhancing intermixing of the waste and combustion gases with the glass and attaining higher particulate retention. Typical mean glass residence times range from 24 to 48 h. This assures homogeneity of the glass material being discharged even with variations in the waste stream. A functional process diagram of the joule-heated melter is shown in Fig. A.17.

Waste Applicability:

Aqueous Liquids: Medium applicability to aqueous liquids. The technology can and has been fed dilute liquid waste streams where evaporation and vitrification of the residue occur. High-level waste may have as little as 20 wt % solids with the balance being liquid.

Organic Liquids: High applicability to organic liquids. Organics present at up to 100 g/L in high-level waste have been destroyed with high destruction efficiencies (>99.99%). For strictly organic hazardous wastes, destruction efficiencies in excess of 99.999% have been demonstrated at Mound and at Pacific Northwest Laboratory.

Wet Solids:	High applicability to wet solids. This report's definition of wet solids is consistent with the primary application of this technology—the processing of waste slurries and sludges.
Dry Homogeneous Solids:	High applicability to dry homogeneous solids. Some size reduction may be required to facilitate the feeding of the unit, but processing of dry solids is an adaptation of the conventional glass industry use of this technology.
Dry Heterogeneous Solids (Small and Large):	This technology is judged not to be applicable to heterogeneous solids because of the presumed metal content. Metals will precipitate to the floor of the melter, not be dissolved, and ultimately lead to electrical shorting between the power electrodes.

Advantages:

This adaptation of the glass industry technology has been thoroughly tested for slurries and sludges typical of high-level mixed wastes. The operating conditions for successfully producing a chemically durable product are well documented. The ability to destroy organics has been routinely demonstrated. At the prescribed operating temperatures (<1200°C), a broader spectrum of electrodes and glass contact refractory can be used. A long reliable operating life, in excess of 2 to 5 years, should be expected without failure. This technology has been designed for totally remote operation. For mixed wastes that pose a significant chemical or radioactive hazard during operations, these designs can be employed with confidence.

Disadvantages:

The relatively low operating temperature of 1200°C limits the waste loading in the product glass. For high-level waste a loading of 25 to 35 wt % of wastes is typical. For contaminated soils or similar compositions, 60 to 80 wt % waste loading may be more typical. However, the relatively high density of the glass (2.5 to 2.8 g/cm^3) may result in high volume reduction. The operating temperature essentially precludes the opportunity to process high-metal-containing waste streams. Here, the metals can settle to the floor, collect, and cause an electrical short between the power electrodes. The capital cost for these high-level waste melters is relatively high. However, long operating lives may be realized, which may offset this disadvantage.

Development Needs:

The specifics of the waste stream need to be defined, and an acceptable glass needs to be tailored for its processing. After laboratory development of these waste glasses, demonstration of the technology with the specific waste stream(s) is needed to quantify the specific throughput and to identify any unforeseen issues. Substantial infrastructure within DOE exists to permit rapid demonstration without large capital investments and time delays.

Vendor List:

American Environmental Management Corp.
Frazier-Simplex, Inc.
Penberthy Electromelt International, Inc.
Recomp, Inc.
Sorg Engineering
Toledo Engineering Co., Inc.

DOE Laboratories Involved in Technology:

Pacific Northwest Laboratory
Savannah River Laboratory
Mound Laboratory

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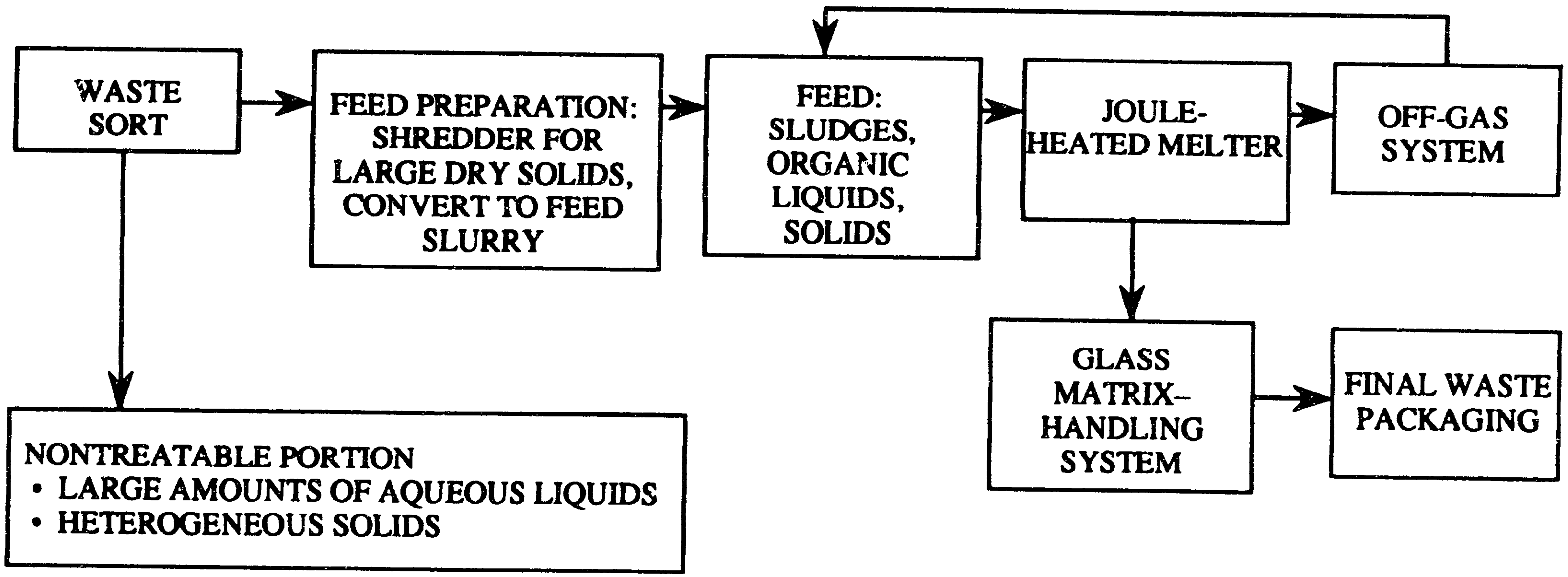

Fig. A.17. Functional process diagram of the joule-heated melter.

Technology Name: Plasma-Arc Furnace

Maturity: Emerging-Pilot

Description:

A plasma-arc furnace uses the energy from a thermal plasma arc, generated by joule heating of a gaseous electrical conductor between two high-voltage electrodes, to combust organics and melt inert waste components. The plasma arc is generated within the furnace primary chamber by a removable plasma torch. Waste is introduced into the furnace into a molten bath of material, which could be inert waste or other material. The high-temperature plasma zone and the molten bath (in excess of 3000°F) combust (or pyrolyze) the organics and melt all other inert materials into the bath. Volatile organics are further treated in a secondary combustion chamber. Very small gas volumes are required for the plasma arc, resulting in low off-gas volumes. Molten solid material can be removed continuously by overflow or poured by batch and forms a leach-resistant, vitrified (glassy) waste form. Furnace operation is similar to a dual-chamber controlled-air incinerator with the substitution of a plasma-arc torch for a burner in the primary chamber. The plasma-arc furnace can reprocess all of its by-products such as fly ash, filters, and scrubber residues. A functional process diagram of the plasma-arc furnace is shown in Fig. A.18.

Waste Applicability:

Aqueous Liquids:	Medium applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids.
Wet Solids:	High applicability to absorbed liquids and sludges with organics.
Dry Homogeneous Solids:	High applicability.
Dry Heterogeneous Solids (Small):	High applicability.
Dry Heterogeneous Solids (Large):	High applicability.

Advantages:

Solid by-product is a vitrified "glassy" slag that is excellent for stabilization of toxic metals and radionuclides. Quiescent combustion in primary chamber results in reduced particulate emissions. Plasma energy assists carbon burnout. Reduced off-gas volume decreases air pollution control equipment costs. By-products such as fly ash, filters, and scrubber residue can be reprocessed through the furnace. The process requires minimal waste pretreatment.

Disadvantages:

This technology has significant electrical energy requirements. Operation, startup, and control of a plasma-arc furnace are more complex than those associated with conventional incineration. High temperatures may lead to high NO_x levels and volatilized heavy metals. This is an emerging technology which has not been demonstrated on an industrial scale.

Development Needs:

Optimization of slag chemistry for metals stabilization, evaluation of variation in slag chemistry resulting from variations in the input stream, reintroduction of condensed volatile metals into slag phase, electrode life studies, destruction and removal efficiency of hazardous organics, safety assessments for heterogeneous waste processing, determination of radionuclide partitioning in slag/metal phases.

Vendor List:

ABB
Plasma Energy Corp.
Retech, Inc.
Westinghouse

DOE Laboratories Involved in Technology:

Idaho National Engineering Laboratory
Pacific Northwest Laboratories

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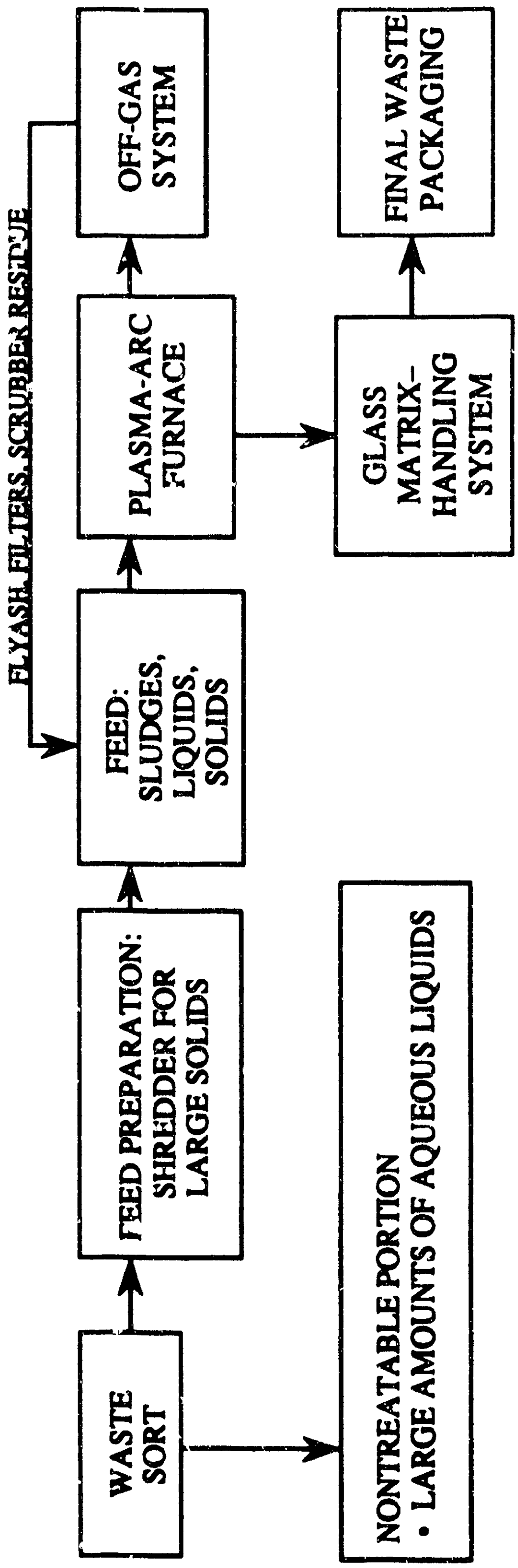

Fig. A.18. Functional process diagram of the plasma-arc furnace.

Technology Name: Microwave Melter

Maturity: Demonstration

Description:

This process utilizes microwave energy for in-container solidification/stabilization of radioactively contaminated nonorganic wastes such as incinerator ash, sludges, or soils. Waste moisture is removed in a belt-driven microwave dryer prior to treatment. The dry waste materials are vitrified inside a metal disposal container in either a batch or continuous-feed mode. Melt temperatures range from 1800–2600° F, and the resulting product is a glassy monolith that meets radioactive disposal criteria for liquid and particulate content, and RCRA land disposal restriction requirements for leaching of toxic hazardous constituents. The process results in volume reductions on the order of 80% with waste loadings on the order of 60%. A functional process diagram of the microwave melter is shown in Fig. A.19.

Waste Applicability:

Aqueous Liquids:	Medium applicability to aqueous liquids.
Organic Liquids:	Medium applicability to organic liquids with a secondary combustion system added (not currently part of system).
Wet Solids:	High applicability to absorbed liquids and sludges with organics.
Dry Homogeneous Solids:	High applicability.
Dry Heterogeneous Solids (Small):	Not applicable to heterogeneous wastes.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

Direct application of energy to the wastes—surrounding equipment remains relatively cool; process occurs inside disposal container, minimizing waste handling.

The waste form will meet applicable waste acceptance criteria for the disposal facilities; equipment is inexpensive and easy to maintain; process requires short heating time to achieve operational temperature (on the order of 30 min); heating can be instantaneously interrupted; heating is uniform in the waste material; energy can be selectively directed to the waste and not the equipment, preventing thermal cycling of the equipment; the waste form is processed in-drum, reducing the material handling and generation of additional waste; in-drum processing eliminates the requirement of producing a pourable, low-viscosity melt; waste volumes are reduced up to 80% compared with current cementation processes.

Disadvantages:

Applicable to dry or near-dry nonorganic wastes only; waste must be relatively homogeneous fines; low throughput results in high unit operating costs; uneven melting of the wastes, especially near the bottom and sides; some oxidation of the metal waste container; meltthrough of the container at hot spots.

Development Needs:

Evaluate the process for other applications (i.e., destruction of hazardous wastes); leachability of the vitrified waste; develop dielectric property models; study container corrosion problems; control heat profiles in small heterogeneous wastes; perform volatility studies on liquid organics.

Vendor List:

Japanese manufacturers

DOE Laboratories Involved in Technology:

Rocky Flats Plant
Oak Ridge National Laboratory
Oak Ridge K-25 Plant
Los Alamos National Laboratory

Bibliography:

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Contact: Robert D. Peterson, EG&G Rocky Flats, Rocky Flats Plant, Denver, Colorado, (303) 966-4051.

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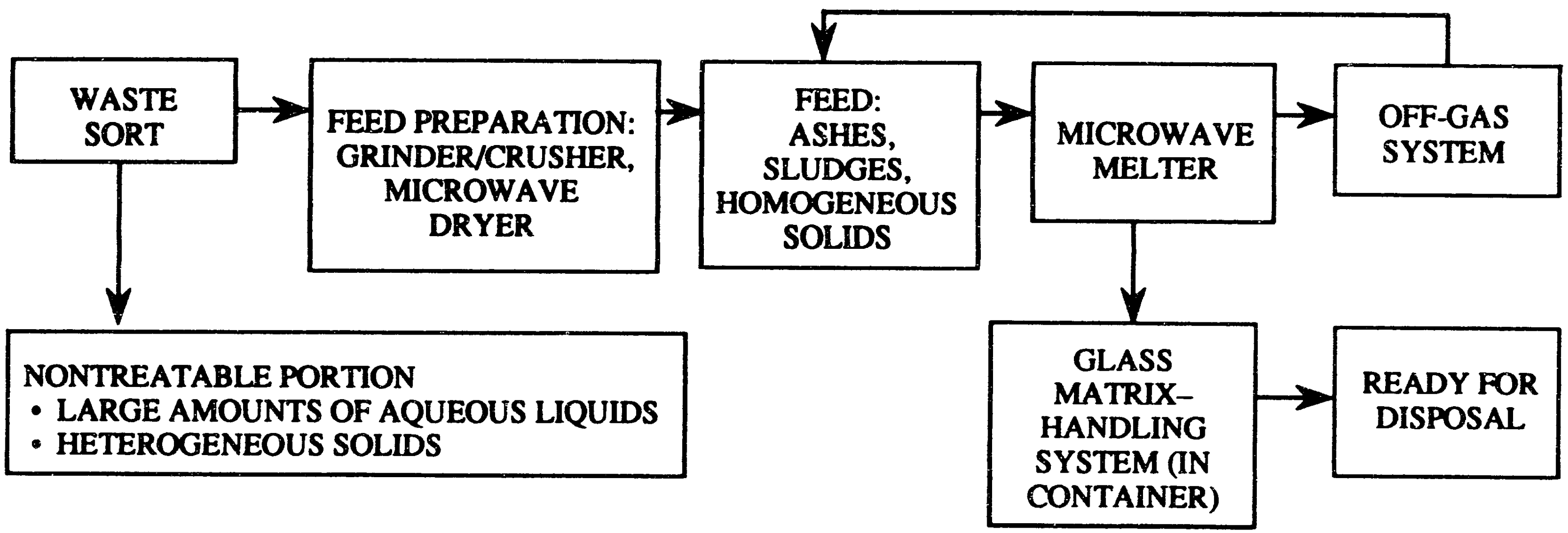

Fig. A.19. Functional process diagram of the microwave melter.

Technology Name: Slagging Kiln

Maturity: Operational-Unique

Description:

A slagging kiln is an incinerator designed to operate at sufficiently high temperatures so that the entire charge of waste material essentially melts into a "slag." Almost all slagging kilns are based on an improved rotary-kiln incinerator design (see "Rotary Kiln" entry for details), requiring more attention to the refractory lining and the slag-handling equipment. Other designs are possible, however, as evidenced in one particular application of a German-designed multichamber slagging kiln. Slagging kilns normally require a secondary combustion chamber to ensure complete destruction of hazardous constituents. The primary chamber functions to combust solid waste to gases at temperatures of 2000 to 2200°F, thus leaving a melted slag residue of the noncombustible components (i.e., alumina and silica compounds, metal, glass). The slag melt progresses through the kiln into a water quench, where it solidifies and fractures into small pieces, and is then drawn from the process. Both primary and secondary chambers are generally supplied with auxiliary fuel systems which can be used for liquid-waste incineration. An extensive off-gas system is generally required to control the high volume of emissions. Slagging kilns are generally used in applications involving high-calorific-value wastes. A functional process diagram of the slagging-kiln incinerator is shown in Fig. A.20.

Waste Applicability:

Aqueous Liquids	Medium applicability to aqueous liquids.
Organic Liquids:	High applicability to organic liquids.
Wet Solids:	High applicability to absorbed liquids and sludges with organics.
Dry Homogeneous Solids:	High applicability.
Dry Heterogeneous Solids (Small):	High applicability to heterogeneous wastes.
Dry Heterogeneous Solids (Large):	High applicability.

Advantages:

Can handle a wide variety of solid, liquid, and sludge waste types; can accept whole metal drums of waste without breaching or shredding. This technology features reduced off-gas particulate loading due to adsorption into the slag and lower excess air requirements. Slag is removed continuously and does not interfere with waste oxidation.

When operated at very high temperatures, the slagging kiln leads to more complete burning and better destruction of difficult-to-destroy compounds.

Disadvantages:

High capital cost for installation; spherical or cylindrical objects may roll through the kiln before complete combustion; need to replace the refractory lining more often; higher temperatures increase probability of volatilizing heavy metals; not efficient for low-calorific wastes; cannot be thermally cycled often (shutdown/startup cycle); feed composition must be tightly controlled; maintaining seals is difficult; large volumes of air required for combustion give rise to large, costly, and difficult-to-operate off-gas treatment systems.

Development Needs:

Better kiln seal design, slag chemistry, advanced off-gas systems, stack monitoring and other real-time performance assurance capabilities; control of heavy metal emissions; combustion by-product formation; submicron particulate emissions.

Vendor List:

Allis Chalmers
Combustion Engineering Co.
Ford, Bacon, and Davis
Rollins Environmental Services
Von Roll, Ltd. (Switzerland)
John Zink Co.

DOE Laboratories Involved in Technology:

Bibliography:

Falcone, P. W., and Buchanan, R. J., "Hazardous Waste Incineration by Slagging—Rotary Kiln Mode," presented at the 20th Annual Mid-Atlantic Industrial Waste Conference, Washington, D.C., June 1988.

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Van de Voarde, N., et al., "High Temperature Slagging Incineration—Recent Operating Experience," presented at Spectrum '86, American Nuclear Society International Topical Meeting, Niagara Falls, N.Y., 1986.

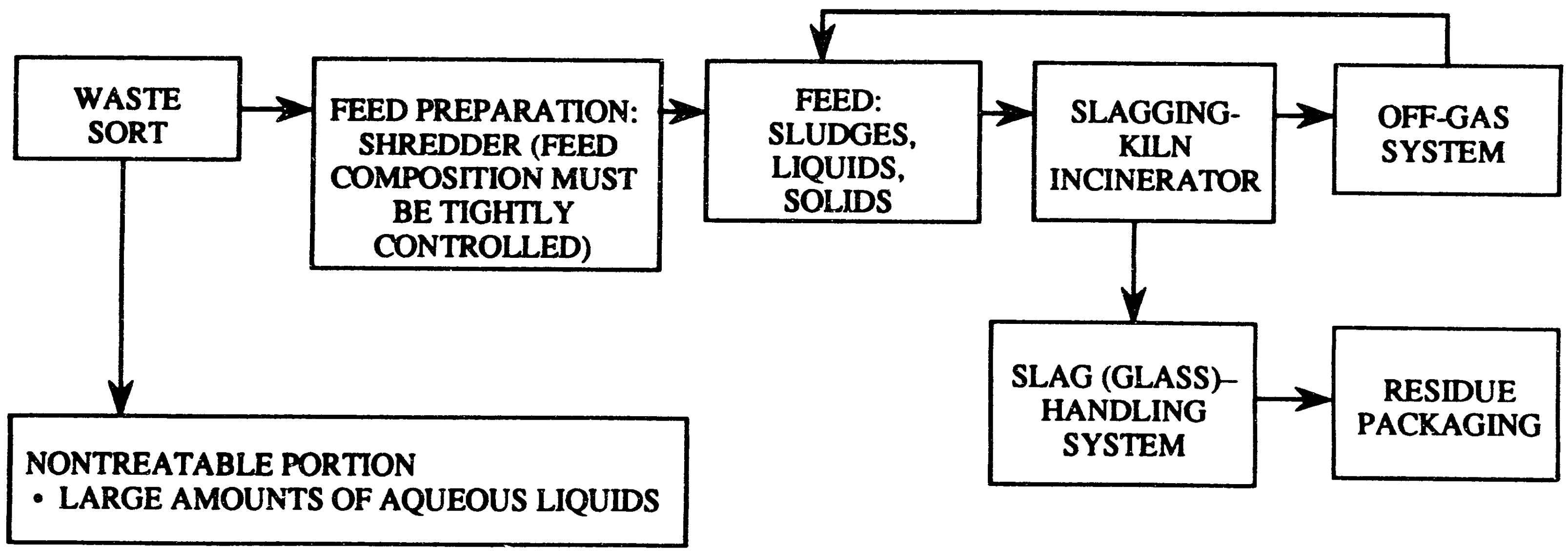

Fig. A.20. Functional process diagram of the slagging-kiln incinerator.

Technology Name: Electric-Furnace Melter

Maturity: Operational-Conventional (has not been demonstrated on waste processing)

Description:

Electric furnaces have been used as smelters in the steel industry for several years. The electric-furnace melter uses graphite electrodes to melt inorganic waste components into a glassy slag and pyrolyze or combust organic waste components. The electrodes may be submerged in the molten bath, where the resistance to the electrical current passing between the electrodes creates the temperatures necessary to melt the material, or the electrodes may remain above the surface of the bath, creating an arc-plasma zone of high temperatures. Temperatures of 1650°C are routinely maintained within the furnace chamber, and higher temperatures are achievable. Waste can be fed to the furnace through chutes, hollow electrodes, or a series of doors which form an airlock. Depending on the type of feeding system used and the size of the waste, some size reduction may be necessary. It may also be beneficial to pretreat the waste with a fluxing agent, such as lime. A functional process diagram of the electric-furnace melter is shown in Fig. A.21.

Waste Applicability:

Aqueous Liquids: Medium applicability, although there is a concern of a steam explosion if liquids get below the melt surface.

Organic Liquids: High applicability. The chamber temperatures are typically 550°C higher than those of conventional incinerators.

Wet Solids: High applicability.

Dry Homogeneous Solids: High applicability.

Dry Heterogeneous Solids (Small): High applicability.

Dry Heterogeneous Solids (Large): High applicability.

Advantages:

This technology can handle a wide variety of waste streams, such as organics, inorganics, and bulk metals. As with all melter technologies, a leach-resistant final waste form is generated. In addition, the high temperatures should provide excellent destruction of organics. As with all electrically heated systems, the off-gas volume is reduced, as are the associated pollution control equipment sizes.

Disadvantages:

The high temperatures result in a high volatilization of toxic heavy metals present in the waste stream, especially in a reducing environment. There is a heavy consumption of electrodes, especially in an oxidizing environment. If melting bulk metals, there is a possibility of steam explosions if liquids get below the surface.

Development Needs:

Testing with various types of waste feed is needed to gain experience, verify applicability, and identify potential problems. Operational and physical parameters must be optimized and methods utilized to keep the heavy metals from volatilizing from the melt.

Vendors:

Electropyrolysis, Inc.
Heat Engineering Corp.
Koch Process Systems
Lectromelt
Mannesmann Demag Corp.
Whiting Corporation

DOE Laboratories Involved in Technology:

Idaho National Engineering Laboratory

Bibliography:

Metalcaster's Reference and Guide, 1st ed., ed. E. L. Kotzin, American Foundrymen's Society, Des Plaines, Ill., August 1972.

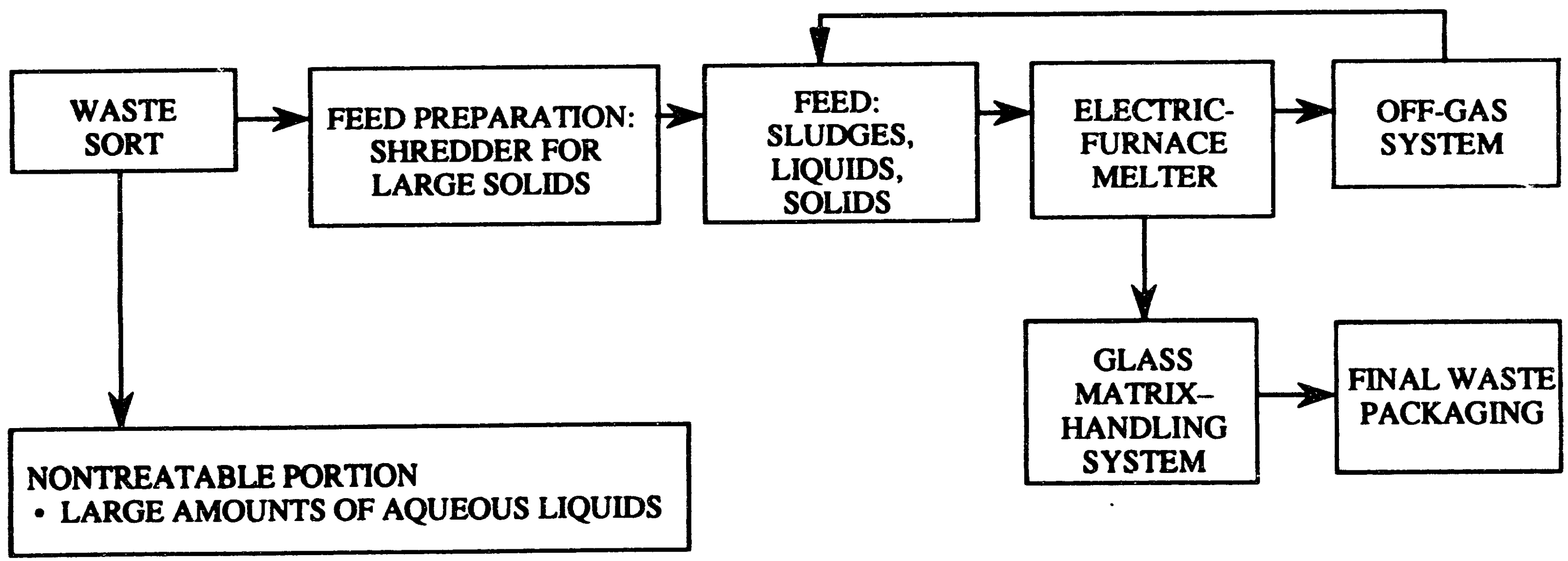

Fig. A.21. Functional process diagram of the electric-furnace melter.

Technology Name:	Fuel-Fired Melter
Maturity:	Operational-Conventional (not demonstrated for waste processing)

Description:

The fossil fuel hearth melting technology is a thermal smelting technology consisting of a molten slag bath into which metal ore, blast furnace slag, and other waste materials are introduced. The specific process variation addressed here is an adaptation of a proprietary commercial metal smelting technology known as "Sirosmelt." The Sirosmelt process utilizes a lance through which air and fuel can be injected under the surface of the slag bath. This injection of air-fuel mixture creates high turbulence within the bath, providing good mixing and combustion of the waste. The system is flexible in producing an oxidizing or reducing environment, depending on the waste being processed. Operational temperatures of the molten bath of as high as 1600°C destroy the organics and melt the inert fractions into a vitrified slag product. Fluxing agents can be introduced into the bath through the lance while larger particle waste forms are fed through an auxiliary feed port. The resulting slag of melted inert material is removed and cast into 1- to 2-ton blocks. A functional process diagram of the fuel-fired melter is shown in Fig. A.22.

Waste Applicability:

Aqueous Liquids:	Medium applicability.
Organic Liquids:	High applicability.
Wet Solids:	High applicability.
Dry Solids:	High applicability.
Dry Heterogenous Solids (Small and Large):	Low applicability to heterogeneous solids due to poor mixing with these feed materials. Lance may enhance mixing and increase applicability.

Advantages:

Lance injection of air creates excellent waste/bath mixing for maximum combustion, relatively simple operating concept with few moving parts, high temperatures resulting in high waste destruction efficiencies.

Disadvantages:

High temperatures within the system will volatilize metals and will generate NO_x, the high turbulence will cause high particulate carryover, and there are contamination control problems in a nonsealed furnace configuration.

Development Needs:

The primary need is to develop and demonstrate the operability of the technology as a waste treatment process. The Sirosmelt process has had very limited testing. As with other melting technologies, effects of heterogeneous waste streams on slag chemistry and process operations, as well as the fate of heavy metals and radionuclides, need further investigation.

Vendor List:

Ausmelt Pty, Ltd. (Australia)
General Glass Equipment Co.
Surface Combustion, Inc.
Toledo Engineering Co.

DOE Laboratories Involved in Technology:

None

Bibliography:

Batdorf, J., Gillins, R., and Anderson, G. L., *Assessment of Selected Furnace Technologies for RWMC Waste*, EGG-WTD-10036, March 1992.

Geimer, R., Hertzler, T., Gillins, R., and Anderson, G. L., *Assessment of Incineration and Melting Treatment Technologies for RWMC Buried Waste*, EGG-WTD-10035, February 1992.

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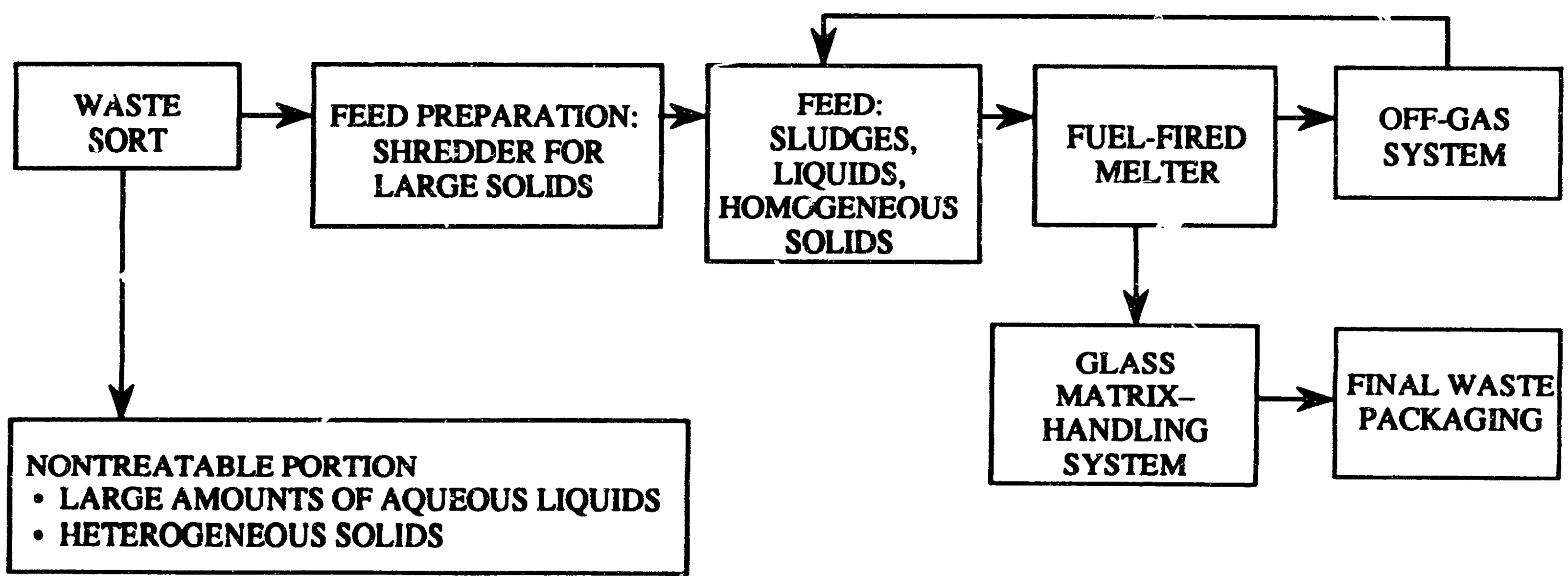

Fig. A.22. Functional process diagram of the fuel-fired melter.

Technology Name: High-Temperature Joule Melter

Maturity: Emerging-Pilot Scale

Description:

The high-temperature joule-heated melter can take many different forms. A specific design is directed toward the overall operational production objectives. This generalized technology is the foundation for nearly all high-quality glass produced in the glass industry. The unit has a processing chamber which contains the molten glass and is lined by refractory. This versatile device can process a broad spectrum of wastes. Organic liquids, wet solids, dry solids, and heterogeneous solids can all be fed to this generalized process if the appropriate off-gas treatment system is connected. The material is fed through a central location. If the waste contains combustible solids or organics, oxidation air is directed into the pile. After the material heats, combusts, and oxidizes, it settles to the molten glass surface, where it melts and is homogenized with the balance of the material in the molten pool. In this arrangement, top-entering electrodes are immersed in the molten pool and provide the joule heating. This allows renewal of the consumable electrodes, which are usually either graphite or molybdenum. Operating temperatures in excess of 3000°F can be sustained by using conventional materials. The joule heating induces natural convection around the electrodes, resulting in good mixing and nearly uniform temperatures within the majority of the bulk glass. The high temperature allows metals such as iron and stainless steel to be included in the waste. Metals settle into the pool, melt, and collect at the bottom. These molten materials can then be oxidized and incorporated into the bulk glass before being discharged into the waste box or to a posttreatment system. Separation of about 2 to 3 ft between the end of the power electrodes and the molten metal prevents significant electrical shorting. A functional process diagram of the high-temperature joule melter is shown in Fig. A.23.

Waste Applicability:

Aqueous Liquids: Medium applicability to aqueous liquids. Direct aqueous liquid feeding onto the pool can consolidate unit operations and may be attractive for certain waste streams.

Organic Liquids: High applicability to organic liquids. Demonstrated destruction efficiencies in excess of 99.999% have been demonstrated at Mound Laboratory and at Pacific Northwest Laboratory.

Wet Solids: High applicability to wet solids.

Dry Solids: High applicability to dry solids because it can oxidize and melt the feed material into a molten pool within the same device.

Dry Heterogenous Solids (Small and Large): High applicability. This technology can accommodate metals contained in the waste. The collection of molten metals at the bottom of the molten pool may be oxidized in place or tapped off periodically.

Advantages:

With the high temperature capability of this technology, metals that may be found in the waste feed can be melted, collected at the bottom, and oxidized. High waste loading can be realized at higher temperatures so that 80 to 100 wt % of the waste may be incorporated into a chemically durable material before being discharged for disposal. The large inventory of molten material allows high variations in the instantaneous composition being fed. The large molten pool, which may represent 4 to 5 days of feeding, can be used to average the waste composition over time and can allow large variations over significantly long periods of time without adversely impacting the quality of the discharged material. The ability to oxidize feed materials directly as indicated or to process slurries, solutions, and sludges without pretreatment allows a very broad range of material to be considered for processing. The configuration is readily adaptable to radioactive operation, because all key replaceable systems can be accessed and replaced from the top.

Disadvantages:

This device is best suited for long-term, continuous operation. Therefore, rapid shutdown and intermittent operation are not recommended. High temperatures within the system will volatilize heavy metals and generate high NO_x.

Development Needs:

The key development need is the demonstration of the different waste streams in a unit of this style. This will allow measurement of instantaneous and specific processing rates to be defined and the identification of phase separation, if any. Tailoring of acceptable glasses may also be required for acceptance. Effects of heterogeneous waste streams on slag chemistry and process operations, as well as NO_x production and the fate of heavy metals and radionuclides, need further study.

Vendor List:

American Environmental Management Corp.
Frazier-Simplex, Inc.
Penberthy Electromelt International, Inc.
Recomp, Inc.
Sorg Engineering
Toledo Engineering Co., Inc.

DOE Laboratories Involved in Technology:

Pacific Northwest Laboratory
Mound Laboratory

Bibliography:

Armstrong, K. M., and Klingler, L. M., *Nitrate Waste Processing by Means of a Joule-Heated Glass Furnace*, MLM-3304, Mound Laboratories, Miamisburg, Ohio, October 18, 1985.

Brouns, R., Balasco, A. A., et al., *Bench Scale Glassification Test on Rocky Mountain Arsenal Basin F Material*, AMXTH-TE-CR-88015, Pacific Northwest Laboratory, Richland, Wash., 1988.

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Klingler, L. M., and Armstrong, K. M., *Glass Furnace Project Final Report: An Evaluation of Operating Experience for Low-Level Nuclear Waste Processing*, MLM-3229, Mound Laboratories, Miamisburg, Ohio, February 28, 1985.

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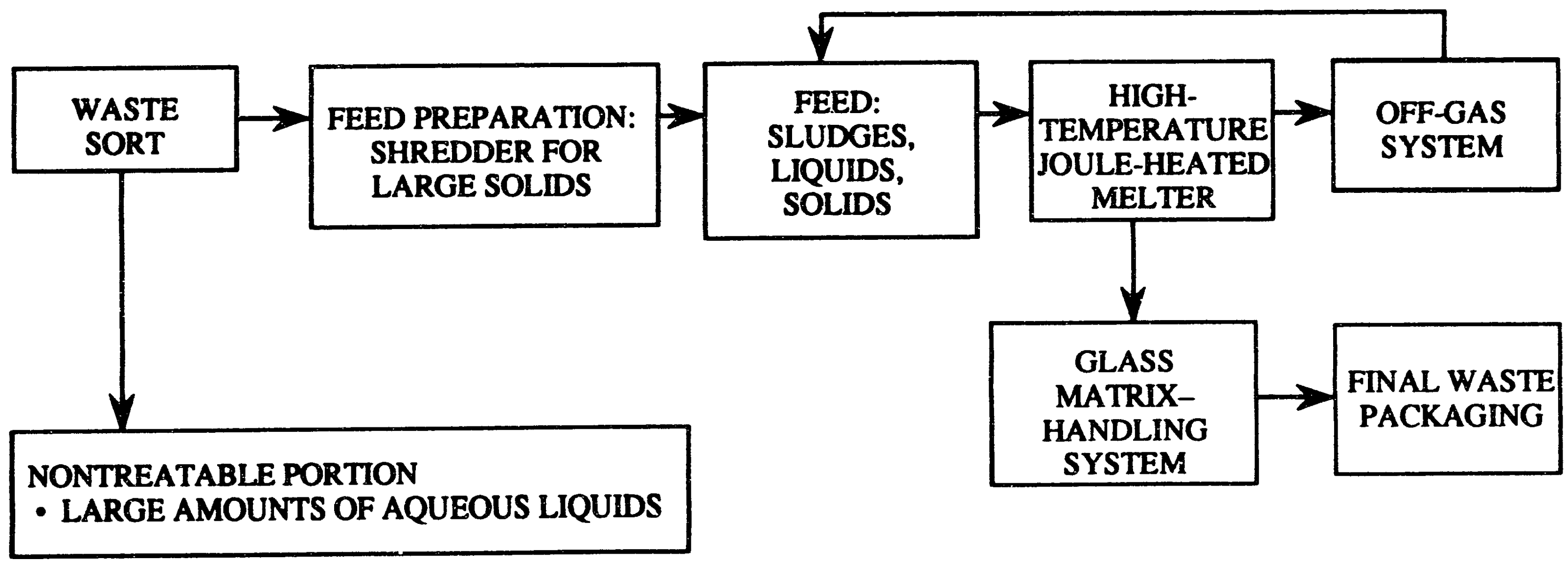

Fig. A.23. Functional process diagram of the high-temperature joule-heated melter.

Technology Name: In-Can Resistance Melter

Maturity: Developmental

Description:

An alloy canister or can is used as both the melting crucible and the disposal container. The can is placed inside a resistance-heated furnace and heated up to 1050°-1070°C. Waste and glass frit are added simultaneously in the desired proportions by gravity feed through a drop tube. The tube can be submerged below the melt surface to increase the absorption of inorganic matter into the melt. If the waste is to be combusted as well as vitrified, oxygen is also added through the drop tube. As the waste and glass frit are added to the melter, the level in the can will rise. When the can is full, the waste and frit feed are diverted into a second in-can melter while the filled can in the first melter is cooled, removed from the furnace, and capped before transportation to a disposal facility. The critical process parameters are temperature, rate of waste/frit addition, ratio of frit to waste, and, for waste combustion, the amount of oxygen in the system. A functional process diagram of the in-can resistance melter is shown in Fig. A.24.

Waste Applicability:

Aqueous Liquids:	Low applicability because of heat input constraints. Treatment via calcination or evaporation may be desirable for large quantities of aqueous liquid waste with the remaining residue treated by in-can melting.
Organic Liquids:	Low applicability.
Wet Solids:	Medium applicability.
Dry Homogeneous Solids:	Medium applicability.
Dry Heterogeneous Solids (Small):	Low applicability. Poor mixing of melt is a concern.
Dry Heterogeneous Solids (Large):	Not applicable.

Advantages:

This process is fairly simple and does not require transfer of the molten material from vessel to vessel. With the exception of the volatile matter that becomes part of the off-gas, all the waste material is fed to the final disposal container. Consequently, the melter is not degraded by the corrosiveness of the melt, and the furnace interior should not be contaminated to the degree that other melters are. These characteristics enhance the remote operability of the melter.

Disadvantages:

The in-can melter has a slower processing rate than other melters. The maximum melting rate is dependent on the can diameter, which is determined by the heat load which the alloy canister can handle. In short, the processing temperature and time are limited by the durability of the canister alloy. At operating temperatures, the alloy canister can be subjected to a severe environment. A corrosive molten glass and high-temperature oxidation will degrade the canister unless an expensive alloy is used. In addition, because the alloy can has a higher thermal expansion than the glass melt, the can contraction from cooling would normally be greater than the glass. As a result, after the can and glass are cooled, the hardened glass will keep the can in an expanded condition with severe mechanical stresses. There can also be some control problems with the in-can melter. The rising molten glass level must be continuously monitored, which is difficult at operating temperatures. The glass frit-to-waste ratio can also be difficult to control if the waste is added directly from the discharge of another waste treatment unit such as a calciner. This method of feed addition can also result in poor blending of the waste and the glass frit.

Development Needs:

Improvements in heat and mass transfer are needed to reduce the melt time. Longer-term testing is needed to identify and solve operational problems. Application to radioactive waste must be verified and the off-gas characterized.

Vendor List:

Not commercially available.

DOE Laboratories Involved in Technology:

Pacific Northwest Laboratory

Bibliography:

Blair, H. T., *In-Can Melting Process and Equipment Development from 1974 to 1978*, PNL-2925 UC-70, Pacific Northwest Laboratory, August 1979.

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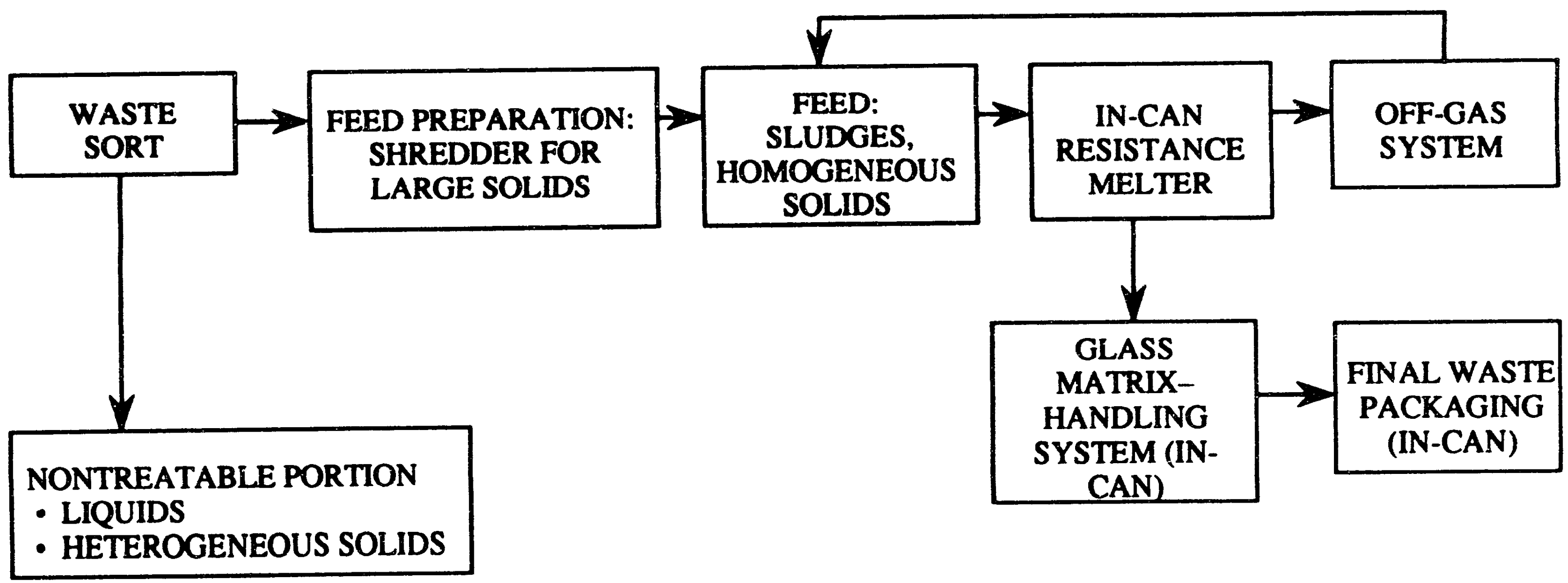

Fig. A.24. Functional process diagram of the in-can resistance melter.

Technology Name: Stirred-Joule Melter

Maturity: Emerging-Pilot

Description:

Stirred-joule melters are joule-heated melters in which the molten material is agitated by a stirrer. Depending on the type of waste feed, different stirrers can be utilized to optimize the process. The waste can be fed in a dry form or in an aqueous slurry; however, a lower throughput results from an aqueous feed. A two-zone melter is used with the top zone highly mixed by the stirrer. The bottom zone is less turbulent so that gas bubbles can separate and rise out of the zone, resulting in a dense glass. Electric resistant heaters are used to pyrolyze organic materials and provide startup heat until electrically conductive temperatures are reached so that joule heating can be established. A functional process diagram of the stirred-joule melter is shown in Fig. A.25.

Waste Applicability:

Aqueous Liquids:	Low applicability to aqueous liquids.
Organic Liquids:	High applicability.
Wet Solids:	High applicability.
Dry Solids:	High applicability.
Heterogenous Solids:	Not applicable because of potential damage to the stirrer by large solid objects.

Advantages:

Because the stirrer increases efficiency in heat distribution, stir melters have a high throughput rate for their size. Throughput rates with the stirrer operating have been eight times greater than those without the stirrer operating. The greater efficiency in heat distribution also permits operation of the stir-melter at lower temperatures, thus allowing increased flexibility in selection of materials for melter components and increased contaminant incorporation into the waste glass. The smaller size and lower operating temperatures also reduce costs by reducing heat losses.

Disadvantages:

Because this technology is basically a variation of high-temperature joule melters, there are the same types of disadvantages for the stirred-joule melter as for the high-temperature joule melter. There is concern about damaging the stirrer if large metallic objects are added to the melter. There is also a concern with heavy metal carryover from volatilization because of the high temperature, long residence time, and potentially reducing environment. As with other vitrifiers, chloride and sulfate salts in the waste are not tolerated very well.

Development Needs:

More work is needed to demonstrate this type of unit on various types of waste streams. In conjunction with this work, different types of glasses can be tested and the chemistry verified. Characterization of the off-gas is needed, and when appropriate, efforts to minimize reduction of metal oxides and thereby minimize volatilization of metals would be beneficial. If organics are to be processed in this type of melter, the unit must be mated to a secondary combustion chamber.

Vendor List:

Glasstech

DOE Laboratories Involved in Technology:

Savannah River Site

Bibliography:

Richards, R. S., and Lacksonen, J. W., "Stir-Melter Vitrification of Simulated Radioactive Waste, Fiberglass Scrap, and Municipal Waste Combustor Flyash," presented at the 93rd Annual Meeting of the American Chemical Society, Cincinnati, April–May 1991.

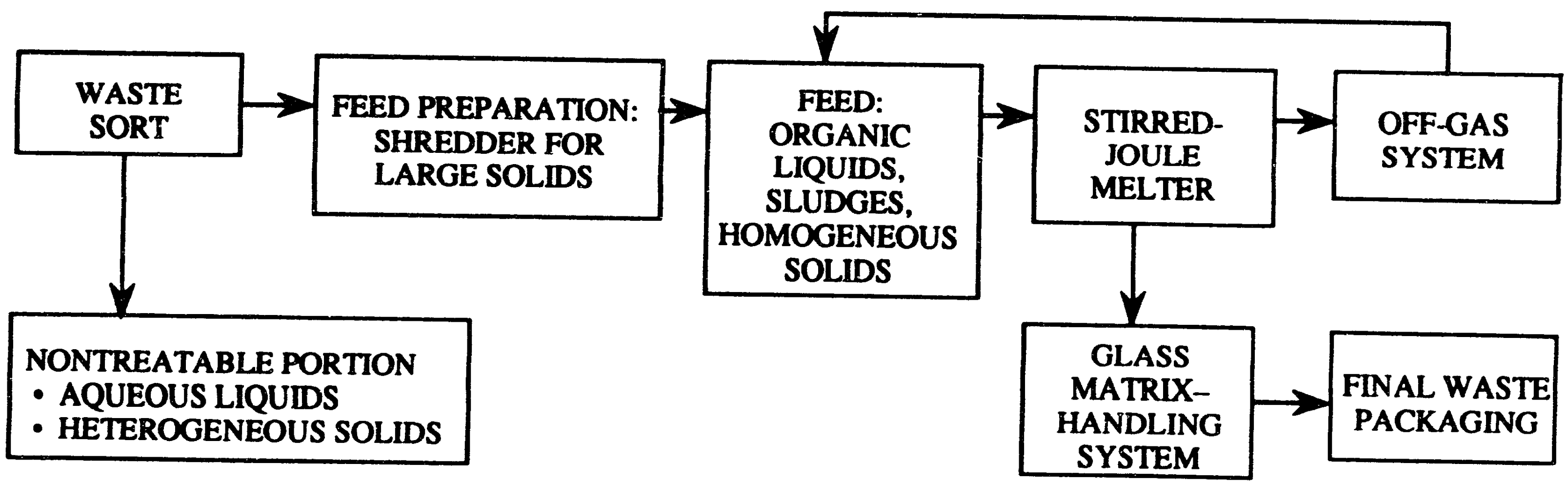

Fig. A.25. Functional process diagram of the stirred-joule melter.

Technology Name: Induction Melter

Maturity: Operational-Conventional

Description:

An induction melter consists of a refractory-lined crucible with an electrical induction coil encircling the crucible for a heat source. A high-frequency power supply provides the electrical input, and a cooling water system is needed to cool the induction coil and the power supply. An induction melter can be used to melt metals or vitrify inorganic materials such as incinerator ash in order to volume reduce the waste and obtain a more stable final waste form. Waste material is placed in the crucible, and the power supply is turned on. The material in the crucible begins to melt, forming a molten mass which flows down into the bottom of the crucible, filling the void spaces between the unmelted waste. Once the waste in the crucible is melted, additional waste material is slowly added to the crucible and allowed to melt before the next batch of material is added. When vitrifying inorganic material, an additive may be used to lower the melting point of the waste material. When melting metals, a slag coagulant is added to the top of the molten mass to aid in slag removal. Once the waste is completely melted and at the desired temperature, the melter is tilted so that the molten mass can be poured into a refractory-lined mold. A functional process diagram of the induction melter is shown in Fig. A.26.

Waste Applicability:

Aqueous Liquids:	Low applicability, with only small amounts of moisture present in the waste. If moisture is added after the melting begins, steam explosions can occur. Even trace quantities of moisture can cause splattering of the molten matter.
Organic Liquids:	Low applicability. In metal melting operations, it is undesirable to enhance contact between the waste and oxygen, or more slag will be formed.
Wet Solids:	Low applicability; can be charged only before the system is heated up.
Dry Homogeneous Solids:	Low applicability.
Dry Heterogeneous Solids (Small):	Medium applicability (metals only).
Dry Heterogeneous Solids (Large):	Medium applicability (metals only).

Advantages:

This technology is used commercially in the foundry industry and is well understood. It provides high density of final waste form, which results in a good volume reduction ratio. The final waste form is highly resistant to leaching. The only waste pretreatment necessary is size reduction of large components to fit in the melter.

Disadvantages:

A slag bridge can form when melting metals, resulting in an insulating effect that will lead to higher temperatures in the melt, which could damage the refractory lining. The slag bridge can also prevent the release of smoke and gases, resulting in a pressure buildup and a possible eruption of the molten material if the pressure breaks the bridge. Moisture can cause steam explosions. A high-frequency power supply can result in generation of a large amount of electrical "noise" throughout the electrical distribution system. The temperature of the molten mass must be carefully controlled to ensure proper transfer of material into the mold.

Development Needs:

Efforts to verify treatment of various types of wastes are needed. Incorporation of a nuclear-grade off-gas treatment system and possibly a secondary combustion chamber is needed. Improvements in monitoring the process, including the melt temperature, would be beneficial. Characterization of off-gas is necessary, and improvements in off-gas monitoring would be beneficial.

Vendors:

ABB Industrial Systems
Ajax Magnethermic Corp.
Inductotherm Corp.
Industrial Furnace Systems
Leco Corporation
Omega
Pillar Industries
Radyne Corporation

DOE Laboratories Involved in Technology:

Hanford
Idaho National Engineering Laboratory

Bibliography:

Gillins, R. L., and Maughan, R. Y., *Progress Report on Metal Sizing and Melting Activities at the Waste Experimental Reduction Facility*, EGG-2434, November 1985.

Katoh, K., Fujisaki, S., and Hirayama, K., "Solidification Tests of Radioactive Incineration Ash with Induction Heat Melting Process," presented at the International Conference on Incineration of Hazardous, Radioactive, and Mixed Waste, San Francisco, May 1988.

Larsen, M. M., and Logan, J. A., *Sizing and Melting Development Activities Using Noncontaminated Metal and the Waste Experimental Reduction Facility*, EGG-2319, EG&G Idaho, May 1984.

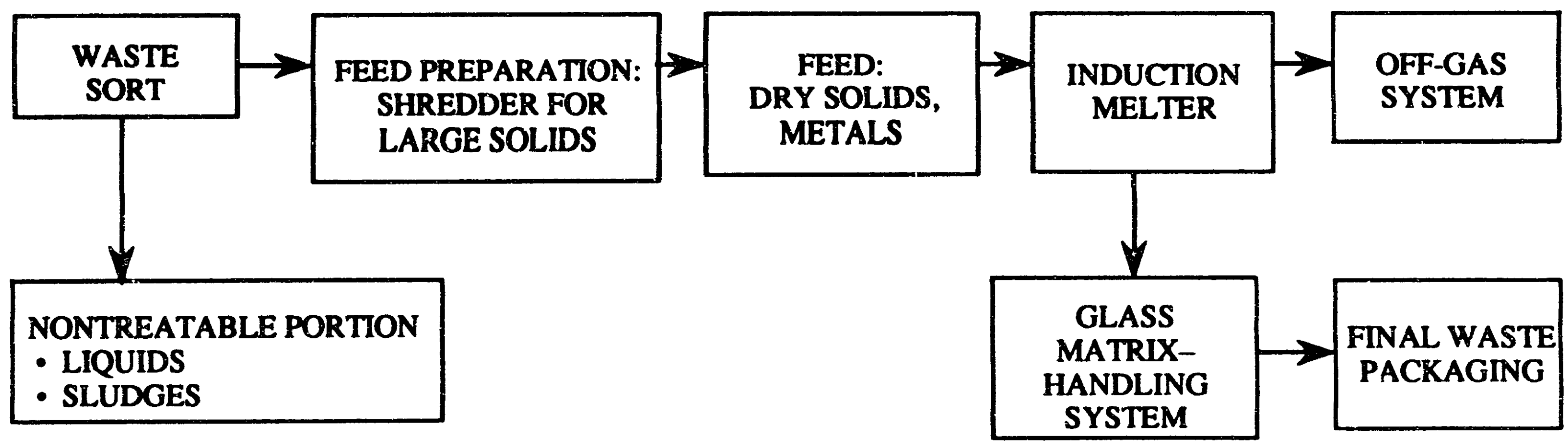

Fig. A.26. Functional process diagram of the induction melter.

Appendix B. ASSUMPTIONS FOR TECHNOLOGY DEVELOPMENT STRATEGY

Appendix B. ASSUMPTIONS FOR TECHNOLOGY DEVELOPMENT STRATEGY

This section discusses issues that were addressed by the Thermal Treatment Working Group (TTWG) as part of the effort to formulate development strategy for the Mixed Waste Integrated Program (MWIP) for DOE mixed waste. These issues relate to development strategies, waste stream prioritization, waste separation, and treatment residuals. The TTWG's responses define the framework and inherent assumptions in the initial MWIP technology development strategy. These assumptions have since become obsolete due to the development of the DOE National Mixed Waste Program and its more global scope. They are presented here to illustrate the bases for the TTWG study.

How should our near-term technology development strategy be balanced by our long-term goals?

The Office of Technology Development (OTD) approach is to use low-risk, minimal development technologies as near-term solutions. The working group (TTWG) will identify these near-term technologies (using a specified maturity criteria), assess the actual developmental state, and recommend specific demonstrations for specific DOE waste streams. (The basis for this recommendation will be discussed in the next question.) After the near-term strategy is developed, the TTWG will address OTD's long-term technology development goals. The TTWG will conduct an in-depth assessment of all thermal technologies and rank them according to group-defined criteria. Included in this strategy will be the group's assessment of issues associated with each technology that must be addressed prior to successful demonstration.

How should we weight the flexibility of a technology? Should we prioritize technologies that are flexible enough to treat several different waste streams, or should we prioritize the waste streams first and consider which technology is most applicable to each category of waste stream, leaving flexibility as a minor consideration?

The TTWG will evaluate technologies for the waste streams to which they are best suited. Thus, the group will first prioritize the DOE waste streams (based on volumes, compliance issues, and public risk—not on availability of treatment technology) and then evaluate technologies applicable to that waste stream. This will generate a list of important technologies, which can then be further refined based on the criteria of waste stream flexibility.

How do we evaluate each technology in areas such as maturity and developmental issues associated with it?

The TTWG has developed an evaluation methodology that rates the technology in areas such as maturity, maintenance requirements, safety risk, operability, flexibility, and effluent/residue. This methodology is described in detail in Sect. 4 of this report. Note three important points concerning this methodology: (1) weighting factors have not been assigned to evaluation criterion (weighting factors will be important if we are to properly interpret the final scores for OTD), (2) cost has not been considered to be a factor, and (3) the evaluation was sometimes based on sketchy information which may or may not be available from other sources. The TTWG recognized this inadequacy by generating a list of "issues that need to be resolved." Preferably, these issues will be resolved before the evaluations are quantitively used by the OTD. In any case, note that these evaluations are inherently biased towards the knowledge and beliefs of the group. A concerted effort was made to remain as objective as possible and to make recommendations with these biases in mind.

How important is the final form of the waste residue after thermal treatment? Should we give preference to technologies that produce enhanced (i.e., stable over long periods of time) residues?

The TTWG recommends that enhanced waste forms be a priority for technology evaluation purposes. Note that these are technology unit operation evaluations. The next step is to evaluate the technologies as part of a system (from waste sorting to final residue disposal). Only in a systems evaluation can a true comparison be made between technologies, since the resultant waste form is produced by the system, not just the technology. The TTWG will address system evaluations in the second stage of our project.

Should we consider waste pretreatment requirements (e.g., sorting or shredding) as a detriment to a given technology?

The TTWG decided that pre-treatment of a waste increases the risk of personnel exposure as well as increasing handling costs (although cost is not an evaluation criterion). Accordingly, we included pretreatment requirements in the "Flexibility and Versatility" criteria described in Sect. 4. Again, this requirement may become clearer when we consider a "systems-level evaluation."

What are the implications of coprocessing low-level (LLW) and transuranic (TRU) wastes—from a technical, regulatory, and institutional viewpoint?

No significant technical issues exist for LLW and TRU waste coprocessing. Thermal treatment is meant only to destroy or stabilize hazardous constituents, regardless of their radiological intensity. Coprocessing issues are therefore primarily regulatory and institutional in nature.

DOE regulations require that the radiological intensity of the residue from the treatment process be properly assessed and managed according to appropriate DOE regulations.

The institutional issues include the following:

- Coprocessing could create TRU waste from LLW, with a corresponding increase in complexity and risk to handle the waste as TRU. The DOE system has no current bans that prohibit the generation of TRU from LLW during treatment. Because one effect of thermal treatment of radiologically contaminated waste is volume reduction and consequent concentration of the radiological species, the potential exists to make TRU concentrations in the residue of LLW even without coprocessing. The philosophy articulated in the DOE's Five Year Plan is to process waste material and then to examine the resulting residue and manage it accordingly. This position assumes that instruments capable of measuring TRU threshold levels in the process residue will be available.

- Coprocessing could result in dilution of the TRU into LLW, depending on the ratio of LLW to TRU, risking adverse public perception of the practice as an attempt to avoid proper management of the waste.

- Coprocessing may present some economic advantages over separate processing. This aspect must be assessed to determine what, if any, advantage of this nature exists.

Appendix C. REGULATORY FRAMEWORK AND PUBLIC RELATIONS

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Due to increasing environmental concerns, federal, state, and local agencies are constantly developing new and more stringent regulations governing the generation, treatment, and disposal of wastes. Construction and operation of a successful thermal treatment system will require a detailed, well-managed regulatory scheme to ensure verbatim compliance. An owner/operator (O/O) of a thermal facility must be aware of the requirements imposed for facility construction/permitting, facility operations, and treatment residue disposal. Thermal systems are beneficial for waste treatment for a variety of reasons. However, it must be recognized that the ultimate goal of waste management is to render wastes acceptable for land disposal; therefore, a great deal of emphasis is placed on identifying the requirements that wastes must meet in order to be land disposed. The requirements identified in this section mainly address low-level mixed waste, but briefly discuss other waste types as well.

C.1 APPLICABLE REGULATIONS

Regulatory requirements applicable to thermal systems can be divided into at least three categories: (1) facility permitting/construction, (2) facility operations, and (3) treatment residue disposal. The O/O of the facility is responsible for ensuring that these requirements are met. Several regulations are applicable and in some cases appear in more than one category.

C.1.1 Facility Permitting/Construction

Prior to construction of the facility, several environmental documentation processes must be completed. Before these processes are commenced, a facility conceptual design must be developed. It is expected at this point that approval for line item funding is in process as well as development of a preliminary safety analysis for the facility.

C.1.1.1 NEPA Documentation

National Environmental Policy Act (NEPA) requirements are an integral part of any project planning process and are set forth in 42 USC 4330, 40 CFR 1500, and DOE Order 4700. NEPA is intended to ensure that every proposed action (in this case, construction of a new thermal treatment facility) has been reviewed for significant effects on the quality of the human environment and that harmful effects to the environment have been minimized. It is important that the appropriate federal and state agencies become involved as early as possible to facilitate this process. The NEPA document(s), once prepared, are submitted, provided for public comment, and approved according to the procedures in 40 CFR 1500 and DOE Order 4700. Individual states may have their own environmental policies in addition to NEPA; if so, it is the responsibility of the O/O of the facility to ensure that these requirements are also met. Upon approval of NEPA documentation, title design may be initiated. Per DOE policy, Title I and II designs are required before construction of the facility.

C.1.1.2 RCRA Permitting

Thermal treatment of mixed waste requires a Resource Conservation and Recovery Act (RCRA) permit. To ensure that hazardous waste incinerators are operated safely and effectively, the U.S. Environmental Protection Agency (EPA) requires that a permit to operate (Part B Permit) be obtained. The RCRA permit application must contain facility design specifications and be written to requirements in 40 CFR Section 264 for facility operations. The permit process is summarized as follows:

1. The RCRA Part B Permit application and the trial burn plan must be submitted at least 180 days prior to construction of the facility. Details of the permitting process are specified in 40 CFR Part 270.

2. The Part B Permit Application will be reviewed by the federal and state agencies to determine whether the facility will meet the performance standards in Sect. 264. A draft permit is prepared if no additional information is required. This draft permit details technical requirements and conditions to operate the facility.

3. The draft permit and trial burn plan will be subject to public comment, a process which may or may not include a public hearing.

4. Subsequent to approval by EPA and the public comment period, EPA issues a four-phase permit to the facility. The O/O may construct the facility per established conditions in the permit. During the four phases of the permitting process, the incinerator will go through initial startup; trial burn; posttrial burn operation while the results are being evaluated; and, lastly, final permit issuance with complete commencement of operations.

The final operating permit (issued by EPA in conjunction with the applicable state) specifies parameters such as operating conditions, waste feed composition, stack emission limits, monitoring requirements, and waste feed rate. Regulations governing these parameters are discussed in Sect. 3.1.2, "Facility Operations."

The requirements for obtaining a permit seem to be incinerator specific as outlined here. However, treatment of mixed wastes by other thermal treatment processes is regulated in 40 CFR 264 Subpart X (Miscellaneous Units), which is similar to Subpart O (Incinerators) although not as specific. Permitting of these facilities refers to the requirements for incinerators, but, in general, specific issues will be negotiated between the O/O and the regulators.

C.1.1.3 TSCA Permitting

Regulations for management of polychlorinated biphenyls (PCBs) and PCB-contaminated items are required by the Toxic Substances Control Act (TSCA) and are established in 40 CFR 761. In general, PCBs are required to be destroyed by incineration or another acceptable thermal process. If a facility will be treating PCB wastes, a TSCA permit must be obtained. The permit process is similar to the RCRA permit process, although not as rigorous. A trial burn is required to demonstrate adequate disposal of PCBs. It is recommended that, if both permits are required, the O/O design a trial burn to meet both RCRA and TSCA requirements. EPA must approve

RCRA and TSCA trial burns before incineration of hazardous and PCB waste operations can commence.

C.1.1.4 Air Permitting

Thermal treatment facilities require air permits per the Clean Air Act (CAA) as new source facilities. These permits are handled and issued at the state level and must meet requirements established in 40 CFR 15, "Controls for New Sources of Air Pollution." This permit process requires determination of whether the facility is to be located in an area where National Ambient Air Quality Standards (NAAQS) are met and will, at a minimum, require engineering justification of facility emission rates, new source air quality impacts, and assessment of other risks to the environment. As a result of this, specific operating limits may be imposed. Air permitting processes must be completed and approved by the state prior to initiating construction of a facility. Each state has its own process and requirements for air permitting and reserves the right to impose requirements more stringent than the federal regulations.

Additionally, facilities will be required to determine whether National Emission Standards for Hazardous Air Pollutants (NESHAPs) apply under 40 CFR 61 of the CAA. NESHAPs are intended to control the source of certain hazardous air pollutants. Promulgation of NESHAPs for any incinerator will be necessary.

C.2 FACILITY OPERATIONS

The following briefly describes the various performance standards, emission limits, and operational parameters that must be met during treatment of mixed waste.

C.2.1 RCRA Requirements

RCRA requires that incinerators be operated according to 40 CFR 264.340-350 (Subpart O). These requirements are specifically set forth in the RCRA Part B Permit and are based on results of the trial burn. Only those wastes specified in the permit may be treated. Emission limits, which may be found in 40 CFR 264, exist for hydrogen chloride (HCl) and particulate. EPA has proposed new limits for products of incomplete combustion (PICs), HCl, and toxic metals. In addition, more stringent monitoring requirements for carbon monoxide, oxygen, and hydrocarbons have been proposed. Although these proposed limits are currently applicable only to incinerators, boilers, and industrial furnaces, it is expected that they will be imposed on other thermal treatment units. Determination of applicability will be negotiated with EPA and the state during the permit process.

C.2.2 TSCA Requirements

PCB waste must be incinerated according to operating requirements in 40 CFR 761.60-761.70; these requirements will be written into the TSCA permit. Incinerators burning nonliquid PCBs are not permitted to emit more than 1 mg/kg of PCBs introduced into the incinerator, and the destruction and removal efficiency (DRE) must be equivalent to 99.9999%. Land disposal restrictions (LDRs) require that PCBs be destroyed in accordance with TSCA requirements.

C.2.3 NESHAPs Requirements

As discussed previously, NESHAPs (40 CFR 61) control hazardous air pollutants by regulating the source. If applicable, some pollutants may require continuous monitoring to ensure that emission levels are not exceeded. For radioactive facilities, NESHAPs limit radiation exposure to 10 mrem/year to the public at the site boundary, a limit which is the same as that specified in DOE Order 5400.5.

C.3 TREATMENT RESIDUE DISPOSAL

Selecting thermal technologies for DOE's mixed-waste streams is complicated by the requirements that are imposed for mixed-waste treatment residue disposal. Mixed waste must be managed to meet both RCRA treatment standards for its hazardous components and DOE performance objectives for its radioactive constituents.

EPA has established LDR treatment standards for each of the listed and characteristic hazardous wastes that are identified in 40 CFR 261. These treatment standards specify requirements that treatment residues must meet in order to be eligible for land disposal. DOE has mandated that all federal, state, and local environmental regulations, including these LDRs, must be met at all DOE sites. The treatment standards were determined by assuming that wastes are treated using the best technology currently available for each waste type. These technologies are termed the best demonstrated available technology (BDAT). The treatment standards are identified as either technology based or concentration based. Technology-based standards are those for which the standard is a specific technology or one that can meet the performance of the specific technology. The concentration-based standards are based either on the hazardous constituent concentrations in the waste (CCW) or on the constituent concentration in the waste extract (CCWE) resulting from the test procedure used, specifically the Toxicity Characteristic Leaching Procedure (TCLP).

Wastes that have treatment standards expressed as a technology must be treated by that specified technology (or technologies) or one that is demonstrated to have equivalent performance. The waste is then considered acceptable for land disposal as long as the treatment facility provides a statement to the disposal facility certifying that the waste has been treated to meet the applicable standard. These standards, listed by RCRA waste code, can be found in 40 CFR 268.42. Although RCRA does not specifically regulate radioactive constituents, technology-based standards (BDATs) have been established for a few specific radioactive mixed wastes (40 CFR 268.42, Table 3). In general, RCRA has identified that wastes exhibiting the characteristic of ignitability as well as many organic wastes be treated by incineration or other thermal treatment. For these waste types, thermal destruction renders the waste land disposable while also converting organics to nonhazardous gases and water, greatly reducing the volume.

Wastes that have standards expressed as concentrations may be treated by any technology as long as the concentration standard is met. Again, the treatment facility is responsible for providing proof to the disposal facility that the waste meets the standard. Treatment standards expressed as CCWE can be found in 40 CFR 268.41, and standards expressed as CCW can be found in 40 CFR 268.43. Both are listed by RCRA waste code. Using thermal treatments to render these wastes land disposable will require that the residue be tested to determine that the standards have been met. Depending on the type of treatment used and the hazardous constituent involved, the residue may require stabilization to meet the standards (mainly for heavy metals to meet the CCWE). Some types of thermal treatment, such as plasma-arc incineration, produce enhanced stabilized waste forms that are not expected to require further treatment or stabilization before disposal.

DOE radioactive and mixed waste must be managed in accordance with DOE Order 5820.2A to ensure protection of the health and safety of the public, DOE and contractor employees, and the environment. It is expected that each DOE site will have a disposal option for its treated mixed waste in order to reduce the likelihood of human and environmental exposure and to reduce potential future liability. If the mixed waste possessed a characteristic hazard that was removed by thermal treatment (followed by stabilization, if necessary), the waste may be disposed of as LLW. If the mixed waste was originally listed, the resulting residue will remain listed mixed waste, even though the treatment standards are met, and will require disposal in a RCRA-permitted disposal facility. For PCB-containing items, disposal in a TSCA landfill is also an option, provided that no RCRA hazardous waste has contaminated the debris. It is expected that this disposal option will be available on-site or that it is being pursued. If waste feed characteristics are well defined, a strategy of delisting the waste may be feasible to allow disposal as LLW. If the waste contains TRU elements at concentrations greater than 100 nCi/g, disposal at the Waste Isolation Pilot Plant (WIPP) or alternate TRU facilities will be required. In any case, waste acceptance criteria as developed by individual disposal sites will need to be met before disposal.

DOE disposal facilities have been developing more stringent waste acceptance criteria in order to mirror the requirements of other agencies, such as EPA and the Nuclear Regulatory Commission (NRC). These agencies are requiring that waste forms be nonliquid, chemically and physically stable, and completely characterized. In addition to these requirements, DOE has adopted a policy to use BDATs whenever possible to reduce waste volume and provide a stable waste form. Implementation of thermal treatments can help DOE to meet these goals and move forward in solving the DOE LLW and mixed-waste problem as mandated in the DOE orders.

The TTWG recommends development of treatment systems by DOE that produce an enhanced final waste form. This approach provides a means for DOE to meet existing disposal requirements and any future requirements that may be imposed, as well as help allay the general public's fears that DOE has not made a firm environmental commitment. This approach could be accomplished by using either primary thermal treatment devices or residue thermal treatment devices.

C.4 PUBLIC ACCEPTANCE ISSUES

Development of any new waste management facility requires the involvement of the public. For example, EPA requires public comment in both the RCRA and NEPA processes. Heightened public awareness is evident as a result of highly publicized environmental catastrophes due to improper waste management practices in the past. Incineration suffers from lack of public acceptance, as illustrated by aborted and delayed attempts to site and build solid waste incinerators across the United States. Although recent environmental awareness has resulted in more stringent waste management regulations, the public does not seem to be convinced that the regulations are sufficient or that the government is adequately enforcing them.

Hazardous, municipal, and medical waste incinerators have received much attention from both the public and scientific community. The public is concerned about perceived health threats imposed by stack emissions of organics and toxic metals. The public, or at least some vocal environmental groups, believe that stricter limits should be developed and that stricter enforcement is required where limits do exist. The public is also concerned about incineration of radioactive wastes. There is often unfounded fear associated with radioactivity in general. Much research has been done in an attempt to put the public at ease, but much more is required to develop an attitude of trust.

Public apprehension of incineration for the above reasons has caused delays in incineration growth, both within DOE and in the commercial sector. These delays can have serious consequences including overburdening landfills and creating potentially unsafe storage of hazardous and radioactive waste due to lack of treatment capacity. This problem must be overcome in order to facilitate development of thermal technologies as an accepted means of treating DOE's problem wastes.

There is a perception in some quarters of the DOE system that development of thermal technologies that differ significantly from conventional open-flame incineration may receive a warmer reception from the public. The logic seems to be that negative feelings associated with incineration in the past will remain despite technology advancements, increased regulatory oversight, and increased public education. Advanced technologies that reduce emissions, achieve destruction in some manner other than open-flame combustion, and generate an environmentally enhanced waste residue may, in the final analysis, be needed to overcome the public's opposition to incineration.

Appendix D. THERMAL TREATMENT WORKING GROUP PARTICIPANTS

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Appendix E. SELECTED ANNOTATED BIBLIOGRAPHY

Appendix E. SELECTED ANNOTATED BIBLIOGRAPHY

Dalton, D., et al. *An Assessment of Off-gas Treatment Technologies for Application to Thermal Treatment of Department of Energy Wastes*, March 1992.

Pollution control equipment to be used during thermal treatment of DOE wastes is evaluated. Descriptions, benefits, and limitations of each technology are discussed as related to specific air pollutants being removed. Regulatory issues and requirements for air pollution control systems are presented. Evaluation criteria are developed as a means to numerically rate or compare each individual technology for a specific off-gas constituent. In addition, four examples of off-gas trains (combination of technologies) are developed and evaluated by using specific waste stream examples.

Johnson, A. J., Meyer, F. G., Hunter, D. I., and Lombardi, E. F., *Incineration of Polychlorinated Biphenyl Using a Fluidized-Bed Incinerator*, RFP-3271, 1981 (also available from National Technical Information Service, Springfield, Va.).

A trial burn of polychlorinated biphenyl (PCB) transformer fluid in a fluidized bed has been completed at the Rocky Flats Plant. Extensive sampling procedures were used to assess the efficiency of the burn; analysis by Rocky Flats laboratories of the samples collected gave a 99.99992% PCB destruction efficiency. This compares well with the independent EPA analysis indicating that 99.9999% of the PCB was destroyed. The fluidized-bed incinerator utilizes a chromic oxide catalyst to achieve destruction at the relatively low operating temperature of 600°C and a primary bed of Na_2CO_3 to neutralize combustion-generated HCl into NaCl. A low operating temperature permits an all-metal system to be used, and the dry off-gas system negates the need for a water- or caustic-filled scrubber.

Koenig, R. A., Borduin, L. C., Hutchins, D. A., Vavruska, J. S., and Warner, C. L., *The Los Alamos Controlled Air Incinerator for Radioactive Waste*, Vols. I–III, LA-9427, 1982–1987.

This three-volume set of reports describes the design and operation of the Los Alamos National Laboratory Controlled Air Incinerator (CAI). Volumes I and II address the rationale, process, equipment, performance, and recommendations pertaining to the CAI as a transuranic-contaminated waste incinerator. The third volume addresses similar categories of information that pertain to modifications to the CAI in the period between 1981 and 1986. These later system changes were motivated by programmatic objectives to use the CAI for additional study of combustion of low-level radioactive wastes and hazardous chemicals (mixed wastes).

Meile, L. J., Meyer, F. G., Johnson, A. J., and Ziegler, D. L., *Rocky Flats Plant Fluidized Bed Incinerator*, RFP-3249, 1982 (also available from National Technical Information Service, Springfield, Va.).

Laboratory- and pilot-scale testing of a fluidized-bed incineration process for radioactive wastes led to the installation of an 82-kg/h demonstration unit at the Rocky Flats Plant in 1978. Design philosophy and criteria were formulated to fulfill the needs and objectives of an improved radioactive waste incineration system. Unique process concepts include low temperature (550°C); flameless fluidized-bed combustion and catalytic afterburning; in situ neutralization of acid gases; and dry off-gas cleanup. Detailed descriptions of the process and equipment are presented along with a summary of the equipment and process performance during a 2-1/2 year operating testing period. Equipment modifications made during the testing period are described. Operating personnel requirements for solid waste burning are shown to be greater than those required for liquid waste incineration; differences are discussed. Process utility and raw materials consumption rates for full-capacity operation are presented and explained. Improvements in equipment and operating procedures are recommended for any future installations. Process flow diagrams, an area floor plan, a process control system schematic, and equipment sketches are included.

Peterson, R. D., "Microwave Vitrification of Rocky Flats TRU Sludge," presented at Spectrum 1990, Williamsburg, Va. (presented by A. J. Johnson).

Microwave vitrification of mixed transuranic (TRU)/hazardous waste at the Rocky Flats Nuclear Weapons Plant is being tested by using actual mixed TRU waste in a bench-scale system and simulated waste in a pilot system. Results from "hot" bench-scale tests indicate that volume reductions of up to 75% are achievable by continuously feeding dry waste and glass frit into a waste container while applying microwave energy. An economic evaluation was completed, showing that volume and weight reductions of up to 87% are achievable over quantities associated with the immobilization process currently in use on wet sludge, with a cost savings of $4.25 per pound of dry sludge produced.

Peterson, R. D., "Pilot/Demonstration Scale Microwave Solidification of Mixed Waste," prepared for the American Society of Mechanical Engineers Mixed Waste Symposium, Baltimore, Md., 1991.

The aqueous wastes from the plutonium recovery areas at the Rocky Flats Plant (RFP) are treated in a hydroxide precipitation process to remove heavy metal compounds. The waste presently produced at RFP conforms to the Waste Acceptance Criteria of the Waste Isolation Pilot Plant, but would not meet land disposal restrictions as mandated by the Resource Conservation and Recovery Act.

Bench-scale microwave solidification tests were completed by using simulated and actual precipitation sludge in a 6-kW, 2450-MHz system. Results have shown that production of solidified waste form with volume reductions of up to 80% is achievable. Pilot-scale tests were also completed using simulated waste in a near-production-size system using a 30-kW, 915-MHz generator. A total of nine runs were performed. Results were similar to those achieved in bench-scale tests with an average volume reduction of 77.7% and an average bulk density of 1.85 g/cm^3. A second-generation solidification system was installed using an advanced design with a 50-kW, 915-MHz microwave generator. Simulated waste, produced using a laboratory-scale rotary vacuum filter, is used in the operation of the process. Two tests have been run to check operation of the system. Both were run using 60 wt % waste loading. Preliminary results indicate that a product density of about 3.2 g/cm^3 is being produced. The material exhibits conchoidal fracturing when broken and contains the proper iron/silicate content to be classified as taconite.

Peterson, R. D., and Johnson, A. J., "Application of Microwave Energy for Solidification of TRU Waste," prepared for Waste Management '88, Tuscon, Ariz.

The application of microwave energy for in-container solidification of simulated transuranic-contaminated precipitation sludges has been tested. Tests have found that volume reductions of 80% are achievable by the continuous feeding of predried sludge into a waste container while applying microwave energy. An economic evaluation was completed showing that volume and weight reductions of up to 87% are achievable over quantities associated with an immobilization process currently in use on wet sludge.

Science Applications International Corporation, *An Assessment of Thermal Destruction Technologies for Application to Department of Energy Mixed Wastes*, DOE/HWP-106, Vols. 1 and 2, August 1991.

Volume 1–Technology Assessment

An assessment of the potential applicability of thermal treatment technologies to DOE's generic waste management needs is presented. All relevant thermal technologies are identified, as well as pertinent technical and cost data for each technology. A total of 35 technologies are identified, not all applicable to DOE waste streams. For those technologies for which sufficient data are available and which are applicable (or potentially applicable) to DOE waste streams, a comparative evaluation is performed. Each technology is evaluated for a set of generic waste streams, and cost/benefit parameters (including applicability to each waste category), adaptability to radioactive waste, capital and operating costs, extent to which the treatment residue is disposable without further treatment, and operating and maintenance factors are considered. In this manner, highly rated potential technologies for specific waste treatment applications are identified.

Volume 2—Technology Data Sheets

Comprehensive data for each technology identified in Vol. 1 are presented, including descriptions, process and cost data, comments on advantages and deficiencies, types of waste treatable, and by-products of these wastes. The data will be input into the DOE Waste Management Information System technology data base being compiled by the Hazardous Waste Remedial Actions Program at Oak Ridge to provide for universal availability of the data to the DOE system.

Semones, G. B., *Performance Evaluation of the First Stage Reactor in Rocky Flat's Fluidized Bed Incinerator*, EG&G Rocky Flats, Inc., 1992.

This report analyzes the performance of the primary reactor of the Fluidized Bed Incinerator (FBI) demonstration unit at the Rocky Flats Plant. Tests performed with the FBI in the late 1970s and early 1980s proved the technology to be viable for volume reduction of mixed waste; however, little was done to understand the fluidization phenomenon. The present study uses data from the FBI demonstration unit to gain insight into its operation. Theoretical analysis shows the first-stage reactor of the FBI operated as designed as a "bubbling" fluidized bed. One finding from this study is that minor variations in gas flow or particle size could cause the bed to change fluidization regimes to either a slugging or a homogeneous bed. A slight reduction in particle size should alleviate these problems.

Knowing in which fluidization regime the bed is operating is desirable for optimizing the system. Many commercial beds operate in the bubbling region due to the turbulent action of the bubbles which keeps exposing fresh solid surfaces to the gas stream. Nominal conditions for the FBI fell into this regime; however, as mentioned above, there was potential for excursions into other, less optimal areas.

This report presents findings on the operation of the FBI. This includes determining the Geldart particle type, minimum fluidization and minimum bubbling velocities, and terminal velocity; classifying the fluidization regime; and analyzing the potential for slugging. This information should prove valuable as Rocky Flats personnel work to design a full-scale Fluidized Bed Unit for treating mixed waste.

Stull, D. M., and Golden, J. O., *Liquefaction and Storage of Thermal Treatment Off-Gases*, EG&G Rocky Flats, Inc., 1992.

A Fluidized-Bed Unit (FBU) is being developed at the Rocky Flats Plant for the destruction of certain radioactive mixed wastes by catalytic oxidation. The resulting oxidation products are ash, carbon dioxide, and water. There continues to be some public concern that conventional off-gas treatment may not be adequate; therefore, a system is being developed to capture the off-gas, store it, and release it only after analysis proves that all appropriate emission standards have been met. Several methods of off-gas storage are being studied. This report investigates liquefaction methods.

The off-gas capture system involves removing most of the water formed by oxidation, leaving a gas stream which consists primarily of CO_2 along with some O_2 and H_2O. Most of the gas recirculates to the FBU, but 10–15% is diverted for liquefaction. The liquid CO_2 is separated from the noncondensable gases and stored in stainless steel pressure vessels. Liquefaction was studied at 1100 psia and ambient temperature (high-pressure process) and at 350 psia and −15°F (low-pressure process). The low-pressure process requires refrigeration to maintain storage conditions.

The high-pressure approach offers less operational complexity and less maintenance. However, the low-pressure process offers separation of the CO_2 at conditions closer to those of the pure gas, lower capital equipment costs, lower energy consumption, more industrial expertise in the process, and the relative safety inherent in the use of lower pressure. The conclusion is that the low-pressure process should be developed for FBU off-gas capture and storage if such a system is determined to be necessary for licensing the FBU.

Tyner, C. E., "Application of Solar Thermal Technology to the Destruction of Hazardous Wastes," *Solar Energy Mater.* **21**, 113–129 (1990).

A very thorough, technically oriented paper focusing on the theory and operation of ultraviolet processing. Results of demonstrations and testing are only briefly described. A short introduction relates the basic concept of UVP. The text which follows provides a very comprehensive and detailed description of the chemistry and theory at work during the solar detoxification process. A brief discussion of results precedes an even briefer technology status report.

Ultrox International Ultraviolet Radiation/Oxidation Technology, EPA/540/A5-89/012, U.S. Environmental Protection Agency, September 1990.

In support of the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation Program, the report evaluates the Ultrox International ultraviolet processing technology for its applicability as an on-site treatment. Treatment efficiency and economic data from the demonstration and seven case studies are evaluated. The primary contaminants addressed are volatile organic carbons (VOCs) and polychlorinated biphenyls (PCBs) in parts per million and parts per billion concentration ranges. The Ultrox system achieved VOC removals greater than 90%. Pretreatment was required for influent that contained high levels of manganese, oil and grease, and suspended solids.

Ziegler, D. L., Johnson, A. J., and Meile, L. J., *Fluid Bed Incineration*, RFP-2016, 1973 (also available from National Technical Information Service, Springfield, Va.).

A fluid-bed incineration process was tested on a laboratory scale for combustion of typical plant waste material. Sodium carbonate bed material was used for in situ neutralization of the hydrogen chloride generated by the large amounts of polyvinyl chloride burned. Waste preparation and an evaluation of catalytic afterburning of reactor off-gases are included.

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