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Low-Level Radioactive Waste Volume Reduction And Stabilization Technologies Resource Manual

National Low-Level Radioactive Waste Management Program

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LOW-LEVEL RADIOACTIVE WASTE VOLUME REDUCTION AND STABILIZATION TECHNOLOGIES RESOURCE MANUAL

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ABSTRACT

This manual on volume reduction and stabilization technologies is intended to serve as a resource document to policy personnel at the state or regional level. The manual provides concise descriptions of currently available and promising methods of volume reduction and stabilization of low-level radioactive waste. Technologies in this manual include cement solidification, bitumenization, evaporation, incineration, high-integrity containerization, shredding, and compaction and supercompaction. Each technology is discussed in detail in relation to how the technology works, its suitability for specific waste types, volume reduction factors typically obtainable, costs, its applicability to 10 CFR 61 and state requirements, its applicability to treatment of mixed waste, its commercial availability and its history of use. An annotated bibliography is included to allow for further independent research on the technologies.

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ACKNOWLEDGMENT AND DISCLAIMER

The authors of this report want to express appreciation to the many vendors and users of the technologies and products included in this report, who so willingly provided information requested. The mention or inclusion of specific products and processes in this report, however, does not imply endorsement by Ebasco, EG&G Idaho, Inc., or the U.S. Department of Energy of any product or process.

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EXECUTIVE SUMMARY

This resource manual was prepared for the U.S. Department of Energy to provide technical assistance to compact regions, host states, and nonmember states in the development of new disposal facilities for low-level radioactive waste (LLW). This manual describes various LLW volume reduction and stabilization technologies and includes an annotated bibliography.

Volume reduction (VR) technologies included in this manual include compaction and supercompaction, evaporation and evaporative crystallization, incineration, and shredding. Compaction is one of the simplest, most effective techniques for reducing the volume of lightly contaminated dry active wastes. Compactors are simple to operate, relatively inexpensive, and available in conventional (drum), box, or supercompactor types. VR factors for compactors vary from 3.8 for the conventional system to 7.7 for the supercompactor. Installation costs range from $20,000 for the conventional compactor to $5,000,000 for the supercompactor.

Evaporators and evaporative crystallizers are excellent volume reducing systems for pre-treatment of large volumes of liquids prior to solidification. Many types of evaporator systems routinely operate in nuclear power plants. Total cost per hour for a multieffect system capable of evaporating 75,000 lb/hour (150 gpm) of water is approximately $44 per hour.

Incineration involves the use of high temperatures to burn and subsequently reduce the volume of LLW. Incinerators have the highest volume reduction factors (50-100) of any VR technology considered in this manual. Capital costs vary from $6.9 million to $8.8 million for incineration of 85,000 lb/year of dry active waste, with annual operating and maintenance costs of approximately $0.5 million, depending on the type of incinerator chosen.

Shredders minimize void spaces within the waste and are often used alone or in association with other VR equipment. They provide a more uniform feed material for incinerators and can enhance the VR capabilities of conventional compactors by as much as 50 percent. Installation costs for shredders range from $135,000 to $460,000, depending on the type and model chosen.

Stabilization technologies included in this manual are cement, bitumen (asphalt), polymeric stabilization media, and high-integrity containers. By far the most frequently used stabilization medium is cement. Cement has a waste loading factor of approximately 50 percent and can cost as little as $65 per cubic foot.

Bitumen is generally used in conjunction with an evaporator or other liquid reduction technology. Bitumen solidifies and encapsulates wastes, having waste loading factors between 45 and 60 percent at a cost per cubic foot of $55 to $75, depending on the volume of waste to be solidified.

The use of polymeric media for stabilization is relatively new, with virtually no operating experience. Although it is the most expensive of the stabilization media considered in this manual, its performance in stability tests consistently exceeds minimum requirements.

Stability can also be achieved by placing wastes into high-integrity containers (HICs), i.e., disposal containers designed to maintain their structural integrity for at least 300 years. Since the HIC eliminates the need to solidify wastes to achieve a stable waste form, the use of the HIC reduces the total volume of waste disposed. Containers made of polyethylene cost as much as $7,500 for a 200-cubic-foot HIC, while containers made of ferralium (a stainless steel alloy) can cost as much as ten times more than their polyethylene counterparts. Although HICs are expensive, their overall cost per year (taking into consideration transportation expenses, manpower requirements, and container costs), can be less than using cement or bitumen to stabilize ion-exchange wastes.

The advantages and disadvantages of these technologies are summarized in Table ES-1.

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TABLE ES-1. ADVANTAGES AND DISADVANTAGES OF LLW VOLUME REDUCTION AND STABILIZATION TECHNOLOGIES

Technology	Type of Treatment	Advantages	Disadvantages
Bitumen solidification	Volume reduction and stabilization	o Properties of bitumen are well known o Compatible with most waste streams o Good leachability characteristics o Comparatively low operating costs o No free-standing water o Waste volume minimized during solidification process o High waste loading capability	o Bitumen is flammable and burns at temperatures as low as 315°C o Bitumen waste forms containing certain waste streams may swell and crack when exposed to water o Exposure to heat can cause phase separation or liquification of the waste form o Solidification process requires elevated temperature o Initial capital costs are relatively high o Off-gas generation during processing o Low structural strength o Incompatible with some inorganic salts o Long-term biodegradability is of concern
Cement solidification	Stabilization	o Simple mixing process o Compatible with most waste types o Good structural strength o Good self-shielding o Low leachability for most radionuclides o Abundant availability o Low cost o Long history and good performance record o Process system available in both in-container and in-line mixing	o pH sensitive o Excessive heat generation o Increased waste volume o Potential for cracking when exposed to water and freeze/thaw conditions o Maintenance problems with dust control, powder feeding system, and premature cement setting
Compactors and supercompactors	Volume reduction	<u>Conventional compactors</u> o Low capital cost o Requires only one operator o Reduces the number of drums shipped off-site, therefore, reducing: - Transportation cost - Burial cost - Paperwork required for off-site disposal o Minimal floor space required <u>Box compactors</u> o Large receptor opening is convenient for large pieces of waste o Larger waste containers result in fewer containers to be shipped off-site and a corresponding reduction in paperwork o Container-handling times are reduced o Hydraulic unit that may require servicing can be located in a nonradioactive area, thus reducing worker exposure during maintenance activities o Containers usually contain skids and do not require pallets as do drums	<u>Conventional compactors</u> o Mechanical components will require maintenance o Potential of oil leaks in the hydraulic lines o Requires use of an overhead crane or forklift with drum-grab attachment <u>Box compactors</u> o Increased capital and individual container disposal cost o Two operators are required to place lid on waste container o Forklift may be required to handle waste containers o Occupies more space

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TABLE ES-1 (continued)

Technology	Type of Treatment	Advantages	Disadvantages
Compactors and supercompactors (continued)		Supercompactors o Dry active wastes previously considered noncompactible are compactible, including pipes, valve bodies, and other metal products o Storage space previously occupied by wastes that were considered non-compactible is reduced o Storage and disposal space at regional burial sites can be reduced o Relatively simple to operate	Supercompactors o Large capital investment o Requires large amount of floor space o Due to high compressive forces, the equipment may require more than usual maintenance o Liquid waste from punctured capsules may be released during compaction
Evaporators and evaporative crystallizers	Volume reduction	Natural circulation o Low-cost o Large heating surface o Low holdup or residence time o Small floor space o Good heat-transfer coefficients at reasonable temperature differences (rising film) o Good heat-transfer coefficients at all temperature differences (falling film)	Natural circulation o High head room o Generally unsuitable for salting and severely scaling liquids o Poor heat transfer coefficients of rising-film version at low temperature differences o Recirculation usually required for falling-film version
		Forced circulation o High heat-transfer coefficients o Positive circulation o Relative freedom from salting, scaling, and fouling	Forced circulation o High cost o Power required for circulating pump o Relatively high holdup or residence time
		Forced circulation with vapor recompression o In addition to those for forced circulation type, cooling water requirements are eliminated and steam heating requirements are reduced	Forced circulation with vapor recompression o High cost o Electrical consumption high due to large compressor motor o Relatively high holdup or residence time
High-integrity containers[a]	Stabilization	o Eliminates need to solidify wastes to achieve a stable waste form o Reduces total volume of waste disposed o Can be used in conjunction with dewatering or drying systems for wet solids o Resistant to corrosion o Convenient means of handling, transporting, and disposing of LLW	o Some types of HICs can be expensive o HICs have a design lifetime of only 300 to 500 years

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TABLE ES-1 (continued)

Technology	Type of Treatment	Advantages	Disadvantages
Incineration	Volume reduction	o Largest volume reduction of any technology o Destroys hazardous organic chemicals present in mixed waste	o Final product has a higher radionuclide concentration than initial waste o Incinerator ash requires stabilization o Relatively high capital and operating costs
Low-speed shear shredders		<u>Hydraulically driven shear shredder</u> o Fast reversing cycle on the order of 2 seconds which protects the shredder from damage o Hydraulics can withstand high shock loadings since shock is absorbed by the fluid not the gearbox o Virtually instantaneous response of hydaulics o Shredder hydraulic pump stand can be used to power ancillary systems <u>Electromechanically driven shear shredders</u> o Requires little space o 30 percent more energy efficient than hydraulic drives o Cleaner units to operate	<u>Hydraulically driven shear shredder</u> o Require large amounts of space for the pump stands o Dirty systems to operate if not properly maintained o Require large amounts of horsepower o Relatively high capital cost <u>Electromechanically driven shear shredders</u> o Shock loadings are absorbed by shaft gearboxes o Reversal times are approximately 30 seconds
Other solidification technologies utilizing various polymers		o Adaptable to many waste streams both solid and liquid o No free-standing water o Extremely low leachability o High compressive and impact strength o Good radiation stability o Ease of working with liquid components o Available in both in-container and mobile mixing systems	o Limited shelf-life for binding chemicals o Release of potentially explosive toxic fumes and fire hazard for the handling of catalyst and promoter o Relatively expensive materials o Requires careful handling and mixing

a. Advantages and Disadvantages of a HIC depend upon the material from which it is fabricated. Advantages and disadvantages of various HIC materials are included in Chapter 6 of the report. Those listed above are general in nature.

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1. INTRODUCTION

This chapter summarizes the purpose, scope, and organization of this manual and provides background information about low-level radioactive waste (LLW) volume reduction (VR) and stabilization technologies. Section 1.1 summarizes the purpose of this manual. Section 1.2 details its scope and organization. Sections 1.3 and 1.4 summarize the pertinent regulatory framework and regulatory history surrounding waste form, stability, and volume reduction requirements. In Section 1.5 the use and limitations of volume reduction data are given. Low-level waste sources and characteristics are described in Section 1.6, and volume reduction economics are discussed in Section 1.7. Section 1.8 is the vendor disclaimer, included because much of the information contained in this manual was obtained from vendors without a complete independent review.

1.1 Purpose of this Manual

The Low-Level Radioactive Waste Policy Act of 1980 (Public Law 96-573) and the Low-Level Radioactive Waste Policy Amendments Act of 1985 (Public Law 99-240) (LLRWPAA) require that each State be responsible for providing for the disposal of low-level radioactive wastes generated within the State, either by itself or in cooperation with others. The LLRWPAA also requires the U.S. Department of Energy (DOE) to provide technical assistance to compact regions, host states, and nonmember states. This assistance includes, but is not limited to, technical guidelines for site selection, alternative technologies for low-level radioactive waste disposal, volume reduction options, and management technologies to reduce low-level waste generation. As DOE's managing contractor for the National Low-Level Radioactive Waste Management Program, EG&G Idaho, Inc. is providing this technical assistance by means of this comprehensive resource manual on volume reduction and stabilization technologies for low-level radioactive waste.

An understanding of current technologies for both stabilizing and reducing LLW volume is essential for managing low-level wastes. This manual is intended to assist policy personnel in developing such an understanding by providing concise descriptions of available volume reduction and stabilization technologies and by serving as a tool for further investigation.

1.2 Scope and Organization of this Manual

This manual is formatted to assist the reader in finding information on volume reduction and stabilization technologies. Detailed information on the following technologies is included in the body of the manual:

- Bitumen solidification (Chapter 2)
- Cement solidification (Chapter 3)
- Compactors and supercompactors (Chapter 4)
- Evaporators and evaporative crystallizers (Chapter 5)
- High-integrity containers (Chapter 6)
- Incineration (Chapter 7)
- Shredders (Chapter 8)
- Other solidification techniques (Chapter 9).

Following detailed descriptions of the technologies are appendices that both aid in independent investigation and provide background information. Appendix A provides background information on regulatory issues and waste types. Appendix B is an annotated bibliography arranged both alphabetically and by technology. Appendix C provides in-depth coverage of selected operating incinerators used either for radioactive waste or similar nonradioactive wastes.

1.3 Regulatory Framework

An understanding of the regulatory framework which forms the basis for commercial low-level waste disposal in the United States is necessary for the proper implementation of volume reduction and stabilization technologies. The Atomic Energy Act of 1954, as amended, established a system of licensing control over the possession, use, transfer, and disposal of most radioactive materials in the commercial sector. This licensing and control program is carried out by the U.S. Nuclear Regulatory Commission

(NRC) (through the Energy Reorganization Act of 1974, as amended) for approximately half of the regulated community. The Atomic Energy Act allows certain regulatory actions of the NRC to be delegated to states under a formal agreement. These "Agreement States" must develop and maintain legislation, regulations, and programs that are adequate to protect the public health and safety and are compatible with those of the NRC (see 10 CFR 150). Agreement State requirements must be equivalent to, or more stringent than, those of the NRC, within well-defined bounds of compatibility. Table 1-1 lists Agreement States as of July 1988.

One of the areas of regulation that can be delegated to the states through the Agreement State program is the regulation of low-level waste disposal. All of the currently operating commercial low-level waste disposal sites are regulated by Agreement States. NRC, however, regulates the disposal of special nuclear materials (a small fraction of both volume and activity received) at two of the disposal sites.

1.4 History of Regulation of Waste Form, Stability, and Volume

Low-level radioactive wastes have been commercially disposed of in facilities practicing shallow land burial technology since 1962. By 1973, six commercial low-level waste facilities were operating. In the early 1960s, radioactive wastes were usually placed directly into containers for permanent disposal. At that time, neither federal nor state regulations existed that specified requirements for waste-form properties. Rather, site-specific, ad hoc requirements were typically developed by the disposal site operators. Those requirements were primarily aimed at operational convenience, not long-term containment of waste. Waste-form properties were considered of secondary importance in overall waste management. Good geologic and hydrologic characteristics of the disposal site were considered the principal means of waste isolation.

From 1975 to 1978, three of the six available commercial disposal sites were closed. The closure of these disposal sites, coupled with increased public concern about environmental and health impacts of nuclear power, led the NRC to begin the rule-making process to address land disposal of low-level radioactive wastes. The NRC's analysis indicated that in every instance of

TABLE 1-1. AGREEMENT STATES AS OF JULY 1988

Alabama	Kansas	North Carolina
Arizona	Kentucky	North Dakota
Arkansas	Louisiana	Oregon
California	Maryland	Rhode Island
Colorado	Mississippi	South Carolina[b]
Florida	Nebraska	Tennessee
Georgia	Nevada[a]	Texas
Idaho	New Hampshire	Utah
Illinois	New Mexico	Washington[c]
Iowa	New York	

a. Regulates an operating low-level waste disposal facility near Beatty, Nevada.

b. Regulates an operating low-level waste disposal facility near Barnwell, South Carolina.

c. Regulates an operating low-level waste disposal facility near Richland, Washington.

migration of radionuclides from disposal trenches, covers over the trenches had failed. NRC attributed this failure to a lack of structural stability of the waste. A draft of 10 CFR 61, Licensing Requirements for Land Disposal of Radioactive Waste (Part 61), was published in July 1981 after extensive discussion with waste generators, site operators, and environmental groups. While the final rule was promulgated in December of 1982, with portions effective on January 26, 1983, enforcement of the waste form and classification requirements was delayed until December 27, 1983, to give the regulated community time to come into compliance. While still relying on good geologic and hydrologic characteristics for a disposal site, 10 CFR 61 contains specific requirements for improved operations, siting, waste classification and waste form, and post-operational and long-term care. Part 61 also establishes classes of low-level waste (designated Class A, B, or C) based on the concentration of each radionuclide present in the waste. The wastes with higher concentrations of radionuclides (Class B and C wastes) must be stabilized prior to disposal. Additionally, these wastes must be segregated from wastes that are not structurally stable. These stability and segregation requirements are intended to ensure that wastes posing a potential long-term hazard (greater than 100 years) do not degrade or promote slumping, collapse, or other failures of the trench cap at a disposal site.

As public concern over low-level waste increased, the only states with operating LLW disposal facilities (Washington, Nevada, and South Carolina) perceived they were accepting a disproportionate share of the risk associated with the nation's use of radioactive materials. These three states took actions that brought the issue to the nation's attention. First, South Carolina imposed restrictions on the annual volume of waste that could be disposed. Second, Nevada required third-party inspections of waste at the generators' facilities. Third, Congress passed the Low-Level Radioactive Waste Policy Act late in 1980, which encouraged development of new disposal sites. This Act set forth the premise that all states are responsible for the disposal of low-level wastes generated within their borders. The Act encouraged states to form interstate compacts to develop new disposal capacity. It also allowed states with operating disposal sites to refuse acceptance of wastes generated outside their compact after January 1, 1986.

In 1985, it became evident that new disposal capacity could not be developed by 1986, and the original Act was amended with passage of the Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA). The LLRWPAA extended the exclusionary date and established milestones and penalty surcharges to encourage the development of new operating disposal sites by 1993. These surcharges and penalties (ranging from a minimum of $10/ft^3 to a maximum of $120/ft^3 or total exclusion of a state's waste from a disposal site) were to be assessed on the disposed volumes of waste. In addition, restrictions on the volume of waste generated by nuclear power plants were specified. Thus, economic and other incentives emerged to reduce the volume of disposed wastes. This emphasis resulted in a 60-percent reduction in the volume of waste disposed of in the state of Washington in 1986, compared to 1985.[1-1] Similar reductions in waste volumes have continued. For calendar year 1988, the operator of the Washington site expects to receive approximately 10 percent of the waste volume received in 1985.[1-2] While waste volumes in 1985 may have been artificially high due to the threat of site closure imposed by the 1980 Act, the overall decrease in waste disposed has been dramatic.

No specific federal standards govern the degree of volume reduction required, aside from the volume limits for power reactors contained in the 1985 LLRWPAA. The LLRWPAA, however, specified annual average amounts of waste beyond which acceptance by the three operating disposal sites is not required: 200,000 cubic feet of waste at Beatty, Nevada; 1,200,000 cubic feet of waste at Barnwell, South Carolina; and 1,400,000 cubic feet of waste at Richland, Washington, for the 7-year period beginning January 1, 1986 and ending December 31, 1992. These volume specifications have not played a major role in decision making because South Carolina and Washington have been receiving substantially less waste than anticipated. Table 1-2 presents annual waste volumes received at the three disposal facilities since passage of the 1985 LLRWPAA.

Due to the escalating costs of disposal and the requirement for long-term stability for some wastes, volume reduction and stabilization continue to play a large role in the management of low-level wastes. With regions and

TABLE 1-2. VOLUMES OF LOW-LEVEL RADIOACTIVE WASTE RECEIVED FROM 1985 TO 1987[1-3]
(cubic meters)

	Year		
Disposal Facilities	1985	1986	1987
Beatty, Nevada	1,389	2,668	9,413
Barnwell, South Carolina	34,389	29,612	27,057
Richland, Washington	40,131	18,833	15,763

states faced with the responsibility for management and disposal of their own low-level wastes in 1992, estimates of waste volumes and assurances of long-term stability of waste forms assume much greater importance.

In 1981, the NRC published a draft Branch Technical Position on Waste Form (BTP) to provide guidance on what constitutes stability. This draft BTP was upgraded to a final BTP in 1983[1-4] and became the basis for conduct of laboratory tests to determine stability. The BTP specifies procedures to determine waste form stability based on six testing conditions: compressive strength, leachability, water immersion, thermal stability, radiation effects, and biodegradability. The first of these, compressive strength, is conducted after each of the other tests (except leachability) to assure that the structural integrity of the waste form has not been compromised. Table 1-3 presents a summary of testing procedures and acceptance criteria in the 1983 BTP, and Appendix A contains specific information on waste-form and stability requirements extracted from the BTP.

TABLE 1-3. U.S. NRC WASTE FORM STABILITY ACCEPTANCE CRITERIA (Reference 1-4)

Test	Recommended Acceptance Criterion	Recommended Test Procedures
Compressive strength	Greater than 50 psi	ASTM C39 (ASTM D1074 for bituminous materials)
Radiation stability[a]	Greater than 50 psi after 10^8 rad exposure	
Leach resistance	Leach index greater than 6	ANSI 16.1 (90 days in demineralized water and synthesized sea water)
Immersion[a]	Greater than 50 psi after 90 days water immersion	90 days in demineralized water
Thermal[a] stability	Greater than 50 psi after 30 thermal cycles	ASTM B553
Biodegradation[a,b]	Negative observation of culture growth	ASTM G21, ASTM G22

a. Following each of these tests, the test specimen must demonstrate possession of a minimum compressive strength of 50 psi using the ASTM C39 procedure or the ASTM D1074 procedure for bituminous materials.

b. If growth is observed during ASTM G21 and G22 testing, long-term testing for at least six months using the Bartha-Pramer procedure must be conducted. The acceptance criterion for the long-term test is less than 10-percent loss of total carbon in the waste form based on extrapolated data for full-size waste form for 300 years.

1.5 Use and Limitations of Volume Reduction Data

Volume reduction hinges on three factors:

- o Waste type or stream
- o Process system
- o Solidification or stabilization technique.

While volume reduction (VR) factors, cost data, and performance figures presented in this manual are representative, special characteristics of specific wastes and process systems may give rise to factors outside the range of this more representative value. Cost data are similarly subject to many independently operating variables and should be used generically. Cost data presented in this report also reflect only relative costs at the time the report was compiled.

VR factors used in this report apply only to the single-component technology and are not necessarily additive when more than one component is assembled into a VR "system." For example, one VR system could include an evaporator and a cement solidifier. The VR factor for processing liquid wastes through an evaporator is approximately 30, but the output from the evaporator must be solidified, typically in cement. Cement solidification can increase waste volume by a factor of 1.3 to 1.5. Therefore, the overall VR factor for the system can be reduced to approximately 20. The presentation of VR factors in this manual is representative of the single component. VR factors for waste processing systems must take into consideration the combined effects of components.

One unique risk of a VR system is that when a total system accounting of treated waste volumes is performed, there may not be as great a reduction of waste volume as anticipated or represented in literature supplied by the vendor. Rather, the radioactivity in the resulting waste has been redistributed, and the waste's form and characteristics have changed. An example of such a system might include an incinerator. Most vendors predict at least a 50-to-1 reduction in waste volume through incineration, based on a comparison of feed-to-ash volumes. However, the requirements of 10 CFR 61.56 will likely require immobilization of the ash, which could almost double the final volume of ash.[1-5] VR systems to manage the ash therefore become important factors to consider.

1.6 Low-Level Waste Sources and Characteristics

The following section describes the sources and characteristics of low-level waste streams undergoing typical volume reduction and/or solidification prior to disposal at a commercial disposal site. In general, there are three major sources of low-level wastes:

- Power reactor operations
- Industrial and institutional activities
- Government research and defense activities.

The primary source of commercial low-level waste is from the operation of nuclear power reactors and fabrication of fuel for those reactors. Industrial manufacturers of radioactive materials and commercial research and testing institutions are the second major LLW source. Low-level waste from government research, defense programs, and weapon production are primarily the responsibility of the DOE and are handled, treated, and disposed of at DOE-owned facilities. These DOE waste streams are not subject to NRC or Agreement State licensing authority and are not discussed in this manual.

Commercial low-level waste streams exhibit highly variable physical, chemical, and radiological characteristics. Appendix A of this manual discusses power-reactor waste streams and waste streams from industrial and institutional generators.

1.7 Volume Reduction Economics

The two major incentives for volume reduction (VR) are economic considerations and regulatory requirements. These two incentives are closely related and include several important factors. The following section presents a brief overview of the subject. Suggested references on VR economics are contained in the annotated bibliography (Appendix B). Regulatory requirements are discussed in greater detail in Appendix A.

The economics of waste disposal depend upon many cost- and waste-related factors including the following:

- Waste production and processing rates
- VR factors for specific wastes
- In-plant operation and maintenance costs
  - Capital system costs
  - Personnel cost
  - Material cost
  - Energy cost
- Interim on-site storage costs
- Transportation costs (including cask charges)
- Disposal costs
  - Handling
  - Perpetual burial fees
  - Surcharges from disposal site operator
  - Surcharges from host state
- Annual cost savings
- Multiyear economic forecasts.

Since the 1970s, disposal costs have been increasing not only due to the increase in transportation and other operating costs, but also due to surcharges imposed on wastes generated outside of compacts with disposal sites. In view of this, incentives exist for generators and processors to invest in volume reduction systems. Since passage of the LLRWPAA new questions have surfaced: (a) what is the economic impact of changing the transportation distances for generators and processors from Barnwell, Richland, or Beatty to shorter distances for the state or regional compact disposal site? (b) what is the economic impact of changes in waste classification caused by application of VR technology? and (c) what is the impact of relatively small volumes of waste projected for several of the low-level waste compact regions?

1.7.1 Transportation

The location of a LLW disposal site directly affects transportation costs. At present there are three national disposal sites. Development of regional disposal capacity could effect a two- to five-fold reduction in transportation costs. As a result, economic forecasts of the advisability of investing in VR technology need to consider transportation distances in assessing overall costs/savings of a VR or stabilization system. The fixed operating costs of a new disposal site (including amortization of preoperating costs, direct operating costs, postoperating costs, interest, and income taxes) must be recovered regardless of the volume of waste disposed of. Whereas effective VR and regionalized disposal will combine to reduce waste transportation costs, the overall cost of disposal may decrease only slightly.

U.S. Department of Transportation and local load requirements can also affect the cost of transporting LLW. In some cases the application of VR techniques can consolidate a shipment of waste to the extent that additional shielding or containment is required. The cost of renting or leasing a shielded Type B package can be significantly more than the cost of renting a Type A package of similar capacity. Weight and load restrictions imposed by local authorities can also affect transportation costs by limiting acceptable hours and transport routes.

Another potential liability of VR is the concentration of radionuclides in the final waste form to be disposed of. The logical outcome of VR systems is higher concentrations of radionuclides and increased radiation levels. These higher radiation levels can result in higher transportation and disposal costs, as activity surcharges are now being imposed at Barnwell, and Type B packaging is considerably more expensive than Type A packaging.

1.7.2 Changes in Waste Classification

One significant economic factor to be considered when concentration levels of radionuclides are increased is the potential reclassification of the wastes from Class A to Class B or C (10 CFR 61.55). Potentially this increase in concentration can result in final waste products that approach or exceed Class C waste limits. Thus a generator may find that VR has resulted in greater than Class C (GTCC) wastes for which no current means of commercial disposal is available. In this situation, a decision must be made concerning dilution of the initial waste to assure disposal of the waste product. By diluting the waste, the generator accepts additional transportation and disposal costs and possible legal or waste-form constraints. The other alternative facing the generator of GTCC wastes is long-term storage of the waste until a disposal mechanism is available. This alternative may be constrained by restrictions imposed by regulators on allowable storage periods at a facility (Reference 1-5). These GTCC wastes may be allowed in a high-level waste repository, but an operating facility is at least a decade away. Cost allocation schedules for GTCC wastes have yet to be determined.

Just as VR techniques can increase concentrations of wastes, solidification of LLW using binder materials can decrease concentrations of waste. Bead resin materials, which by themselves are Class B wastes requiring stabilization, often revert to Class A stable waste upon solidification with a binder such as cement. The resulting solidified mass represents a greater volume of waste to be disposed at an additional cost.

1.7.3 Other Cost Considerations

Some disposal sites have imposed handling surcharges based on curie content and radiation levels in addition to the volume-based surcharges imposed by the host states.

In summary, each of the above cost factors need to be considered in determining the least expensive VR and waste management options available for each major waste type. Some vendors of shielded shipping casks and high-integrity containers have computerized economic programs that allow potential customers to analyze the many variables affecting VR and stabilization economics. (See Appendix B, Section 3.2 on economics for pertinent references.)

1.8 Vendor Disclaimer

Much of the information included in this manual was compiled from vendors' technical papers, promotional material, buyer guides, trade publications, and other generally available sources of up-to-date product information. Lists of vendors in this manual for a specific product or service are not necessarily complete. Inclusion in this manual of a vendor's name or product is not meant to constitute endorsement of the product or service. In addition, there is no warranty, express or implied, nor any legal liability or responsibility for the accuracy, completeness, or usefulness of any information supplied by a vendor or of any apparatus, product, or process discussed in this manual.

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2. BITUMEN SOLIDIFICATION

Bitumen (asphalt) has been used in Europe as a solidification agent for LLW for several decades, but only recently has it been used in the United States for solidification and stabilization of radioactive waste. Bitumen systems are considered to be both waste stabilization and volume reduction technologies, as the heat that is required to melt the bitumen assists in evaporating in liquid waste. This chapter focuses on bitumen systems in the United States and describes the performance of bitumen against the requirements of the NRC.

This chapter is divided into seven major sections. Section 2.1 provides a general description of bitumen, while Section 2.2 describes the various tests for performance. Section 2.3 is a summary and review of regulatory requirements. Section 2.4 provides technical details, with costs given in Section 2.5. Section 2.6 discusses bitumen as a solidification agent for mixed waste, and Section 2.7 lists vendors and users of bitumen solidification and stabilization technology.

2.1 General Description of Bitumen

Bitumen is a generic term for a thermoplastic material that softens at relatively low temperatures. Each type of bitumen has different physical characteristics depending on its chemical composition. Certain types of bitumen can soften to become a viscous fluid at room temperature; others require temperature as high as 300°C before exhibiting plasticity. Upon cooling, the latter material hardens into a monolithic semisolid. Chemically, bitumen is a mixture of high molecular weight asphaltene and malthene hydrocarbons. Asphaltene occurs at ambient temperatures as a black brittle solid with a high melting point. The hardness of bitumen is usually proportional to the asphaltene content. The malthene hydrocarbon component gives bitumen its viscous fluid properties. The NRC Branch Technical Position (BTP) on Waste Form refers to bitumen as a "viscoelastic" material based on its behavior under compressive loads (Reference 1-4).

Bitumen is a major by-product of the petroleum and coal-tar refining process as well as a naturally occurring material (e.g., "tar" pits). It has most commonly been used as an ingredient in road building materials or as a waterproofing material. The use of bitumen as a solidification agent in European nuclear power plants has provided plants in the United States with a relatively new, but proven, technology to consider.

In the United States, the first bitumen solidification system was installed in 1982 at the Consumer Power Company's Palisade Generation Station in South Haven, Michigan. Since then six other bitumen systems have been installed nationwide. Table 2-1 lists the location, plant type, and other data on these seven permanent bitumen systems.[2-1]

Bitumen does not react chemically with the majority of materials comprising low-level radioactive waste. Bitumen solidifies waste materials by entrapment within its structure, isolating the wastes from contact with water and providing structural stability. Advantages and disadvantages of bitumen as a solidification agent are presented in Table 2-2. The main advantages of stabilization using bitumen are its leach resistant characteristics, low operating cost, and handling ease. On the other hand, bitumen has several disadvantages. One disadvantage is that it does not perform well with certain dehydrated salts, such as sodium sulfate, sodium nitrate, magnesium chloride, and aluminum sulfate. When a dehydrated waste containing these salts is exposed to water, rehydration occurs, which could cause the solidified monolith to deteriorate. Another disadvantage of bitumen solidification is its high carbon content which may limit its resistence to biodegradation. The issue of biodegradation is still undergoing extensive laboratory testing.

During the solidification process, heat is required to melt bitumen into a viscous form to mix with the waste materials. The potential for fire resulting from vaporization of volatile organics caused by heating during the mixing process has been a major criticism of the use of bitumen as a solidification agent. Additionally, bitumen itself can have a low ignition temperature. Some types of bitumen can be ignited at temperatures as low as 315°C. The potential for burning of a bitumen-solidified waste during a

TABLE 2-1. BITUMEN SOLIDIFICATION SYSTEMS INSTALLED IN THE UNITED STATES (Reference 1-4)[a,b]

Location	Plant Type	No. of Extruder/ Evaporator Trains	Delivery/ Start-up Dates	Primary Wastes to be Processed
Bellefonte	Pressurized water reactors	1	1986/1987	Concentrates (sulfates and borates), bead resin, powdered resin
Seabrook	Pressurized water reactors	1	1984/1985	Concentrates, bead resin
Hope Creek	Boiling water reactors	2	1983/1987	Concentrates, bead and powdered resin, dry active wastes
Fermi 2	Boiling water reactors	1	1982/1987	Concentrates, bead and powdered resin
Palisades	Pressurized water reactors	1	1980/1982	Concentrates (primarily borates), bead resin, powdered resin
Mine Mile Pt. #2	Boiling water reactors	1	1980/1987	Concentrates, powdered resin, bead resin
Midland	Pressurized water reactors	1	1980/NA	Concentrates (primarily borates), bead resin

a. This listing is provided by Waste Chem, one of two active bitumen vendors. The other bitumen vendor, ATI (US Ecology) provides services through their mobile units. ATI has not installed any permanent systems as of this date.

b. Installed or contractually committed.

TABLE 2-2. ADVANTAGES AND DISADVANTAGES OF BITUMEN SOLIDIFICATION

Advantages	Disadvantages/Concerns
o Properties of bitumen are well known	o Bitumen is flammable and burns at temperatures as low as 315°C
o Compatible with most waste streams o Good leach-resistant characteristics	o Bitumen waste forms containing certain waste streams may swell and crack when exposed to water
o Low operating cost compared to other solidification agents o No free-standing water	o Exposure to heat can cause phase separation or liquification of the waste form
o Waste volume minimized during solidification process	o Solidification process requires elevated temperature
o High waste loading capability	o Initial capital costs are relatively high
o Operating experience in Europe	o Off-gas generation during processing
	o Low structural strength
	o Incompatible with some inorganic salts
	o Long-term biodegradability is of concern

transportation accident has also been of concern. Since the identification of this concern, overall planning and design of solidification systems using bitumen have been modified to minimize any potential fire hazard during the solidification process and transportation of the resulting waste. Apparent resolution has since been reached by some vendors and the regulatory agencies. Commercial bitumen solidification systems are currently available in mobile and permanent units.

Other operational difficulties with bitumen include the solidification of organic resins. These difficulties can be overcome by clay additives.[2-2] These additives also adsorb waste oils and organics that would otherwise prevent bitumen from hardening at room temperature. Additionally, clay helps retard flammability of bitumenized wastes. Clay sometimes is also used as an additive to further immobilize radionuclides such as Sr-90 and Cs-137 because of clay's adsorptive properties for these elements. Lastly, any bitumen-processing system used to evaporate liquids must not overlook the potential for generation of volatile organics that may be included in distillates. Potential for generation of volatile organics is minimized with the use of harder forms of bitumen (e.g., oxidized bitumen).

2.2 Performance Data

One of the favorable characteristics of bitumen is its insensitivity to most chemical compounds. As a result, it is compatible with most low-level wastes, and has been used for the solidification of a wide range of liquid, sludge, and semisludge wastes. Table 2-3 presents a list of reactor and nonreactor waste streams suitable for bitumen solidification.

The ability of bitumen to solidify waste streams is measured in terms of "weight percent waste loading" or "waste-to-binder ratio." Waste loading is the amount of waste that can be encapsulated in the waste form (by percent) to produce a stable monolithic solid. The amount of waste loading permissible for bitumen solidification varies according to waste stream composition, concentration, and types of additives contained in the bitumen. Data obtained on waste form samples that have successfully met

TABLE 2-3. LOW-LEVEL WASTE STREAMS COMPATIBLE WITH BITUMEN SOLIDIFICATION

Reactor Waste Streams	Nonreactor Waste Streams
o Floor drain	o Uranium and thorium metal shavings
o Boric acid (pressurized water reactor concentrates)	o Incinerator ashes
o Deep bed resin[a]	o Others[b]
o Powdered resin	
o Decontamination solution	
o Filter sludge	
o Sodium sulfate (boiling water reactor regenerates)	
o Others[b]	

a. Deep bed resin includes cation and anion bead resins and mixed bead resins.

b. Compatibility of these waste streams with bitumen solidification is determined on a case-by-case basis.

acceptance criteria of the BTP testing procedures indicate that the range of waste loading factors is between 50 to 60 percent by weight for boiling water reactor (BWR) and pressurized water reactor (PWR) evaporator concentrates, 45 to 50 percent by weight for filter media and powdered and beaded resins, and approximately 30 percent by weight for decontamination solutions.

Most waste solidification processes increase the final waste volume because of the added binding material required during solidification. Bitumen solidification however does not require the presence of water; in fact, water content of liquid waste streams is removed during the solidification process. This achieves a relative reduction in the volume of waste generated compared to other systems, such as cement, which require the use of water. Laboratory tests reported a volumetric efficiency of the bitumen process ranging from 2 to 3, indicating 50 to 60 percent volume reduction. Volumetric efficiency is defined as the ratio of input waste volume to the final waste form volume. For waste streams containing low concentrations of solids, volumetric efficiencies have been recorded as high as 7 to 8. Most other solidification processes achieve a volumetric efficiency of less than 1.

Over the past couple of decades, the performance of bitumen as a solidification agent has been extensively tested in several European countries. Most of these test results indicate bitumen is an acceptable solidification agent. In the U.S., limited laboratory testing of bitumen began in 1976.

Since publication of the BTP (see Section 1.4), extensive field and laboratory tests have been conducted by vendors to demonstrate performance of their products to the waste generators and regulators. The performance of bitumen products was tested and evaluated in accordance with acceptance criteria recommended in the BTP. These test results revealed that all of the bitumen waste forms met the NRC acceptance criteria. Results of those tests are presented in licensing topical reports[a] for NRC review and approval. Documentation demonstrating the safety and effectiveness of waste processing systems and stabilization agents intended for use at nuclear power plants is accomplished through the NRC's topical report process. Once the NRC approves a topical report submitted by a vendor for a product, the product can be used subject to specific licensing approval for each facility. Three waste processing systems designed for use with bitumen have been approved by the NRC and are listed in Table 2-4. The NRC review of the safety aspects of the processing system is separate from the NRC review of the ability of the final waste form to meet stability requirements defined by the BTP. This review is similarly carried out through the topical report process. For a nuclear power plant to be able to use bitumen, it must be approved to use both the system (hardware) and the stabilization agent. Table 2-5 lists topical reports the NRC has approved for bitumen as a stabilization agent. A brief review of the performance of bitumen solidified waste against the BTP criteria follows.

2.2.1 Leachability Test

Typically, wastes solidified using bitumen with 50 percent waste loading have a range of leachability indices[b] from 8 to 14.[2-3] These results are well above the NRC's recommended minimum leachability index of 6. During early laboratory leaching tests, a number of sodium sulfate waste samples solidified with bitumen failed the leachability test after the

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a. The regulatory process associated with the NRC review of licensing topical reports is discussed further in Appendix A.

b. Leachability index is an index value that characterizes the leaching of radionuclides from a material under a given set of conditions. This index value is determined by the leaching test procedure defined in ANS 16.1.[2-5] The NRC requires all stable wastes to possess a leachability index of greater than 6.

TABLE 2-4. REGULATORY REVIEW STATUS OF BITUMEN PROCESS SYSTEMS[2-4]

Vendor	System Type	Report No.	Status
WasteChem (Werner & Pfleiderer)	Bitumen solidification	WPC-VRS-1	Approved
Associated Technologies, Inc. (U.S. Ecology)	Bitumen solidification	ATI-VR-001	Approved
JGC, Corp.	Bitumen solidification	JGC-TR-001	Approved

TABLE 2-5. REGULATORY REVIEW STATUS OF BITUMEN WASTE FORMS (Reference 2-4)

Vendor	System Type	Report No.	Status
WasteChem (Werner & Pfleiderer)	Bitumen	WM-90	Approved
Associated Technologies, Inc. (US Ecology)	Bitumen	WM-91	Discontinued[a]

a. The NRC expects ATI to resubmit its report. Existing uses of the material may continue until a final determination is made by the NRC.

samples had been immersed in water for 7 to 10 days. Cause of the failure was partly attributed to the incompatibility between dehydrated inorganic salts and bitumen and partly due to the overloading of the solidification medium with waste. This is of concern because the most commonly generated inorganic salt waste is sodium sulfate waste, the result of regenerating spent resins. Future volumes of sodium sulfate wastes may decrease to negligible amounts, however, since many waste generators have modified their waste processing systems to use disposable resins. Consequently, the issue of incompatibility of bitumen with sodium sulfate waste may not greatly affect the usefulness of bitumen as a general solidification agent.

2.2.2 Compressive Strength Test

Since bitumen is a thermoplastic (viscoelastic) material, it flows (albeit slowly) or creeps under pressure at ambient room temperature. The range of tested compressive strength of bituminous waste form samples are generally lower than other waste forms. The documented results show a range of compressive strength between 55 psi and 300 psi. The oxidized type of bitumen exhibits higher compressive strength.

2.2.3 Immersion Test

The immersion test is one of the most severe stability tests required in the BTP. Since it is the most severe test, it is often used by vendors to determine the maximum possible loading capacity for a specific waste stream to demonstrate the compatibility and cost-effectiveness of a stabilization medium. Effects of water immersion on the sample of stabilized waste are determined by the sample's ability to maintain a post-test compressive strength of greater than 50 psi. Results of vendor tests confirmed that water immersion can have a severe impact on the structural strength of bitumen waste-form samples. On the average, the test showed a decrease of compressive strength between 10 and 50 percent. However, all but two of the samples presented in the vendor licensing topical reports met the NRC acceptance criterion of greater than 50 psi. The loss of compressive strength was directly proportional to the increase in the amount of waste loading.

2.2.4 Radiation Effects Test

All samples of waste stabilized using bitumen performed well during radiation testing, as indicated by vendor testing data. Post-test compressive strengths of the samples remained unchanged when compared to pre-test strength. These results indicate that radiation has little or no effect on waste stabilized using bitumen.

2.2.5 Thermal Stability Test

The NRC requires waste-form samples to be subjected to 30 cycles of extreme temperature fluctuation between +60°C and -40°C. The NRC acceptance criterion for thermal stability is a post-test compressive strength of greater than 50 psi. A review of laboratory and vendor test data supported the conclusion that temperature cycling has no effect on bitumen-stabilized waste forms.

2.2.6 Biodegradation Test

One area of concern regarding bitumen is its potential susceptibility to biodegradation due to its high carbon content. Initial biodegradation tests detected bacterial and/or fungal growth on some test samples. Bitumen vendors, in accordance with the requirements of the BTP, are conducting long-term tests to determine the effects of this growth on the stability of the waste form.

In summary, the performance of bitumen in the tests prescribed in the BTP indicates that bitumen is a good stabilization agent for most low-level waste streams. However, its potential application to wastes other than those reported in the vendors' topical reports must be evaluated on a case-by-case basis for the following reasons:

- Bitumen, when mixed with certain organic compounds, becomes less viscous

- Waste streams containing oxidants such as nitrate salt may present a fire and explosive hazard when mixed with bitumen

- Heating of the other waste/bitumen mixture during the solidification process may pose a safety hazard that needs consideration, e.g., anything that is capable of evolving a volatile organic.

2.3 Regulatory Requirements and Review

The NRC requires that Class B and C wastes, or Class A wastes to be disposed of with Class B and C wastes, comply with the requirements of 10 CFR 61.56(a) and (b) for waste-form characteristics and stability. The BTP contains the testing requirements for demonstrating waste form stability. A process control program (PCP) is also needed to periodically monitor and control the consistency of the resulting waste products. In addition to stability requirements, the waste solidification processing systems are required to meet the requirements of 10 CFR 20, Occupational Safety and Health Act (OSHA) regulations, and other appropriate environmental regulations. If the processing system is installed at a nuclear power plant or connected to the gaseous release system of a nuclear power plant, the design of the solidification system must also satisfy the pertinent regulations and regulatory guides of 10 CFR 50. (Appendix A contains a listing of regulatory pertinent requirements.)

Three vendors have submitted topical reports to the NRC on bitumen processing systems (Table 2-4). Two vendors have submitted topical reports on bitumen as a solidification agent (Table 2-5). One of these two reports has since been withdrawn by the vendor, but is expected to be resubmitted. All three of the operating low-level waste disposal sites currently recognize that the oxidized form of bitumen meets the stability requirements of 10 CFR 61. The State of Washington (Richland disposal site) allows the use of nonoxidized bitumen as a solidification agent for wastes that are not required to be stabilized.

2.4 Technical Details

2.4.1 Types of Bitumen

There are five generic types of bitumen, each with its own distinct physical and chemical characteristics. The five major types are direct-distilled bitumen, oxidized bitumen, cracked bitumen, emulsified bitumen, and pitches. Direct-distilled bitumen and oxidized bitumen are the two types of bitumen used for waste solidification. Direct-distilled bitumen is also sometimes called nonoxidized bitumen. It is the direct residue from distillation of petroleum. For this reason, direct-distilled bitumen usually contains a fair amount of volatile compounds and is highly flammable. It does not maintain good compressive strength and has a low softening temperature (34°C to 65°C). It can be used to solidify, not stabilize, LLW for shipment to the Richland, Washington, disposal site. The only type of bitumen allowed as a stabilization agent in the United States is oxidized bitumen. Oxidized bitumen is a harder material than the direct-distilled bitumen. It has good compressive strength and is formed by blowing hot air at approximately 300°C through certain petroleum residues. Among the various types of bitumen, it has the highest softening temperature, 70°C to 140°C, and temperature fluctuations usually have little effect on the material. The other three types of bitumen (cracked bitumen, bitumen emulsion, and pitches) are not used as solidification agents because of their tendency to remain in liquid form at ambient room temperature.

2.4.2 Bitumen Solidification Processes

There are five basic methods for solidifying waste with bitumen. Of the five methods, only two are used for commercial application in the U.S. Currently, oxidized bitumen is used with the screw-extruder process, and the direct-distilled (nonoxidized) bitumen is used with the thin-film evaporator process. The other methods--the stirred bitumen process, the temporary emulsion process, and the sedimentation process--are either available only in Europe or are in the experimental stage. In addition to the five basic processes, there are other types of stand-alone specialty equipment such as the intensive dryer/mixer or blender/mixer. These perform essentially the same function as the screw-extruder and thin-film evaporator, which is to mix waste solids with bitumen and to remove any water content in the waste stream. Sometimes these specialty systems are also used as preprocessors to bring wet waste streams to total dryness to assure proper waste encapsulation.

The two commercial systems, the screw-extruder method and the thin-film evaporator, are described below. Additional information on evaporators can be found in Chapter 5 of this manual.

2.4.2.1 Screw-Extruder. The screw-extruder system is designed to allow excess water in the waste to be evaporated during the mixing process. The extruder uses a twin-screw design similar to that used in the plastics industry. In this process, the bitumen and the wet solid wastes are pumped into one end of the extruder, which spreads the waste binder mixture into a thin film onto a heated surface of the extruder barrel. Large solid wastes are finely ground, thoroughly coated with bitumen, and homogeneously dispersed throughout the binder material. The surface of the barrel is usually heated to about 170°C, which effectively vaporizes any excess water in the waste to produce a homogeneous viscous waste and bitumen mixture. The evaporated water is directed into a condensate system for recirculation or release into the environment after treatment. The mixture goes directly into drums for cooling and disposal.

2.4.2.2 Thin-Film Evaporator Process. The thin-film evaporator process utilizes a thin-film evaporator, which operates at a temperature high enough to result in the evaporation of water from liquid and solid waste streams.

Waste and molten bitumen are simultaneously metered into the top of a vertical thin-film evaporator where the mixing and evaporation take place simultaneously. Motor-driven rotor blades spread a thin film of waste and bitumen on the heated interior surface of the evaporator, resulting in evaporation of water in the waste. The dry waste residue particles and bitumen are mixed by the action of the rotating blades. The combined mixture is directly discharged from the bottom of the evaporator into the burial containers. Solidification of the waste mixture occurs within the burial container as the bitumen cools.

In a production line version of this process, the drums are filled in one operation and then allowed to cool. If required, more of the bitumen mixture can be added until the drum is completely filled. In this production process, drums are usually mounted on a turntable or conveyor to allow a continuous operation that includes filling, cooling, sealing, monitoring for surface dose rate, and removal of the waste package to storage or disposal.

2.5 Cost

The cost of solidifying radioactive waste with bitumen is about $60 per cu ft for small volumes and $75 per cu ft for large volumes regardless of the waste stream and concentration level.[2-6] Permanent systems are available through one of the two U.S. vendors (WasteChem) in various models. Each model has its own processing capacity and flow rates. The purchase price for a single permanent unit ranges from $1 million to $3 million. The other U.S. vendor (ATI) offers only services provided through their mobile units. The third vendor (JGC) has not submitted a topical report for its solidification agent.

2.6 Mixed Waste

Oxidized bitumen is a potential solidification agent for treating some aqueous mixed or hazardous wastes due to its VR and encapsulation properties. However, its potential application for other wastes must be evaluated on a case-by-case basis since its compressive strength is reduced with certain organic compounds and since mixing with nitrates, oxidants, and volatile organics may cause a safety hazard.

2.7 Vendors and Users

Below are lists of selected vendors and users of bitumen solidification systems.

Vendors:

(1) WasteChem Corp.
1 Kalisa Way
Paramus, NJ
(201) 599-2900

(2) Associated Technologies, Inc.
212 S. Tryon
Charlotte, NC
(704) 376-5752

(3) JGC Corp.
2-1, 2-chrome Ohtemachi, Chiyoda-ku
Tokyo, Japan
03/279-5441

Users:

(1) WasteChem Corp.

Consumers Power Company
Palisade Generation Station
2770 Blue Star Memorial Highway
Covert, MI 49043
(616) 764-8913

Public Service Electric and Gas
Hope Creek Station
P.O. Box A
Hancock's Bridge, NJ 08038
(609) 935-7400

Niagara Mohawk Company
Nine Mile II Station
P.O. Box 63
Lycoming, NY 13093
(315) 349-2110

Detroit Edison Company
Fermi 2 Station
6400 North Dixie Highway
Newport, MI 48166
(313) 586-4000

New Hampshire Yankee
Seabrook Station
P.O. Box 700
Seabrook, NH 03874
(603) 474-9521

Tennessee Valley Authority
Belefonte Station
P.O. Box 2000
Hollywood, AL 35752
(205) 259-1324

(2) Associated Technologies, Inc.

Duke Power Company
P.O. Box 33189
432 South Church Street
Charlotte, NC 28242
(704) 373-4732

Illinois Power Company
Clinton Nuclear Station
RR3, Box 228
Clinton, IL 61727
(217) 935-8881

Arizona Power Company
Palo Verde Station
P.O. Box 49
Palo Verde, AZ 85343
(602) 386-4476

Commonwealth Edison
Dresden Station
RR1
Morris, IL 60450
(815) 942-2920

2346K

3. CEMENT SOLIDIFICATION

Cement is the most commonly used solidification agent for stabilizing radioactive wastes. In early LLW applications cement was used only to solidify liquids or to provide shielding for solid waste. Subsequent to promulgation of 10 CFR 61, vendors developed special additives to adjust the setting characteristics of cement, allowing its use with dispersible solids and specific waste streams. The additives also improved waste-loading efficiency. The resulting cement-based waste products can meet the stability requirements of 10 CFR 61 with a broad range of wastes. This chapter describes cement-stabilization technology, how it compares with the NRC's requirements for a stable waste form, and provides information on its costs and usage.

This chapter is divided into seven major sections. Section 3.1 provides a general description of cement, while Section 3.2 describes the various tests for performance. Section 3.3 is a summary and review of regulatory requirements as they pertain to cement-stabilization technology. Section 3.4 provides technical details, with costs given in Section 3.5. Section 3.6 discusses cement as a solidification agent for mixed waste, while Section 3.7 lists the vendors and users of cement-stabilization technology.

3.1 General Description

Cement is the generic term used for inorganic materials that are used to bind together sand, stones, or other materials in order to make an artificial rock-like material (free-standing monolith). Concrete consists of larger aggregates with or without fine materials, bound together by cement. This chapter concerns the use of cement.

Cement solidifies liquid radioactive waste by both chemical reaction (hydration) and physical encapsulation of the waste. It is the hydration reaction that causes cement to harden into a free-standing monolith. As cement cures, free water in the cement mixture is chemically bound until essentially all the water is incorporated into the hardened matrix. Three general types of cement can be used to solidify LLW: Portland, gypsum, and masonry cements.

Cement was one of the first materials considered for low-level waste solidification because of its long history of documented performance. It is inexpensive and readily available. It has reasonably good leach-resistant characteristics and is compatible with most wastes. It possesses reasonably high compressive strength to meet all six BTP stability criteria.

Table 3-1 presents an overview of the advantages and disadvantages of cement solidification technology.

Cement is an alkaline medium and is highly sensitive to the pH of the final mixture. Cement mixtures will not cure if the pH is too low. Although cement itself is quite effective in raising the pH of most wastes, its capability to do so is limited, particularly with highly acidic wastes. Additives such as lime are often used to raise the pH of the waste prior to mixing with cement. Typical power plant radioactive waste streams with low pH include boric acid wastes (PWRs) and carbonic wastes. Untreated detergent wastes, oils, and other organic liquids can also be difficult to solidify with cement because they tend to coat the cement particles and prevent them from interacting with water required for the hydration process. They can be solidified, however, with a gypsum cement and emulsifier.

Cement has been successfully used to solidify most of the waste streams generated from nuclear power plants, and can be used to solidify most of the liquid wastes generated by industry and institutions. There are numerous commercial cement solidification systems available on the market. Some of these systems have been designed to be permanently installed as part of the radioactive waste processing system at nuclear power plants, while others are mobile systems that provide services on a contract basis. These mobile systems are either skid mounted or truck mounted for transport to designated locations.

TABLE 3-1. ADVANTAGES AND DISADVANTAGES OF CEMENT SOLIDIFICATION

Advantages	Disadvantages/Concerns
o Simple mixing process	o pH sensitive
o Compatible with most waste types	o Excessive heat generation during setting
o Good structural strength	o Increased waste volume
o Good self-shielding	
o Low leachability for most radionuclides	o Maintenance problems with dust control, powder feeding system, and premature cement setting
o Abundant availability	o Heavy waste product
o Low cost	
o Long history and good performance record	
o Process system available in both in-container and in-line mixing	

3.2 Performance Data

In general, most liquid, sludge, or semiliquid low-level wastes can be solidified with cement. Typically, cement must be mixed with a sufficient quantity of water at a ratio of approximately 4 to 1 by weight to form a workable mixture (i.e., 4 parts of cement by weight to 1 part of water). The performance characteristics of a cement-solidified waste product depend on the cement type, the waste characteristics, the waste to cement ratio (i.e., percentage of waste-loading), and the proprietary additives used. For these reasons, a process control program (PCP) and test batches for each identifiable waste product are required for users of approved products, and full-scale testing is required by users of products not generically approved by the NRC or the applicable Agreement State.

Cement systems are often used to solidify bead resin materials. These resin materials cannot be added, however, in the same proportions as nonresin wastes because the resultant product can swell and crumble during the immersion tests required by the BTP. Table 3-2 presents a listing of low-level waste streams that can be solidified with cement with a high degree of confidence.

While early laboratory test data have shown that cement is capable of achieving a waste loading factor as high as 75 percent by weight for some aqueous wastes, the range of the average waste loading factor presented in the topical reports submitted to the NRC by vendors is between 47 and 52 percent by weight for all waste streams and contamination levels. Volume efficiency of cement-solidified waste forms range from 0.7 to 0.9, indicating a 10 to 30 percent increase in volume.

Waste-form products solidified by cement have generally performed well against all of NRC's BTP stability criteria. A summary of the BTP acceptance criteria and test requirements were discussed in Section 1.4. A more detailed discussion on the NRC waste-form stability requirements is presented in Appendix A. The six BTP-recommended tests for determining waste-form stability are compressive strength, leachability, water immersion, thermal stability, radiation effects, and biodegradability. The compressive strength test is conducted after each of the other tests (except

TABLE 3-2. LOW-LEVEL WASTE STREAMS COMPATIBLE WITH CEMENT SOLIDIFICATION

Reactor Waste Streams	Nonreactor Waste Streams
o Floor drains	o Tritiated water
o Sodium sulfates (boiling water reactor concentrates)	o Uranium and thorium metal shavings
o Boric acid (pressurized water reactor concentrates)	o Incinerator ashes
o Deep bed resin[a]	o Others[b]
o Powdered resin	
o Decontamination solution	
o Filter sludge	
o Filter cartridge	
o Others[b]	

a. Deep bed resin includes cation and anion bead resins and mixed bead resins.

b. Compatibility of these waste streams with cement solidification is determined on a case-by-case basis.

leachability) to assure that the structural integrity of the waste form has not been compromised. A brief review of the performance of waste solidified with Portland cement versus the six BTP stability criteria follows.

3.2.1 Compressive Strength Test

The nominal compressive strength of cement is in the range of 1,000 to 2,000 psi. Cement can, however, attain compressive strength as high as 5,000 psi by adding less water to the mixture. A review of vendor test data shows that wastes stabilized using cement possess compressive strengths ranging from 130 to 3,700 psi depending on waste stream types and waste loading factors.

3.2.2 Leachability Test

The leachability indices[a] for cement-solidified waste forms range from 6.5 to 8.5. Although these leachability indices are not as good as those tested for bitumen and polymer systems, they are adequate to meet the NRC required minimum of 6.

3.2.3 Immersion Test

As discussed in Section 2.2, the NRC's acceptance criterion for a waste form is its ability to maintain a post-test compressive strength of greater than 50 psi. The water immersion test procedure requires a sample of the waste to be submerged in demineralized water for a minimum of 90 days. A survey of vendor test results indicates that water immersion has little or no impact on the structural stability of cement-solidified waste samples. All of the samples tested exhibited compressive strengths from 200 psi to over 2,000 psi. In fact, the compressive strength of some of the waste forms increased due to rehydration.

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a. The leachability index is an index value that characterizes the leaching of radionuclides from a material under a given set of conditions. This index value is determined by the leaching test procedure defined in ANS 16.1 (Reference 2-5). The NRC requires all stable wastes to possess a leachability index of greater than 6.

3.2.4 Thermal Stability Test

A review of the test data showed that the post-test compressive strengths of all cement waste forms remained unchanged compared to the pre-test strengths. These test results indicate that temperature fluctuations have negligible effects on the structural strength of cement waste forms.

3.2.5 Radiation Effects Test

The BTP requires that all solidified waste form samples be subjected to 10^8 Rads of radiation. The BTP's radiation stability acceptance criterion is a post-irradiation compressive strength of greater than 50 psi. The evaluation of radiation effects on cement waste forms was not conclusive, although all test data met the BTP acceptance criterion. It is generally observed that extremely high levels of radiation, such as those required in the BTP procedure, can cause deterioration of encapsulated organic ion-exchange media and reduce the overall structural strength of the cement samples. Most of the organic ion-exchange media generated in nuclear power plants contain much lower levels of radioactivity, and so these test results have not prohibited the use of cement for solidifying organic ion-exchange media wastes.

3.2.6 Biodegradation Test

None of the samples of waste solidified with cement exhibited signs of bacterial or fungal growth.

The above test results apply only to Portland cement. Commercial formulations using gypsum, in general, do not perform as well when tested against the six BTP stability criteria. Commercial formulations using gypsum work best with oil and organic waste streams, wastes not well suited to solidification with Portland cements. Test data on gypsum waste forms (oil and organic wastes solidified with gypsum) are limited and are not available for discussion here. Masonry cement is used for specialty applications and performance test data are extremely limited.

In summary, the major advantages of cement are low cost, abundant availability, and adaptability to various waste types and disposal environments (Reference 2-3).

3.3 Regulatory Status

As discussed previously, wastes containing Class B or Class C wastes, or Class A wastes disposed of with Class B or C wastes, must satisfy the waste characteristic and stability requirements of 10 CFR 61, specifically 10 CFR 61.56(a) and 10 CFR 61.56(b). The solidification systems must also meet the requirements of 10 CFR 20, OSHA regulations, and other appropriate environmental regulations. Additionally, if the processing system is installed at a nuclear power plant in conjunction with other processes (such as incineration where flue gas is released through the gaseous processing system at a nuclear power plant), the design of the solidification system must also satisfy the pertinent portions of 10 CFR 50 and the regulatory guidance stemming from the regulations (e.g., regulatory guides, draft regulatory guides, industrial codes) (Appendix A).

The NRC, in their topical report review process, considers the solidification agent and the processing system separately, even though processing systems and products may not be interchangeable. The NRC has reviewed the topical reports for seven process systems that use cement as the solidification agent (Table 3-3). Three additional systems are currently under review. Topical reports on five cement solidification agents have also been submitted by four vendors (Table 3-4). Most of the vendors' name-brand cements contain proprietary additives to enhance performance and waste loading ability. As shown, none of the cement products has been documented sufficiently for NRC approval under 10 CFR 61. The NRC and the Agreement States, based on acceptable past performance, have granted interim approval to specific cement-based products until specific approvals by the NRC have been denied or granted. These cement products are as follows:

TABLE 3-3. REGULATORY REVIEW STATUS OF CEMENT PROCESSING SYSTEMS
(Reference 2-4)

Vendor	System Type	Report No.	Status
Hittman Nuclear	Cement solidification	HN-R1109	Approved
Atcor	Cement solidification	ATC-132	Approved
Atcor	Cement solidification	ATC-8019-1	Approved
Chem-Nuclear	Cement solidification	4313-01354	Approved
LN Technologies	Cement solidification	PS-53-0378	Approved
UNC	Cement solidification	UNC-S-8000	Approved
Bartlett	Cement solidification	BN-1	Approved
Nuclear Packaging	Oil/cement	TP-03	Under review
Nuclear Packaging	Cement/portable	TP-04	Under review
Nuclear Packaging	Cement/encapsulation	TP-06	Under review
Nuclear Packaging	Cement	TP-01	Withdrawn
Nuclear Packaging	Cement	TP-05	Withdrawn

TABLE 3-4. REGULATORY REVIEW STATUS OF CEMENT WASTE FORMS
(Reference 2-4)

Vendor	Waste Form Type	Docket No.	Status
Vikem	Cement/oil waste	WM-13	Discontinued
Nuclear Packaging	Cement/gypsum	WM-71	Withdrawn
Chem-Nuclear	Cement	WM-19	Withdrawn[a]
Chem-Nuclear	Cement	WM-96	Withdrawn[a]
Chem-Nuclear	Cement #1	TBD	Under review
Chem-Nuclear	Cement #2	TBD	Under review
Chem-Nuclear	Cement #3	TBD	Under review
LN Technologies	Cement	WM-20	Under review
Hittman Nuclear	Cement	WM-46	Under review
Hittman Nuclear	Cement (SG-95)	WM-79	Withdrawn[a]
Stock	Cement	WM-92	Discontinued[a]
U.S Gypsum (Envirostone)	Gypsum	WM-51	Approved[b]

a. Actions completed in calendar year 1988.

b. Approved for single waste stream for one year.

- o Chem-Nuclear cement
- o Envirostone
- o LN Technologies cement
- o Hittman Nuclear cement.

Use of a cement solidification system and cement solidification agent requires a process control program to periodically monitor the consistency of the waste feed materials and the resulting waste products.

Cement is often used as a stabilization medium to encapsulate small sealed sources requiring stabilization prior to disposal. In this application, the material to be stabilized is placed into a disposal container, and the cement mixture is poured around the waste, taking care to center the waste, usually a sealed source, in the container. The BTP on waste classification allows the concentration of wastes containing small sealed sources to be calculated taking into account the volume or weight of any stabilizing agent. Averaging over a container larger than a 55-gallon drum is generally not allowed. When used as an encapsulating medium in this type of application, concrete (cement with aggregate) can also be used.

3.4 Technical Details

3.4.1 Types of Cement

Cements that have been used for waste solidification are Portland cement, masonry cement, and gypsum. Portland cement is the most common type of cement and is used extensively in construction. Masonry cement is designed for plasticity and is generally used for grouting purposes. Gypsum, also known as "plaster of paris," is a carvable material often used for molding purposes. Plastic (polymer and monomer) additives to these cements form products often referred to as poly-impregnated cement. The additives chosen can affect the leaching characteristics of the cement product. The following briefly discusses the three common types of cements used for low-level radioactive solidification.

3.4.1.1 Portland Cement. Portland Cement is the most common type of cement and was the original solidification agent used for radioactive wastes. Portland cement is produced by calcining clay and limestone at high temperatures, resulting in the following components: dicalcium silicate, tricalcium silicate, tricalcium aluminate, and tetracalcium alumina ferrite.

Adjusting the quantities of these components or introducing additives to Portland cement can change the strength, setting time, amount of heat generated during setting, and the cement's resistance to shrinkage. There are five types of Portland cement with well-defined properties designated as Types I to V (ASTM standard C150). Type I cement is a general-purpose cement. Type II cement is a slow-setting, sulphate-resistant cement and produces only a moderate amount of heat during setting. Type III cement is fast-setting, with high compressive strength, but generates significant heat during setting. Type IV is a slow-setting cement with low heat generation. Type V cement is highly resistant to sulfate and is generally used in marine environments. The choice of cement is highly dependent upon the waste to be processed. Most vendors consider their formulations to be proprietary.

3.4.1.2 Masonry Cement. Masonry cement, or high lime cement, is a variation of Portland cement in which Portland cement is mixed with equal portions of slaked lime. Masonry cement has high plasticity, which makes it more workable. The setting process for masonry cement is similar to that of Portland cement. In the presence of water, the high alkalinity introduced by the slaked lime produces a rapid setting effect. It is best suited to some waste streams that are difficult to solidify with Portland cement. Masonry cement has been used for the solidification of waste containing boric acid or borated salts. The bulk density of masonry cement is about 35 percent less than that of Portland cement, thereby allowing the encapsulation of greater waste volume than Portland cement. Masonry cement was one of the many types of cement tested during early laboratory development of waste solidification agents and is particularly known for its water-retention capacity. While this characteristic makes masonry cement capable of producing a final waste without any free-standing liquid, the same characteristic limits the performance of masonry cement in the immersion test. Other than the specialty application indicated, masonry cement generally does not perform as well as Portland cement. Because of its performance and limited application, masonry cement has not been actively pursued for development into a commercial product. Therefore, stability performance test data on this solidification agent are limited.

3.4.1.3 Gypsum. Gypsum, a category of cement, has also been used as a solidification agent. A gypsum product is manufactured and marketed by U.S. Gypsum Company under the trade name of Envirostone. Gypsum is a finely ground, nonflammable powder that, when mixed into liquid waste, forms a solid cast with no free-standing liquid. Envirostone consists of a calcium sulfate semihydrate binder in conjunction with a polymer. The purpose of the polymer is for interstitial sealing of the waste form to inhibit the infiltration of water into the waste form. It performs best when wastes are in neutral or acidic pH range. It is well suited for the solidification of boric acid wastes but is poorly suited to alkaline wastes due to excessive curing times. Acidic chemicals are often added to assure proper solidification of alkaline waste stream mixtures. U.S. Gypsum reports that Envirostone also performs well for the solidification of spent resins and oils.

3.4.2 Processing Techniques

In general, there are two types of mixing processes: in-container mixing and in-line mixing. In-container mixing processes involve mixing the wastes and solidification agent inside the disposable containers. In-line mixing involves mixing of the solidification agent and wastes before transferring the mixture into individual containers for disposal. Specialty equipment is also available that can process wet solids wastes to remove any moisture from the waste stream prior to mixing with cement for solidification.

3.4.2.1 In-Container Mixing Technique. The techniques and sequences for in-container mixing of waste with the cement binder vary from system to system. There are three general types of in-container mixing techniques: in-drum passive mixing, mixing with a reusable mixer, and mixing with a disposable mixer. These are discussed below.

- In-drum passive mixing involves pouring the cement and liquid wastes into a disposable container in their proper proportions. The container is then capped and sealed either with or without a mixing weight. The mixing weight can be a simple steel rod or several metal ball-bearings. The container is then tumbled from end to end for a prescribed number of times to ensure that the compounds inside the container are thoroughly mixed. A schematic diagram showing a typical in-drum passive mixing system is presented in Figure 3-1.

- Mixing with a reusable mixer is conducted inside the container using a mixing rod welded to the motor. After mixing is complete, the mixer is retracted from the container. The cement and waste mixture is then left to set. The container is capped and sealed after the waste form has hardened, and the mixer is reused in other containers.

- Mixing with a disposable mixer is conducted inside the container using a disposable mixing rod connected to a motor located outside the container. After mixing is complete, the disposable mixing rod is left in the container. The cement and waste mixture is then left to set. The container is capped and sealed after the waste form has hardened.

3.4.2.2 In-Line Mixing Technique. Generally in-line mixing requires the wastes and solidification agents to be added to a mixing vessel, where they are thoroughly mixed before being poured into individual containers. In-line mixing systems are designed to operate in a batch or continuous mode, connected to receive waste streams directly from the plant's waste

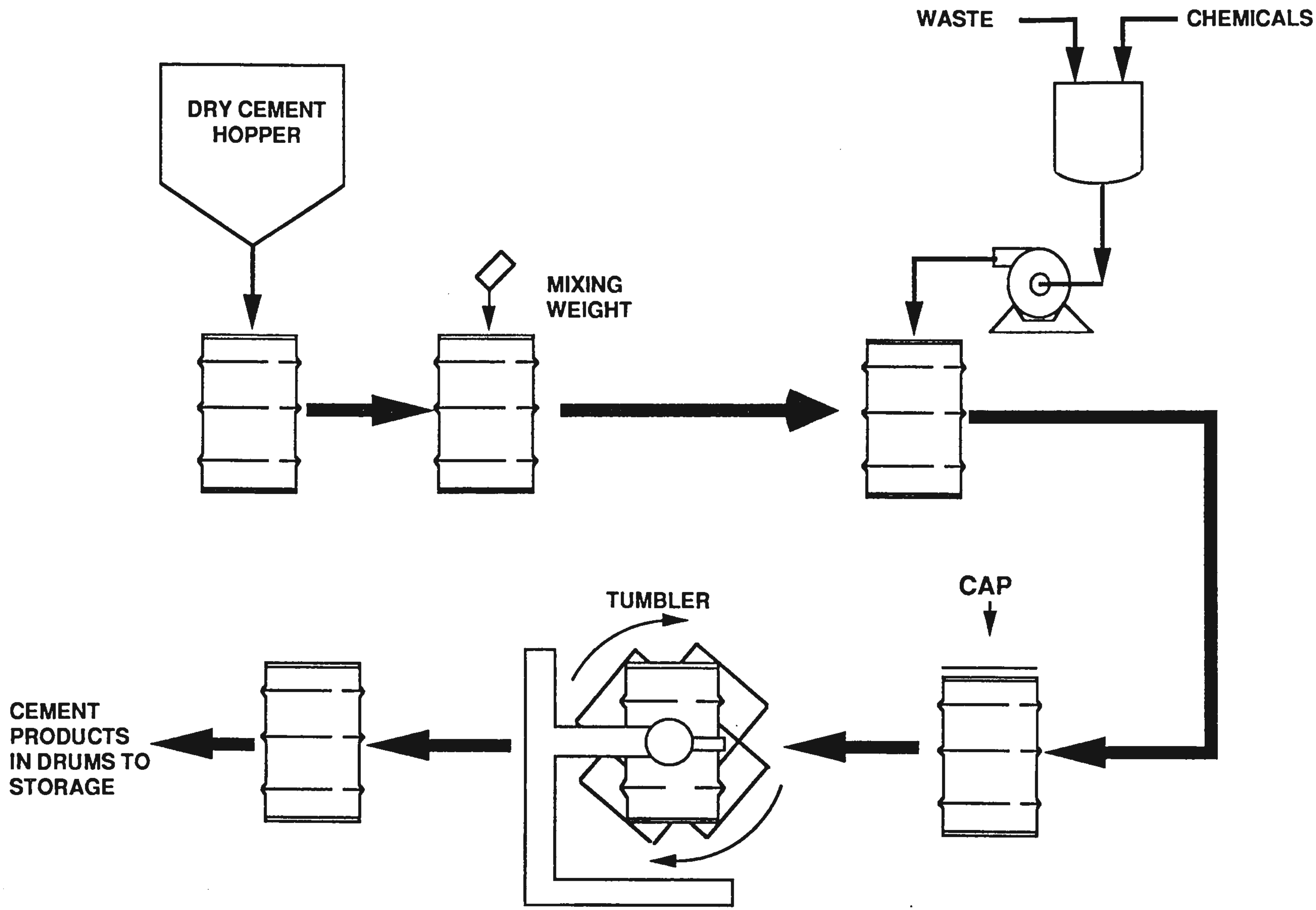

Figure 3-1. Typical in - drum passive mixing process.

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treatment systems. For batch-mode mixing, the wastes and solidification agent are mixed in batches then delivered to individual containers. For continuous-mode mixing, wastes and solidification agents are metered and fed continuously into a mixing vessel. The combined mixture is then continuously fed into the disposal containers.

3.5 Costs

Costs for cement solidification systems are difficult to assess because cement solidification systems can be both facility based and serviced via mobile units. Estimates of the total cost per cubic foot of solidified material range from $65 to $85, depending on the wastes and systems involved. The cost of the packaging is included in this range.

3.6 Mixed Waste

Apart from solidifying low-level waste streams, cement also has been a potential candidate agent for the solidification of mixed wastes (LLW with a hazardous waste component) and hazardous wastes. However, application to mixed waste types must be evaluated on a case by case basis, depending on specific waste characteristics. Disposal of the resultant mixed waste form may be subject to both the Atomic Energy Act and the Resource Conservation and Recovery Act requirements, as amended. To date, much laboratory experience has been gained on solidifying mixed radioactive and chemically hazardous wastes with cement, primarily at the Idaho National Engineering Laboratory. However, further development work is needed to make cement a viable commercial product for that application. There is no licensed and permitted disposal facility for commercially generated solidified mixed wastes, and certain untreated mixed wastes are banned from land disposal. Additionally, while cement is suitable for immobilizing chemically contaminated metal scraps and certain hazardous compounds, it is incompatible with a number of metallic salts and organic materials. These areas of incompatibility can be improved through further laboratory research and development efforts.

3.7 Vendors and Users

The following lists selected users and vendors of the cement solidification systems.

Partial List of Vendors:

(1) ChemNuclear Systems, Inc.
220 Stoneridge Drive
Columbia, SC 29210
(803) 256-0450

(2) Delaware Custom Material, Inc.
P.O. Box 1128
Milesburg, PA 16853
(814) 234-4452

(3) LN Technologies Corp.
1501 Key Road
Columbia, SC 29201
(803) 256-4355 or
(803) 252-3512

(4) Stock Equipment Company
16490 Chillicothe Road
Chagrin Falls, OH 44022
(216) 543-6000

(5) U.S. Gypsum Company
101 S. Walker Drive
Chicago, IL 60606
(312) 606-3849

(6) Hittman Nuclear, Inc. (formerly Westinghouse Hittman, Inc.)
1256 N. Church St.
Moorestown, NJ 08057
(609) 722-5700

Partial List of Users:

(1) La Salle County I & II Commonwealth Edison Co.,
P.O. Box 220
Marseilles, IL 61341
(815) 942-0150

(2) Susquehanna Steam Electric Station
Pennsylvania Power and Light Co.,
P.O. Box 467
Berwick, PA 18603
(717) 542-2181

(3) Nuclear Metals, Inc.
2229 Main St.
Concord, MA 01742
(617) 263-3119

4. COMPACTORS AND SUPERCOMPACTORS

Compaction is one of the simplest and most effective techniques for reducing the volume of dry active waste (DAW). As such, it is particularly suitable for generators of large volumes of lightly contaminated wastes. Compactors are simple to operate, inexpensive, and available in various designs, forms, and sizes.

This chapter discusses various features of compactors. Section 4.1 describes the types of compactors available, with performance considerations given in Section 4.2. Section 4.3 provides regulatory information and status. Section 4.4 presents detailed technical design and operational information for each type of compactor, and Section 4.5 shows cost ranges. Section 4.6 discusses the use of compactors for mixed wastes, with Section 4.7 listing vendors and users.

4.1 General Description

Compaction is a process by which a material is physically compressed into a smaller volume. Designs of compactors range from the less expensive hand-operated types to fully automated systems using electronically controlled hydraulic systems. Waste can be compacted inside a a 55-gallon drum, wooden box, steel box, or other container, depending on the design of the compactor. Three types of compactors are used to reduce low-level waste volumes:

- Conventional compactors
- Box compactors
- Supercompactors.

Each of these has its range of operating capabilities. Conventional compactors compact wastes directly into 55-gallon drums, exerting forces from 10 to 30 tons. Box compactors are capable of accepting larger objects and developing compressive forces up to 250 tons. Their rectangular-shaped containers also utilize space more efficiently than conventional compactors. Supercompactors (also called high-force or high-pressure compactors) are the most powerful types available. As a are the most powerful types available. As a general rule, supercompactors can exert forces of greater than 1,000 tons. Consequently, they can accept and compact nearly all DAW including steel piping and metal components that fit into the final disposal container. Manufacturers in Belgium, France, and Germany have been leading the development of these supercompactors.

To preserve the operating life of compactors and to ensure operational safety, certain restrictions are generally observed. For example, dense and hard materials with little final volume reduction are typically not compacted, and pyrophoric and explosive materials are not suitable for compaction. Additional technical details regarding these types of compactors are presented in Section 4.4.

The volume reduction efficiency of a compactor depends on the applied force, the bulk density of the waste material, and the spring-back characteristic of the material when compaction pressure is released. Based on the above, techniques have been developed that improve the volume reduction capability of compactors. These include preshredding and the development of antispring-back devices. As discussed in Section 8, shredding can improve the compactibility of waste material by as much as 50 percent when used in conjunction with conventional compactors. Antispring-back devices use polyethylene or steel discs in drums, or metal frames in boxes, to lock the compacted material in place and prevent it from springing back to refill the container.

An important general advantage of compactors for low-level waste volume reduction is the ease with which they can be installed with enclosures and filtering devices to control airborne radioactive particles. Shielding materials can also be readily added to reduce worker exposure.

Differences in the design capabilities of the three types of compactors result in each having its own specific advantages and disadvantages. These advantages and disadvantages are discussed in the following subsections and are summarized in Table 4-1.

TABLE 4-1. ADVANTAGES AND DISADVANTAGES OF COMPACTORS

Advantages	Disadvantages
I. Conventional compactors	
o Low capital cost	o Mechanical components will require periodic maintenance
o Requires only one operator	o Potential of oil leaks in the hydraulic lines
o Reduces the number of drums shipped off-site, therefore, reducing: - Transportation cost - Burial cost - Paperwork required for off-site disposal	o Requires use of an overhead crane or forklift with drum grab attachment
o Minimal floor space required	
II. Box compactors	
o Large receptor opening is convenient for large pieces of waste	o Increased capital and individual container disposal cost
o Larger waste containers result in fewer containers to be shipped off-site and a corresponding reduction in paperwork	o Two operators are required to place lid on waste container
o Container-handling times are reduced	o Forklift may be required to handle waste containers
o Hydraulic unit that may require servicing can be located in a nonradioactive area, thus reducing worker exposure during maintenance activities	o Occupies more space
o Containers usually contain skids and do not require pallets as do drums	
o Container shape more efficient for storage, transportation and disposal	
III. Supercompactors	
o Dry active wastes previously considered noncompactible are compactible, including pipes, valve bodies, and other metal products	o Large capital investment
o Storage space previously occupied by wastes that were considered no longer compactible is reduced	o Requires large amount of floor space
o Storage space at regional burial sites can be reduced	o Due to high compressive forces, the equipment may require more maintenance than other compactor types
o Relatively simple to operate	o Liquid waste from punctured capsules may be released during compaction

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4.2 Performance Data

Most conventional compactors operate directly in 55-gallon drums and accept only wastes that yield to relatively low pressures. Therefore, prior to compaction all waste must be sorted to remove components resistant to pressures of approximately 30 psi. The larger box compactor delivers up to ten times greater compressive forces and has a greater capacity, allowing for the compaction of larger, bulkier objects.

The advantage of a box compactor is that it requires less sorting and direct contact with the waste package, hence minimizing worker exposure to radiation. Also, the box compactor can accept larger waste objects than the drum type compactor. Since fewer waste packages contain the same volume of wastes, the amount of paperwork (preparation of shipping manifests, surveys, and other records) is reduced. In addition, there is less direct contact with the waste packages since all handling operations must be conducted mechanically due to the size and weight of the container. Not only can more waste be placed into a box compactor, but the rectangular boxes are more dimensionally efficient for storage or disposal than 55-gallon lrums.

Supercompactors exert compressive forces approximately ten times greater than box compactors. Six companies have signed contractual agreements with foreign manufacturers to market supercompactors in the U.S. One of the most powerful supercompactors is operated by Scientific Ecology Group at its Tennessee waste processing plant. This unit can deliver up to 5,000 tons of force. A slightly smaller device manufactured by the Hansa Project of West Germany can press up to 2,200 tons. The Hansa model is being marketed in the U.S. by INET Corporation under the trade name of "SUPERPACK." Two units of SUPERPACK were sold in Europe, one in Italy and one in West Germany. Three other Superpack units were sold in the United States, with one under contract negotiation. Another supercompactor model is being marketed by Stock Equipment Company. The Stock Equipment model is designed and manufactured by Fontijne of the Netherlands and is capable of delivering compressive forces up to 1,500 tons. Stock Equipment

Company installed one supercompactor in Parks Township, Pennsylvania, for Babcock and Wilcox. Preliminary tests have been completed, but operations have not yet begun due to problems with solid waste and air quality permits.[4-1]

The performance of supercompactors may be illustrated by the experience of the SUPERPACK system at the Brunsbuttel Nuclear Plant in West Germany.[4-2] To demonstrate its performance and capability, 100 tons of compactible wastes were pressed into 4,000 caustic soda drums using a conventional compactor. Each drum had a capacity of 180 liters, equivalent to 47.5 U.S. gallons. Then 2,365 of these conventionally compacted drums were supercompacted into 658 55-gallon drums, reducing the waste volume of 15,016 cubic feet to 4,843 cubic feet and achieving an overall volume reduction factor of 7.7 over the original waste volume.

4.3 Regulatory Requirements and Status

While the treatment of low-level waste by compaction must be carried out under an NRC or Agreement State license, no specific regulations exist that require the preapproval of a compactor design by a federal or state regulatory agency or that provide specific guidance for compactor design and operation. In most cases, compactors are installed at nuclear power plants, with their design described in the operating plant's safety analysis report (SAR). NRC's review and approval of the plant's compactor design is conducted formally through the SAR review process under the operating license of the plant. Operators of compactors for processing low-level radioactive waste are required by 10 CFR 20 to maintain exposures of employees and public to levels that are as low as reasonably achievable (ALARA). Releases of airborne radioactivity are regulated under the Clean Air Act radionuclide provisions and Appendix B of 10 CFR Part 20. Other individual state and local permits may also be required. Compactors are also required to meet Occupational Safety and Health Administration (OSHA) requirements established in 29 CFR 1910 to protect operators from hazards other than radiation.

4.4 Technical Details

The following paragraphs present detailed technical design and operational information on each of the three types of compactors.

4.4.1 Conventional Compactors

The most widely used compactor for low-level waste consolidation is the 55-gallon drum conventional type shown in Figure 4-1. This unit consists of an electrically driven pump, a hydraulic cylinder to which the platen is attached, and a ventilation system comprising a prefilter, a HEPA filter, and a fan. These units supply compressive forces from 10 to 30 tons. The performance data of commercially available conventional compactors differ significantly. Typically, uncompacted waste with a density of 8 lb/ft^3 can be compacted to a density of about 30 lb/ft^3. With the use of antispring-back devices, the performance of these compactors can be improved to achieve densities as high as 40 lb/ft^3.[4-3]

Operationally, an empty 55-gallon drum is placed on the rolling drum support plate, pushed under the drum enclosure, and held in place by the drum plate locking device. The drum enclosure is then opened, filled with waste, and covered. Once the unit is activated, oil is pumped to the hydraulic cylinder that lowers the platen, compressing the waste in the drum. This operation is repeated until the drum is full.

During operation, a potential exists for the release of radioactive particulates. To prevent this, fans are mounted on the drum compactors to draw air around and up the sides of the drum. The outlet of the fan can be connected to either the facility's ventilation system or a filter (prefilter and HEPA filter) supplied with the unit. Other safety features are usually provided to prevent the unit from operating if the drum is not in place or if the shroud door is not closed tightly.

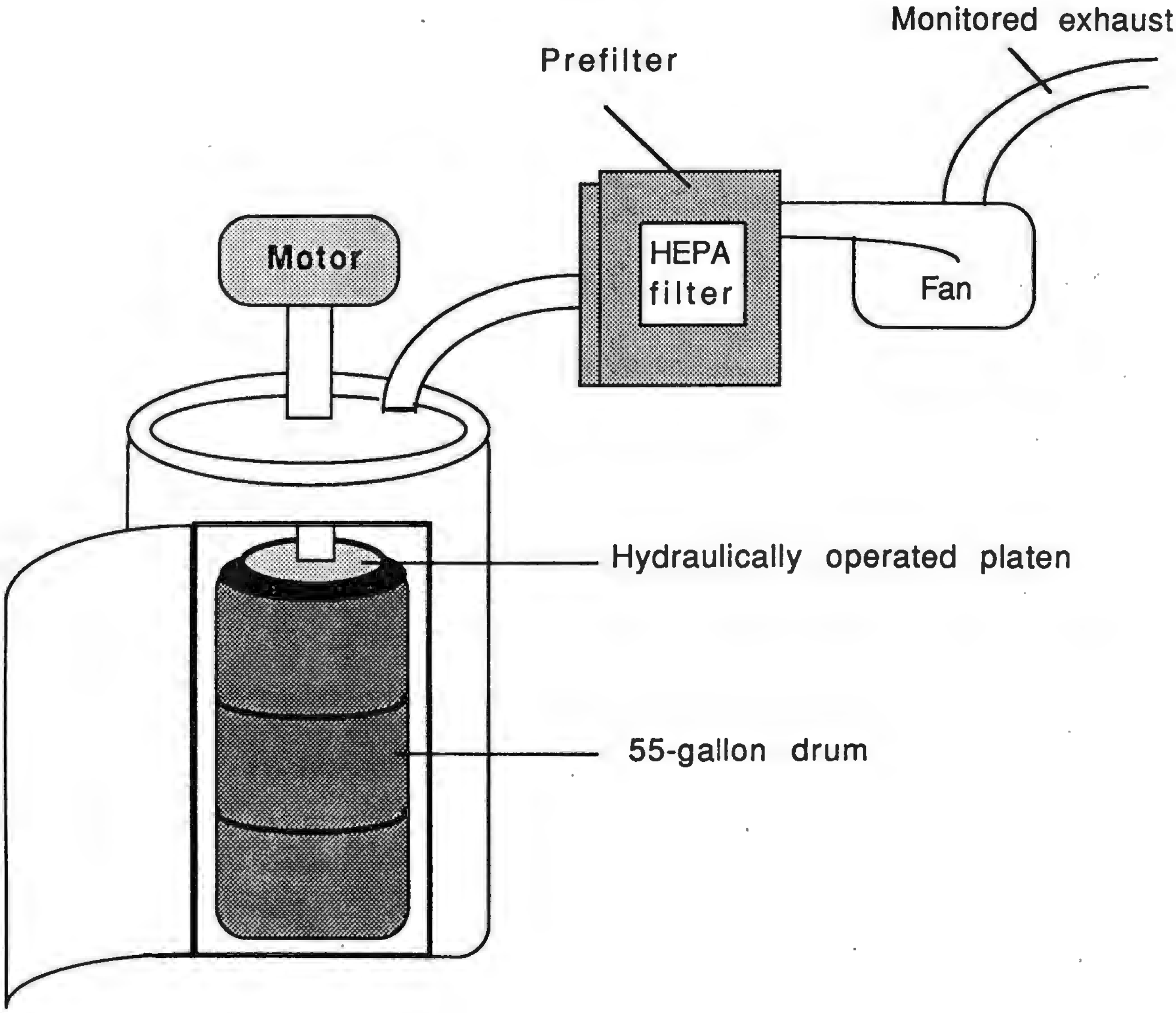

Figure 4-1. Conventional compactor.

Sorting of waste is required as conventional compactors cannot compact tools, pipes, valves, large HEPA filters, concrete, and heavy gauge metal. The advantages and disadvantages of conventional compactors are presented in Table 4-1.

4.4.2 Box Compactors

As previously stated, a box compactor is similar to a conventional compactor except that waste is compacted into wooden or steel boxes. The most common size of box used with the box compactors is 90 ft^3. Other box sizes range from 44 to 100 ft^3. Box compactors can develop compressive forces ranging from 30 to 250 tons. The design of a box compactor consists of four main components:

- Compactor/ram
- Hydraulic unit
- Filter system
- Controls.

As shown in Figure 4-2, a complete steel enclosure is provided around the compactor/ram unit for radiation shielding and to control airborne particulates.

To operate the box compactor, the container access door is fully opened to allow placement of the empty waste container inside the compactor with the help of a forklift. This door can be of one-piece or two-piece construction. In one-piece construction, the door moves vertically upward to allow waste loading. In two-piece construction, the door opens outward toward the operator.

The filtration system consists of a roughing filter (or prefilter), a HEPA filter, and a fan. The outlet of the fan is connected either to the facility ventilation system or to the filtration system supplied with the unit. Once in operation, the fan runs continuously to assure that no radioactive particulates escape into the environment.

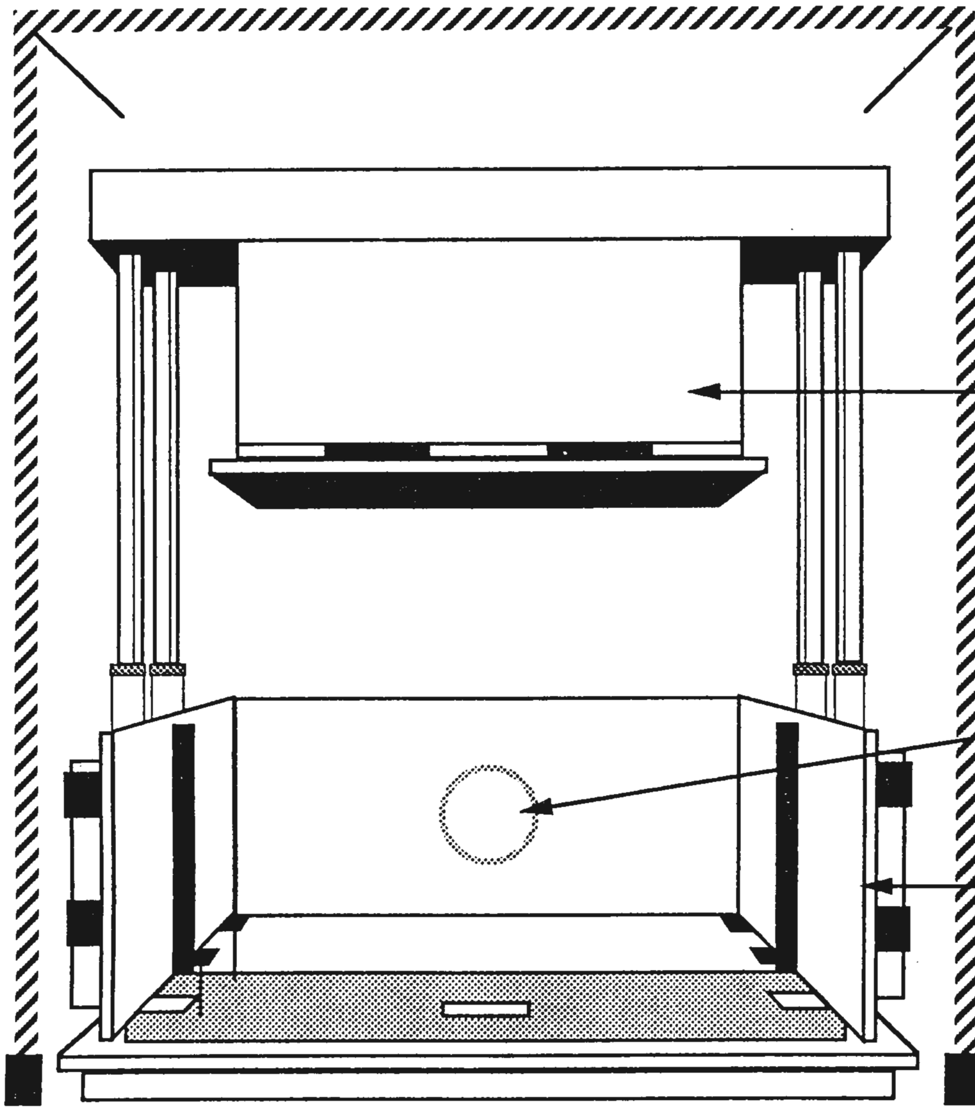

Figure 4 -2. Typical box compactor.

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With the access door open, the steel enclosure acts as a hood with negative pressure, sweeping air into the enclosure. The horizontal ram and the interior surfaces of the box compactor are made of stainless steel or carbon steel coated with epoxy paint for ease of decontamination.

During operation, compactible DAW is placed in the metal box. Once full, the access door closes and the horizontal ram is driven downward by a hydraulic pump. The ram compresses the waste in the waste container and then is returned to its upper position in the metal enclosure. The container is refilled and the same process is repeated until the waste springs back (rises up) to the rim of the metal box. An antispring-back device can be installed to improve compaction efficiency.

The advantages and disadvantages of box compactors are presented in Table 4-1.

4.4.3 Supercompactors

Supercompactors can deliver a compressive force of 1,000 tons or greater. They have the capability of compressing just about any type of DAW generated at a nuclear power plant including those wastes that cannot be compacted in a conventional or box compactor. Essentially, supercompactors are extensions of conventional and box compactors with more powerful hydraulic drivers. All supercompactors are designed with an enclosure and equipped with air filtration systems to restrict the release of airborne contaminants. Supercompactors can be installed permanently or provided in mobile units.

4.4.3.1 Stationary Unit. The design of stationary supercompactors varies by vendor, and each is unique. One such type, the Fontijne supercompactor marketed by Stock Equipment, is used for this discussion as the prototype stationary unit. The Fontijne supercompactor is an automatic system consisting of a cylindrical compaction press operating at 1,500 tons, compressing 55-gallon drums and their contents. The system uses approximately 90 kw/hr electrical power and requires an air supply of 0.9 standard cubic meters per hour (25 SCFH). This system is equipped with a feed conveyor, a drum piercing subsystem (to allow the escape of air trapped during compaction), a central hydraulic power source, and a control console. The piercing station and the press itself are designed to be installed in a negative pressure isolation chamber to minimize particulate emissions during the actual compaction process. The compactor uses a single cylinder piston guided by four press columns that are driven by two double-acting cylinders in a vertical line. It is used to compact containerized waste. To contain the drum to be compacted and to maintain a specified diameter of the compacted waste, a mold with a hardened steel lining is used. In operation, the mold is lowered onto a base over the drum to be compacted and seated against a round steel platen. The piston compresses the drum and its contents with a compaction time of approximately 2 minutes. The compactor base is provided with a drain to handle liquids that may leak from punctured containers. The supercompacted 55-gallon drum, or the so-called "Hockey Puck" is then loaded into an 85-gallon overpack drum.

The Fontijne supercompactor has been in use for four years at the Netherlands government facility processing all of that country's DAW, including that from nuclear power plants. With a processing rate of 10,000 drums per year, this system is considered to have extensive field operational experience.

The advantages and disadvantages of a supercompactor (both mobile and stationary) are presented in Table 4-1.

4.4.3.2 Mobile Units. The Westinghouse/Hittman unit is used as the prototype system for this discussion on the design and operation of a typical mobile unit.

The Westinghouse/Hittman unit employs a 1,000-ton hydraulically operated compactor mounted in a 40-foot trailer (Figure 4-3). The mobile trailer contains the following:

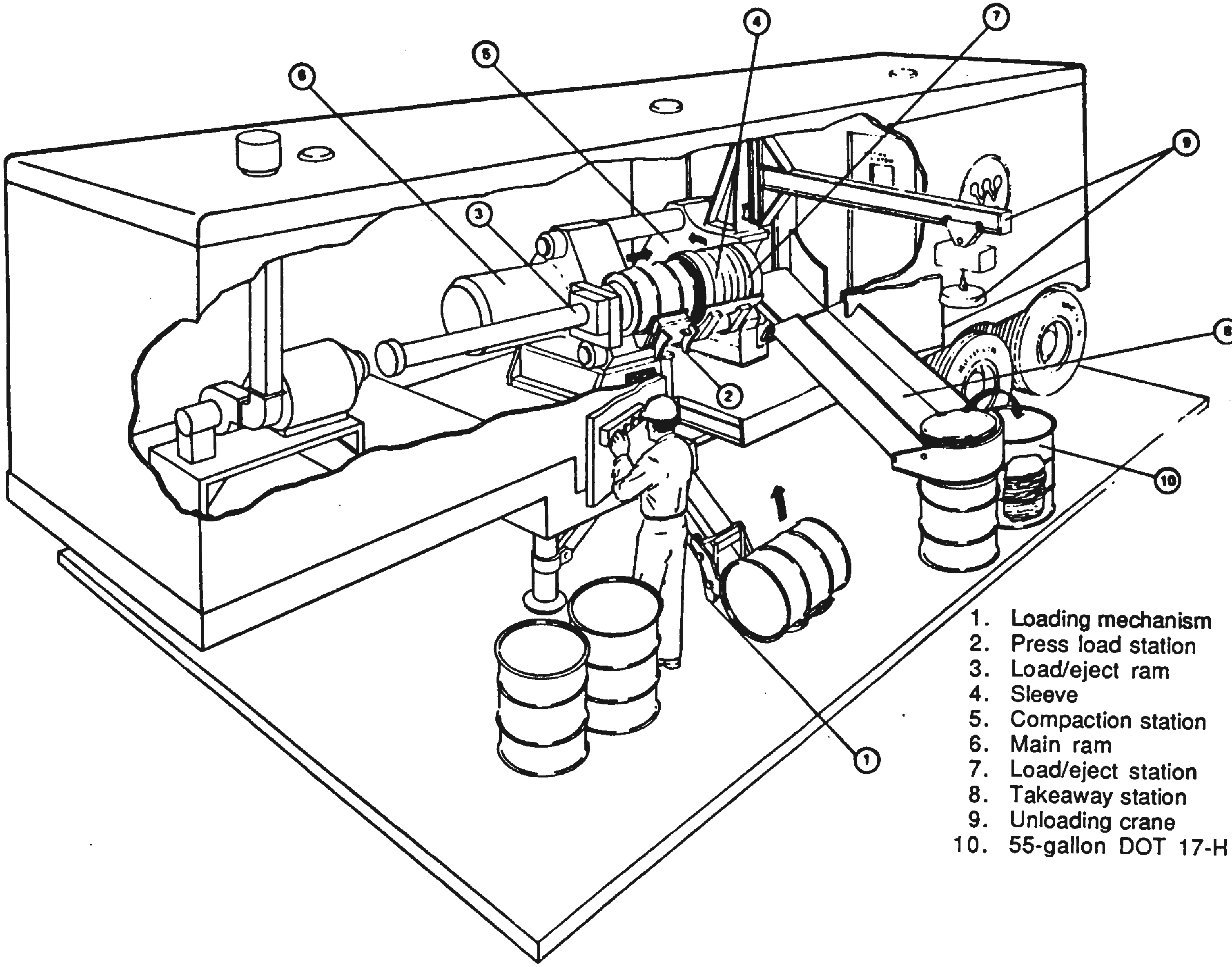

Figure 4-3. Mobile supercompactor (from Westinghouse Hittman Company).

- o Waste container loading mechanism
- o Press load station
- o Load/eject ram
- o Compaction station
- o Main ram
- o Drum removal station
- o Unloading crane
- o Air filtration system
- o Liquid collection
- o Hydraulic power unit.

The air filtration system collects and filters all airborne matter from the sleeve and the tent that encloses the trailer's main operating doors. The filter system consists of a prefilter and a HEPA filter. The press operates only if the filter system is operating.

A liquid collection system consists of two tanks, alarms, and the necessary controls. Such a system is necessary because moisture resulting from humidity and absorbed by the waste would be forced out during the compaction cycle due to the level of compressive forces generated by a supercompactor. The tanks are provided with the necessary controls to prevent the press from operating if the liquid level in either tank is high. The collected liquids are treated and solidified for disposal by the same process used for other radioactive liquid wastes.

When in use, the system requires two operators. Shielding is provided to protect workers. The sleeve is provided with interchangeable inserts allowing for the compaction of 52-gallon caustic soda drums or 55-gallon drums. The process achieves a net waste density in excess of 60 pounds per cubic foot when processing dry active waste.[4-4] In operation, the waste container loading mechanism raises and deposits the drum in the press load station. The load/eject ram transfers the drum to be compacted from the load station to the sleeve and then retracts.

The sleeve then rotates with the drum inward into the press compaction station. The main ram travels toward the drum, compacting it and retracting it after compaction is complete. The sleeve containing the compacted drum inside, or "hockey puck," rotates outward to the load/eject station and is ejected by the load/eject ram of the takeaway station.

The mobile units have the same advantages and disadvantage as the stationary units except that they are designed to be mounted in a trailer for transport to various processing locations.

4.5 Costs

The cost of a box compactor is higher than a conventional compactor. Installation of a typical conventional drum-type compactor costs between $20,000 and $75,000, whereas installation of a box compactor costs from $125,000 to $250,000. The majority of the supercompactors are designed and manufactured in Europe or Japan and cost from $1 million to $5 million to purchase and install. A study conducted in 1984 that evaluated the economics of operating a supercompactor in the United States concluded that supercompactors are best utilized in a central processing facility or in a mobile unit that services a number of plants and facilities.[4-5] The total cost per cubic foot of processing waste with compaction technology depends not only on the initial cost of the compactor but also on operating and maintenance costs, manpower requirements to prepare a shipment of waste, transportation costs, and throughput of waste.

4.6 Mixed Waste

Compactors can be used to reduce the volume of mixed wastes in the same manner that they are used for LLW, hazardous waste or other solid waste applications. Care must be exercised to assure the waste materials to be compressed are not reactive or incompatible with the compressive forces to be applied, the container or other waste. If a compactor is to be used to treat mixed waste, it may be required to be permitted under RCRA as a treatment facility (40 CFR 264). Compacted mixed waste must be disposed of in accordance with RCRA requirements whether or not the compaction facility is RCRA-permitted. Compaction of mixed waste has the advantage of disposing of a comparatively smaller volume of mixed waste. Compaction, by itself, does not reduce the hazard of the mixed waste nor does it change the regulatory status of the mixed waste.

4.7 Vendors and Users

The following lists selected users and vendors of the different types of compactors.

Vendors:

Conventional Compactors

(1) Consolidated Bailing Machine Company
Rad Waste Dept.
P.O. Box 61025
Jacksonville, FL
(800) 231-9286

(2) Stock Equipment Company
16490 Chillicothe Rd.
Chagrin Falls, OH
(216) 543-6000

(3) S&G Enterprise, Inc.
5627 N. 91st St.
Milwaukee, WI
(414) 464-5310

Box Compactors

(1) Container Products Corporation
P.O. Box 3767
Wilmington, NC 28406
(919) 392-6100

(2) CGR Compacting, Inc.
Box 29, RFD #1 North Hill
Readsboro, VT
(802) 423-7070

Supercompactors

(1) Stock Equipment Company
16490 Chillicothe Rd.
Chagrin Falls, OH
(216) 543-6000

(2) INET Corporation
8450 Central Ave.
Newark, CA
(415) 797-9600

(3) Westinghouse-Hittman Nuclear Incorporated - Mobile Units
9151 Rumsey Rd.
Columbia, MD
(301) 964-5007

(4) ChemNuclear Systems Inc. - Mobile Units
220 Stoneridge Dr.
Columbia, SC
(803) 256-0450

(5) US Ecology Nuclear
7066-A Commerce Circle
Pleasanton, CA
(415) 463-9280

Users:

Conventional Compactors

(1) University of Washington
Environmental Health and Safety, GS-05
201 Hall Health
Seattle, WA 98195
(206) 543-0463

(2) Maine Yankee Generating Station
P.O. Box 408
Wiscasset, ME 04578
(207) 882-6321

Box Compactors

(1) Maine Yankee Generating Station
P.O. Box 408
Wiscasset, ME 04578
(207) 882-6321

(2) Sequoyah Generating Station
P.O. Box 2000
Soddy Daisy, TN 37379
(615) 870-6500

(3) Idaho National Engineering Laboratory
Attention: WERDS, Mail Stop 8104
Idaho Falls, ID 83415
(208) 526-4403

(4) Edwin I. Hatch Plant
P.O. Box 439
Baxley, GA 31513
(912) 367-7781

(5) Vogtle Plant
Route 2, Box 299A
Waynesboro, GA 30830
(404) 554-9961

<u>Supercompactors</u>

(1) Scientific Ecology Group
P.O. Box 2350
Oak Ridge, TN 37830
(615) 481-0222

(2) Allied Technology, Inc.
2403 Fruitvale Avenue
Yakima, WA 98909
(509) 457-6360

(3) ChemNuclear, Systems, Inc.
P.O. Box 225
Northwest Frontage Road
Channahon, IL
(815) 467-4700

5. EVAPORATORS AND EVAPORATIVE CRYSTALLIZERS

This chapter describes the use of evaporation and evaporative crystallization processes as methods of volume reduction. Considering that evaporator technologies are controlled by physical and chemical characteristics of the waste streams and not by their radioactivity, almost any type of evaporation technology can be applied to LLW consistent with keeping radiation exposures "as low as reasonably achievable" (ALARA). Evaporators are used extensively in association with the nuclear power plant industry. They are typically used for treatment of relatively large volumes of liquids. Section 5.1 provides a general description of the technologies, including the various evaporator types and configurations. Performance data for typical evaporator systems are discussed in Section 5.2. Regulatory considerations for evaporation systems are presented in Section 5.3. Descriptions of existing systems are used to provide additional technical details for complete evaporation systems in Section 5.4. Cost considerations are described in Section 5.5. The application of evaporator technology to mixed waste is discussed in Section 5.6, with evaporator vendors listed in Section 5.7.

5.1 General Description

Evaporation is a technique used to concentrate liquid effluent, in this case LLW, by using heat to drive off relatively pure water. The basis for evaporation is simply the separation of volatile from nonvolatile material. This phenomenon is observed in everyday circumstances.

Typical effluents include sodium sulfate from boiling water reactors (BWRs) and ammonium sulfate and boric acid from pressurized water reactors (PWRs), as well as sodium nitrate from defense operations.[5-1] Typical concentrations of salts in the concentrated waste leaving the evaporator range from 60 to 200 grams/liter.[5-2] Evaporative crystallizers remove even more water, producing an effluent with approximately twice the concentration of salt than derived from the typical evaporator.

When separating a solution of salts in water, the water can be vaporized from the solution without salt removal because, for all practical purposes, salts are nonvolatile under normal operating conditions. Loss of water by evaporation leaves behind a more concentrated solution of radioactive material (often called sludge or evaporator bottoms), thereby reducing the volume of radioactive liquid waste requiring disposal. Evaporator bottoms account for 700 to 7,000 ft^3/year of waste from a typical nuclear power generation station (Reference 5-2). The vaporized water can be condensed and reused in process applications or in many cases can be discharged.

The basic evaporation/crystallization scheme is shown in Figure 5-1. The system works as follows (the numbers in parentheses correspond to flows in the figure): the feed consists of water contaminated with low concentrations of dissolved radioactive material (1); the feed is heated with steam in a heat exchanger, boiling off some of the water (2); this produces a mixture of hot liquid and evaporated water vapor (3); the vapor and liquid are separated into two streams (4): relatively pure water vapor (5) and a liquid solution highly concentrated with nonvolatile radioactive material (6). The highly concentrated liquid waste is only a fraction of the volume of the feed solution (1), greatly reducing the quantity of material requiring special radioactive waste disposal techniques. The steam that enters the heat exchanger leaves as condensate, which is a liquid. This condensate can be returned to the steam generator and reused for additional steam generation. A portion of the concentrated waste is recirculated to save energy and maintain consistent operation. Energy from the purified water vapor (5) may be reused to provide steam for the heating and boiling step (2). The reuse is discussed under Section 5.1.3 (Vapor Recompression).

In general, evaporators are capable of producing concentrations of the treated effluent of up to 12 weight percent for boric acid LLW and 25 weight percent for sodium sulfate. On the other hand, crystallization systems produce slurries of sodium sulfate up to a 50 weight percent concentration (50 percent water and 50 percent salt).

The types and configurations of commercially available evaporators are described in the following subsections. The discussions cover natural

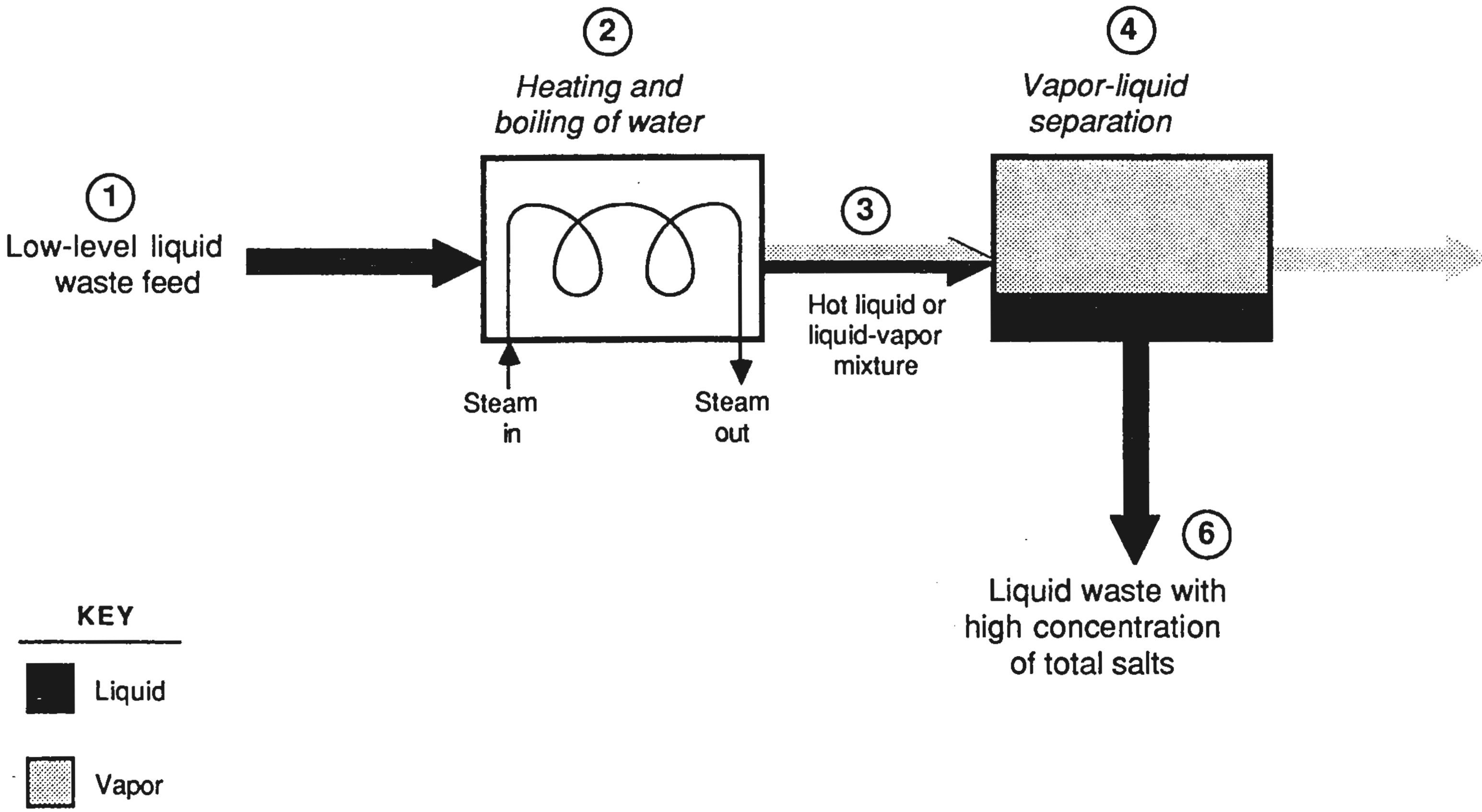

Figure 5-1. Simplified evaporation process. The circled numbers correspond to flows described on p. 5-2.

circulation evaporators, evaporative crystallizers using forced circulation, and evaporators utilizing vapor recompression. Table 5-1 identifies the advantages and disadvantages of these types of evaporators.

5.1.1 Natural-Circulation Evaporators

Heat transfer is the most important aspect of evaporator design. In general, the heater is designed so LLW feed is delivered to the inside of the tubes, with steam contacting the outside of the tube surface. Natural circulation evaporators have long vertical heat exchanger tubes so that the contaminated liquid flows upward through the tubes (rising film) or the liquid flows downward (falling film) through the tubes. These types are discussed below.

5.1.1.1 Rising-Film Evaporator. In a rising-film evaporator, the waste feed is delivered to the bottom of the heater. Liquid on the inside of the heater tubes is brought to a boil by steam. Natural circulation occurs because the rising vapor helps move the liquid upward. As the fluid moves up the tube, more vapor is formed, causing a thin film of liquid to form along the tube surface. This improves the heat transfer and allows more water to boil off.

As shown in Figure 5-2, the vapor leaving the heater enters a vapor body, which serves to separate the evaporated water and remaining liquid. The resulting liquid waste is relatively concentrated with radioactive material as compared to the waste feed. A portion of the concentrated waste may be recirculated to save energy and move the feed liquid upward.

The water vapor coming out of the vapor body contains entrained liquid. This mist is removed using an entrained liquid-vapor separator, as shown in Figure 5-2. The liquid removed from the mist is recycled as waste feed. The vapor coming out of the separator is free of mist and is sent to a condenser. The condenser uses cooling water to change the water vapor into liquid. The "pure" water can be reused in the facility or discharged.

TABLE 5-1. ADVANTAGES AND DISADVANTAGES OF EVAPORATOR TYPES USED IN LIGHT-WATER REACTOR POWER PLANTS

	Evaporator Type		
	Natural Circulation	Forced Circulation	Forced Circulation with Vapor Recompression
Advantages	o Low-cost o Large heating surface o Low holdup time o Small floor space o Good heat-transfer coefficients at reasonable temperature differences (rising film) o Good heat-transfer coefficients at all temperature differences (falling film)	o High heat-transfer coefficients o Positive circulation o Relative freedom from salting, scaling, and fouling	In addition to those for forced circulation: o Cooling water requirements are eliminated o Steam heating requirements are reduced
Disadvantages	o High head room o Generally unsuitable for salting and severely scaling liquids o Poor heating transfer coefficients of rising-film version at low temperature differences o Recirculation usually required for falling-film version	o High cost o Power required for circulating pump o Relatively high holdup or residence time	o High cost o Electrical consumption high due to large compressor motor o Relatively high holdup or residence time
Best Applications	o Clear liquids o Foaming liquids o Corrosive solutions o Large evaporation loads o High temperature differences - falling film o Low-temperature operation - falling film	o Crystalline product o Corrosive solutions o Viscous solutions	o Crystalline product o Corrosive solutions
Frequent Difficulties	o Sensitivity of rising-film units to changes in operating conditions o Poor feed distribution of falling-film units	o Plugging of tube inlets by salt deposits detached from walls of equipment o Corrosion-erosion problems resulting from improper feed pH adjustment	o Same as normal forced-circulation evaporators

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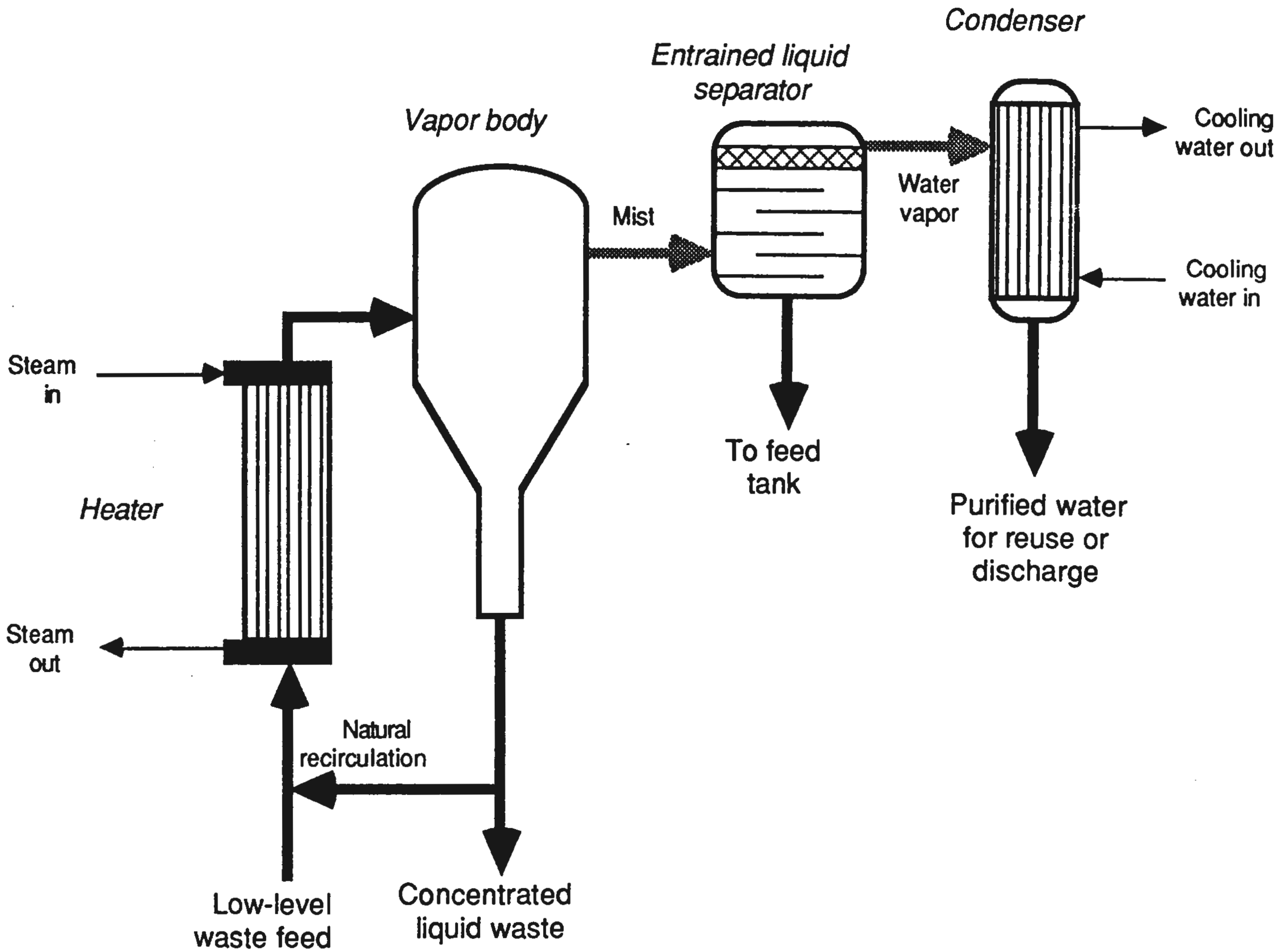

Figure 5-2. Rising-film evaporator with natural recirculation.

The heater shown in Figure 5-2 is separate from the vapor body and is called an external heater design. Evaporators that combine the heater and vapor body into a single unit are of the internal heater design. External heater designs permit easier access to the tubes for cleaning, maintenance, or replacement.

5.1.1.2 Falling-Film Evaporator. With falling-film evaporators, the waste feed is delivered to the top of the heater and the liquid flows downward due to gravity. The heat transfer performance of this configuration is improved because a thinner, faster-moving film is produced. The size of falling-film heaters is smaller than for rising-film heaters. The falling-film evaporator has a pump to circulate the liquid to the top of the unit. It is not used for forced circulation. The chief problem with the falling-film evaporator is attaining uniform liquid distribution at the top of the tubes.

Although operating costs are relatively low with natural circulation evaporators, they have been replaced by more effective forced-circulation evaporators.

5.1.2 Forced-Circulation Evaporators

5.1.2.1 Evaporative Crystallizer. The most common type of evaporator crystallizer, the forced-circulation evaporator, is capable of removing sufficient water so the salts form crystals (from a supersaturated solution).

Many solids dissolve only partially in water. The maximum amount of a substance that will dissolve in water is called the substance's solubility. The change in solubility as a function of temperature for sodium sulfate is shown in Table 5-2. At 100°F, a saturated 100-pound sodium sulfate solution would contain 33.1 pounds of dissolved sodium sulfate and 66.9 pounds of water. If the temperature of this solution were raised to 180°F, only 30 pounds of sodium sulfate would remain dissolved, and 3.1 pounds of sodium sulfate would be undissolved. This undissolved portion would form solid crystals. This phenomenon is the basis for evaporative crystallization.

TABLE 5-2. SOLUBILITY OF SODIUM SULFATE IN WATER[5-3]

Temperature (°F)	Solubility (weight percent)
100	33.1
140	31.2
180	30.0
220	29.6

A simplified evaporative crystallization process is shown in Figure 5-3. This process is similar to the natural-circulation process shown in Figure 5-2 except that a larger recirculation pump is used to enhance circulation, and the heater does not boil the liquid. In this process, liquid waste feed is mixed with a relatively large portion of concentrated liquid waste and fed at a high rate through the heater. The liquid is heated less than 10°F by the heater.[5-4] As the liquid enters the vapor body, where the pressure is slightly less than in the heater tubes, some of the liquid evaporates. The vapor enters an entrainment separator and then a condenser, as described previously. The majority of the concentrated liquid waste coming out of the vapor body is recirculated. This allows the circulating liquid to be a suspension of dissolved salts and undissolved salt crystals. The equipment is designed to handle circulating solids.

The major advantage of this type of system is that greater waste volume reduction can be achieved. However, operating costs are high due to extensive pumping requirements.

5.1.2.2 <u>Wiped-Film Evaporators</u>. Wiped-film evaporators (sometimes called agitated-film, thin-film, or scraped-film evaporators) use a hot fluid inside a tube to heat the low-level waste and evaporate water. Liquid waste is spread on the outside of the tube by a rotating assembly of blades, creating an easily evaporated thin film. However, these evaporators are not particularly effective in evaporating water, and expensive construction details make this technology unattractive (Reference 5-4).

5.1.2.3 <u>Extruder-Evaporator</u>. The extruder-evaporator system combines evaporation and solidification of the concentrated waste as shown in Figure 5-4 and as described in greater detail in Chapter 2. In this process, low-level waste is fed to an extruder-evaporator and mixed with molten asphalt (or other solidifying material). The mixture of waste and asphalt is conveyed through the extruder by an augering motion. The extruder is heated by steam to evaporate water from the waste, although steam does not come in direct contact with the waste mixture.[5-5]

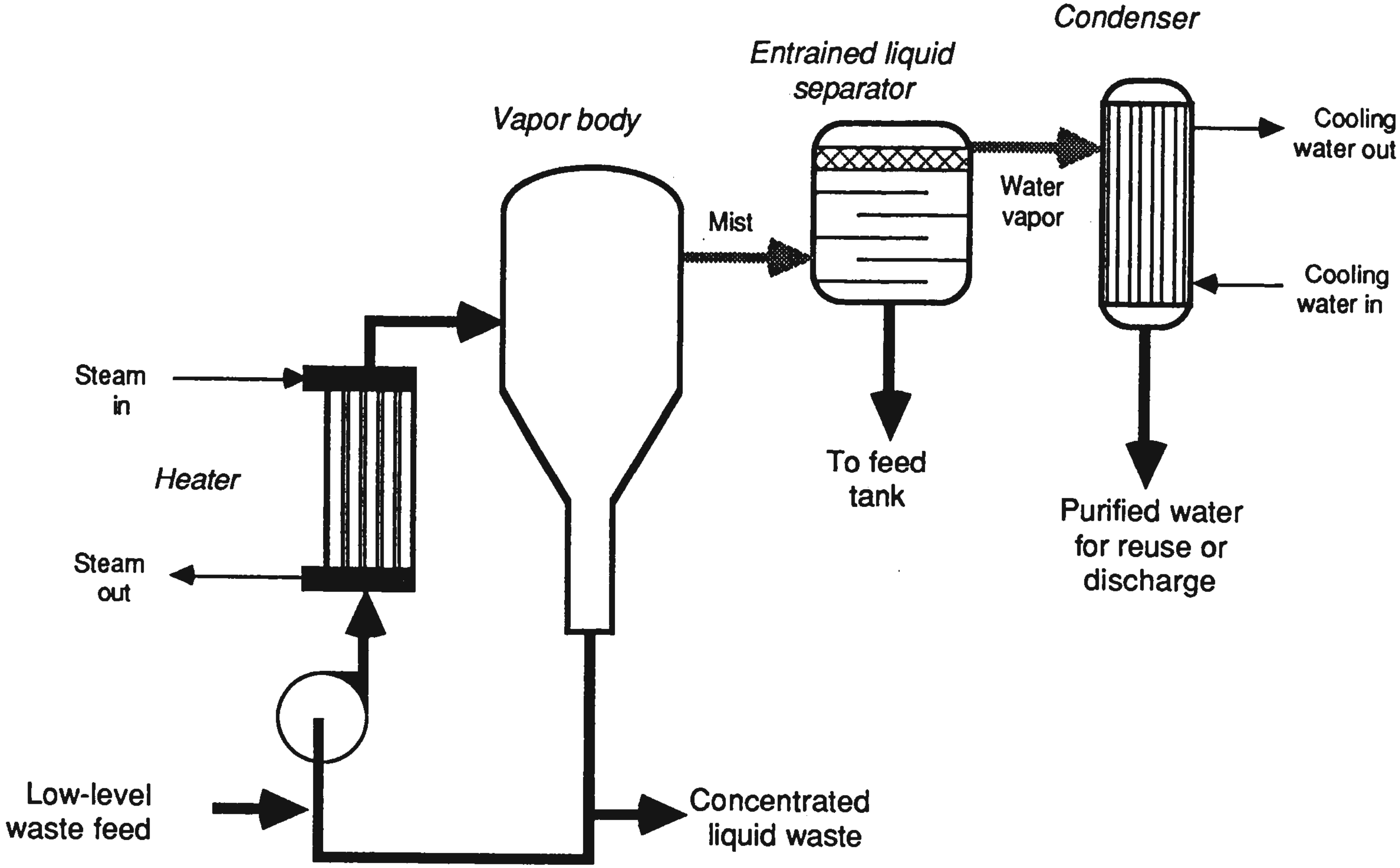

Figure 5-3. Forced-circulation evaporator.

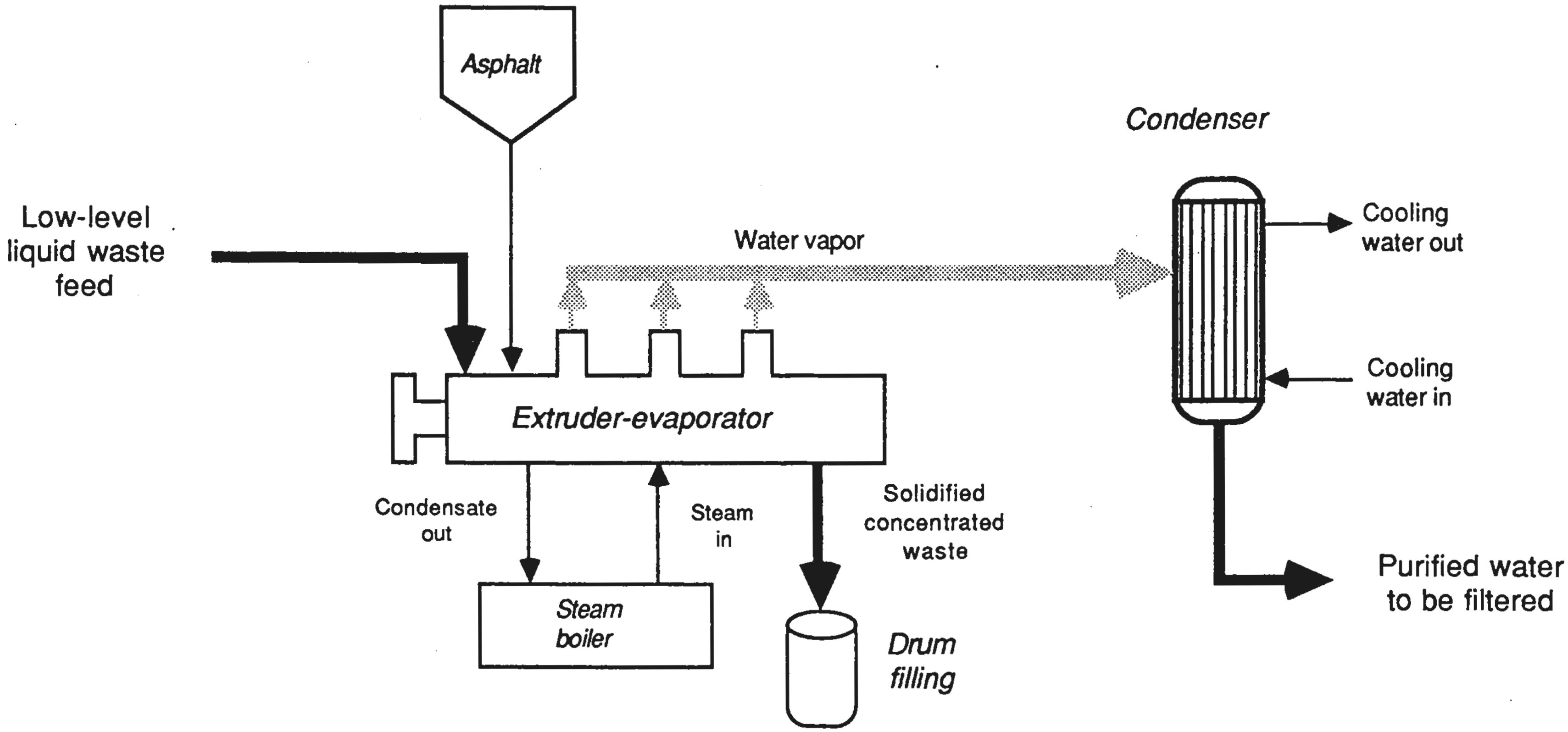

Figure 5-4. Extruder-evaporator with waste solidification.

The evaporated water is then condensed and undergoes subsequent filtration steps for oil and contaminant removal. The mixture of concentrated waste and asphalt flows into 55-gallon drums and solidifies upon cooling. This process produces a solidified waste, unlike the other evaporator systems discussed in this section. Stabilization using bitumen is discussed in Chapter 2 of this report.

5.1.3 Evaporators with Vapor Recompression

After water has been evaporated and sent through an entrained liquid separator, essentially pure water vapor or steam is produced. Figures 5-2 and 5-3 show the steam being condensed with cooling water. However, it is often economical to use this steam to provide the energy to evaporate water from the liquid waste feed. This process is termed vapor recompression and is shown in Figure 5-5.

The low-grade steam coming out of the entrained liquid separator is delivered to a compressor. The compressor increases the pressure and temperature of this low-grade steam. This steam is supplemented by a small amount of makeup steam and then sent to the heater. Vapor compression can result in energy savings of over 80 percent.

5.1.4 Multieffect Evaporators

Multiple-effect evaporators provide another means of increasing energy utilization. This evaporator system uses the vapor from one evaporator (called an effect) as the heating source for the next (more concentrated liquid) effect in the system. In this way, the steam is used a number of times, reducing the system energy costs. Vapor compression between effects is not required, since successive effects are normally operated at lower absolute pressures. This evaporator type is normally used only for large-scale applications.

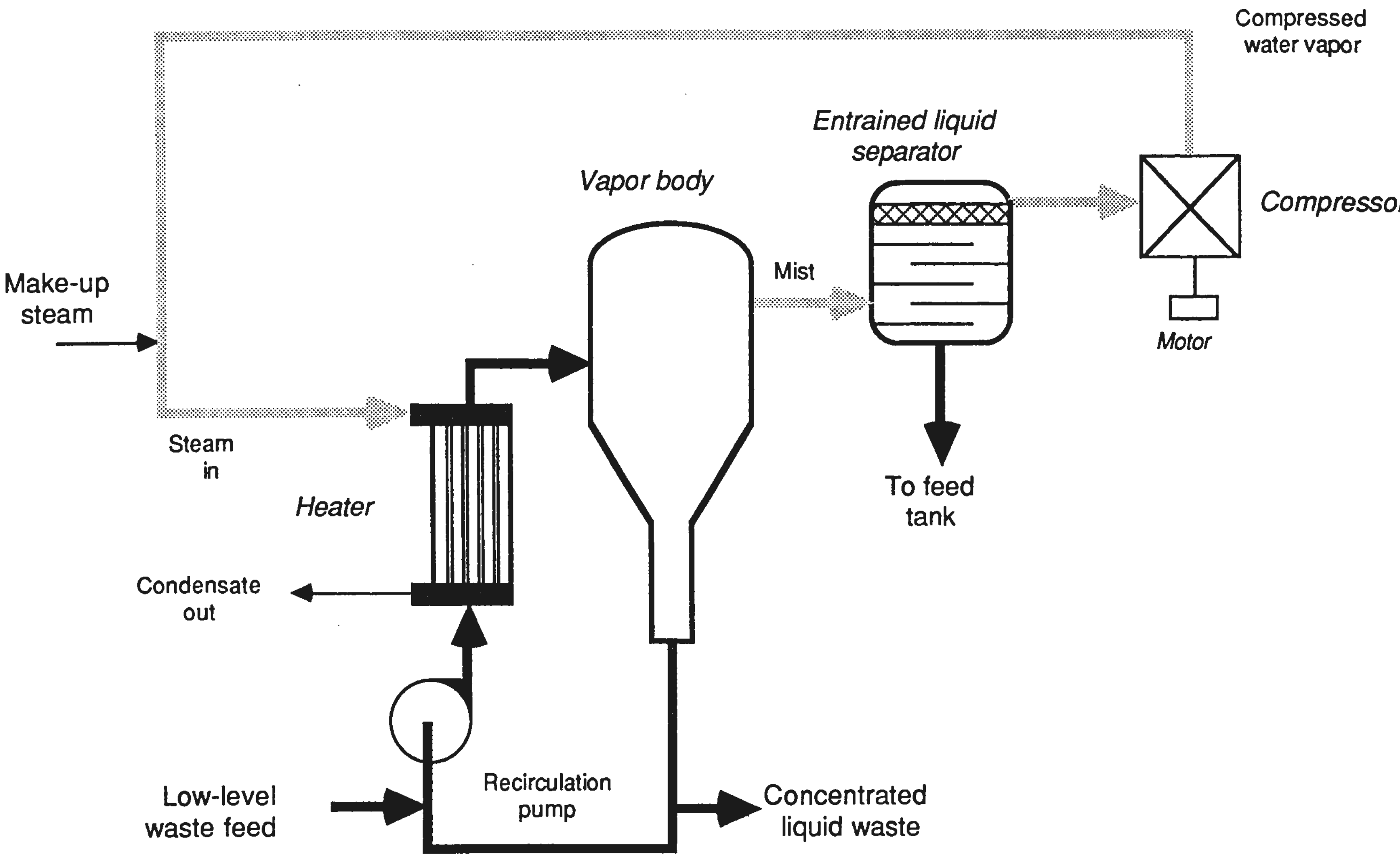

Figure 5-5. Forced-circulation evaporator with vapor recompression.

5.2 Performance Data

This section briefly describes the current and future installations of evaporation/crystallization facilities at nuclear power stations and typical volume reduction (VR) and decontamination factors (DF).

5.2.1 Current and Future Installations

A total of 38 evaporator systems have been installed for treatment of liquid effluent from commercial nuclear reactor facilities.[5-6] Of these 38 evaporators, 53 percent have been applied to aqueous (water) liquids; 13 percent to concentrates; 29 percent to filter residues, resins, and sludges; and 5 percent to nonaqueous liquids. Of these evaporation facilities, 5 have discontinued operation. In 1984, it was reported that other advanced VR commitments have included 1 mobile wiped-film evaporator, 7 evaporative crystallizers and 1 evaporative extruder, with another 13 evaporative crystallizers and 5 evaporative extruders planned.[5-7] Many of the early evaporators for nuclear facilities were sized in the 1 to 10 gallons/minute (gpm) range. These units were found to be undersized. Typical units today are sized in the range of 15 to 30 gpm (900 to 1,800 gallons/hour).

5.2.2 Waste Generation

Evaporative crystallizer-VR factors for concentrated liquids range from 3.5 to 3.9 for wastes from pressurized water reactors (PWRs) and from 1.7 to 2.1 for wastes from boiling water reactors (BWRs) (Reference 5-7). Evaporative extruder units have achieved VR factors ranging up to 6.6 on wastes from PWRs and 3.8 on wastes from BWRs. VR factors for sludges and ion-exchange resins are approximately 2.0 for evaporative extruders. Mobile evaporators have achieved a VR factor of 5.4 on concentrated liquid from a PWR.

The decontamination factor (DF) for an evaporator can be defined as the ratio of the radioactive contaminant concentration in the feed to the contaminant concentration in the distillate (evaporated liquid). Typical

DFs range from 100 to 10,000 for radionuclides (not including iodine) and from 100 to 1,000 for iodine. This means that for iodine, the radioactivity concentration of iodine in the evaporated liquid will be 100 to 1,000 times less than that in the feed stream.

5.3 Regulatory Status

Evaporators are evaluated as part of the licensing process of a nuclear facility. No specific regulations have been promulgated that exclusively apply to evaporators. Since the evaporation or crystallization process involves the evaporation of a liquid (usually water) from a contaminated effluent, a relatively clean liquid and a concentrated effluent are formed.

The desired concentrations of radionuclides in effluent and sludge will depend on the end use of the water, which may include reuse in a process, discharge to evaporating or percolation ponds, or disposal following solidification.

Because of this, evaporator/crystallization systems must comply with regulations, codes, and standards pertaining to releases to the environment and final disposal. The disposal of solid and sludge residues are discussed in other sections of this manual as are the applicable regulations. Applicable regulations, codes, and standards that apply directly to the evaporation/crystallization process are provided below. A complete list is provided in Appendix A.

- 10 CFR 20.302 — Monitoring and Obtaining Approval of Proposed Procedures
- 10 CFR 50, Appendix A Criterion 64 — Monitoring of Radioactive Releases
- 10 CFR 50, Appendix I — As Low As Is Reasonably Achievable in Light Water Reactors

o	10 CFR 50.34	Design Objectives for Equipment to Control Releases of Radioactive Material into Effluents at Nuclear Power Reactors
o	10 CFR 50.36	Semi-Annual Effluent Reports
o	40 CFR 190	Environmental Radiation Standards for Nuclear Power Operations
o	ANS 40.35 (Draft)	Volume Reduction of LLW
o	10 CFR 61	Waste Classification and Stability Requirements

Many other codes and standards are applicable to the construction and operation of evaporator/crystallizer facilities, including those of the American Society for Testing and Materials (ASTM), National Electrical Manufacturers Association (NEMA), National Fire Protection Association (NFPA), and American National Standards Institute (ANSI).

5.4 Technical Details

Detailed evaporator system design standards, performance data, and operating characteristics are included in this section. Focus is placed on understanding the systems as a whole, from pretreatment to evaporation to post-evaporative operations.

Figure 5-6 shows a general overview of major processes used as part of, or in conjunction with, the evaporation system. These processes include pH adjustment to reduce acidity, evaporation, post-evaporative drying of the concentrated liquid or slurry waste, recompression or condensation of water vapor, and treatment/disposal of the concentrated waste material.

In order to understand the whole evaporation scheme, two separate systems will be described: a forced-circulation evaporator and a forced-circulation evaporative crystallizer with vapor recompression. The processes of pH adjustment and concentrated waste treatment/disposal will also be summarized.

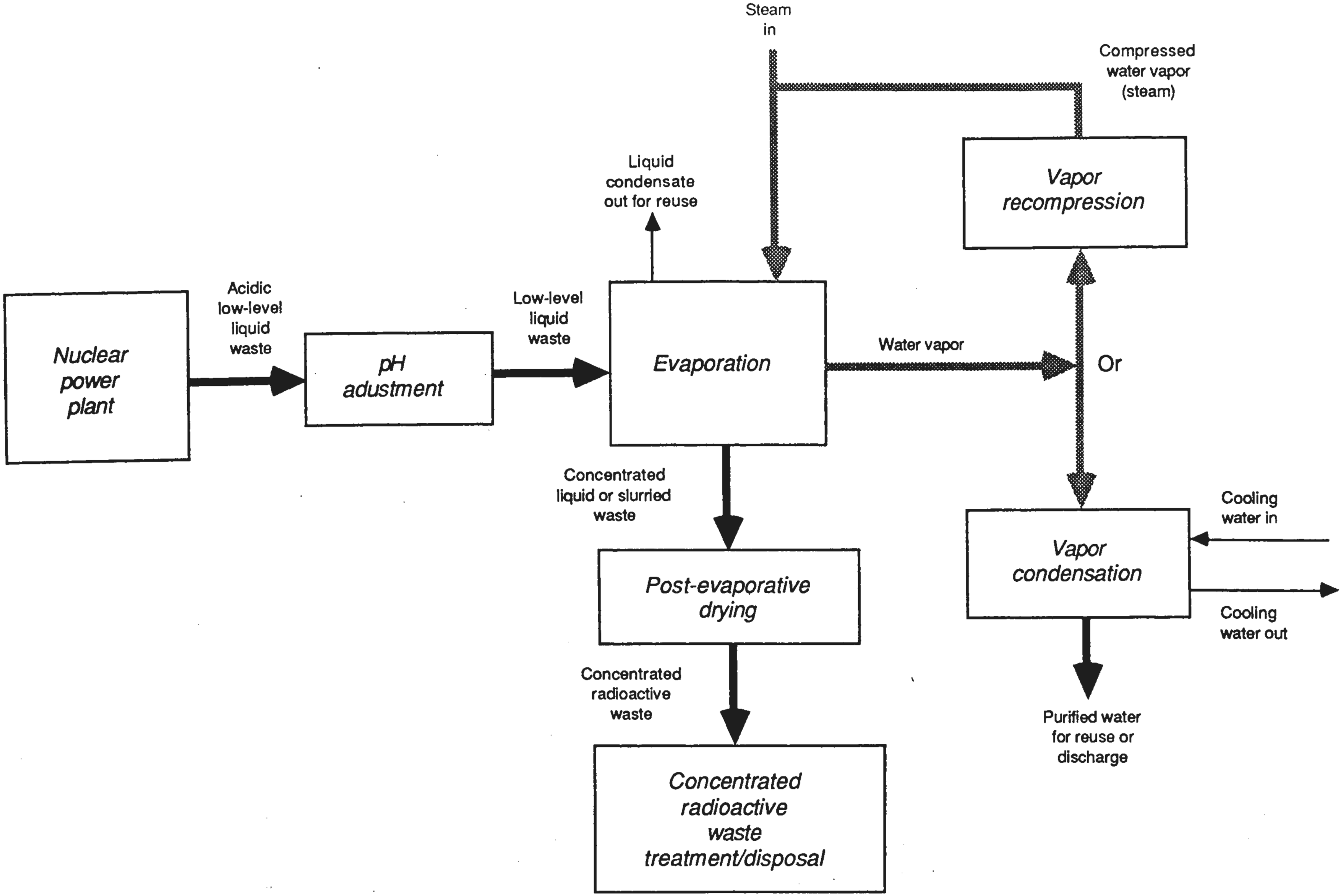

Figure 5-6. Overall evaporation/evaporative crystallization process.

5.4.1 pH Adjustment

Many early radioactive waste evaporators were constructed of 304, 304L, 316, and 316L stainless-steel materials. However, these materials are susceptible to corrosion, pitting, and stress cracking under conditions sometimes encountered during evaporation. These conditions include acidic pH, temperatures above 150°F, thermal cycling, and elevated levels of dissolved chlorides in the liquid waste.[5-8]

Prior to processing any liquid waste by evaporation, the corrosivity of the waste must be adjusted to prevent equipment damage. A pH of 7 is considered a neutral solution. If the pH of the solution is less than 7, the solution is considered acidic. If the pH of the solution is greater than 7, the solution is considered basic. Typically, the feed stream would be adjusted to a pH of 7-9 to ensure that the waste being processed is not acidic. Normally, sodium hydroxide (caustic soda) is added to the feed stream to increase the pH of the feed stream. Operating an evaporator in the acidic range for long periods of time requires special materials of construction, which add substantially to the cost of the equipment.

5.4.2 Forced-Circulation Evaporator

A simplified flow diagram for a forced circulation evaporator is shown in Figure 5-3. A pump withdraws liquid from the vapor body and forces it through the heater. Circulation is maintained regardless of the water evaporation rate (Reference 5-4).

Evaporators of this type can produce concentrated liquid wastes with a total solids concentration of about 25 percent. Natural-circulating evaporators are capable of producing liquid waste with about 20 percent dissolved solids (Reference 5-8). Typical evaporator operating characteristics are given in Table 5-3.

TABLE 5-3. TYPICAL FORCED-CIRCULATION EVAPORATOR OPERATING CHARACTERISTICS (Reference 5-8)

Feed flow rate	15 - 30 gallons per minute
Feed liquid temperature	50 - 120°F
Steam pressure	12 - 20 psi gauge
Steam temperature	240 - 260°F
Water evaporation rate	6,000 - 10,000 pounds per hour
Solids content of concentrated liquid waste	20 - 25 percent by weight
Solids content of water from the condenser	Less than 1 part per million

5.4.3 Forced-Circulation Evaporative Crystallizer with Vapor Recompression

Evaporative crystallizers are capable of producing concentrated liquid waste with a much higher solids content, as high as 50 percent by weight (Reference 5-3). The higher concentration of solids is achieved by forced circulation of undissolved (suspended) solid crystals; however, special materials resistant to pitting, erosion, and stress cracking are required to stand up against the circulating suspended solids. For BWRs, the standard alloy for the vapor body, recirculation system, and heater is Incolloy 825. The material of construction for PWRs is Inconnel 625.

The operating characteristics for an evaporative crystallizer are similar to those shown in Table 5-3. However, temperatures and pressures are somewhat lower and solids content significantly higher with evaporative crystallizers.

The vapor recompression system can substantially reduce the operating costs of an evaporator system. Typically, a single-stage centrifugal compressor is used. The compressor is driven by an electrical motor, steam turbines, or diesel engines. All of the vapor leaving the entrained liquid separator is compressed and returned to the heater. Essentially all of the operating costs of the unit are associated with electrical power for the motor-driven compressor and recirculation pump. A typical compressor for a 20 gpm evaporator is sized to compress 5,170 cubic feet of vapor from 14.5 psia to 26 psia, producing superheated vapor. The efficiency of the compressor is in the 76 percent range. To prevent the possible leakage of radioactive vapors from the compressor, a steam buffer is provided between the seals.

In a 20 gpm mechanical vapor recompression system, the evaporated vapors are compressed to above atmospheric pressure (approximately 22-26 psia). The recompressed vapors provide the majority of heat required to maintain the designed evaporation rate. Typically, only between 300 and 1,000 lb/hr of steam are required for make-up. This steam requirement is usually provided by a small electric boiler at startup.

5.4.4 Concentrated Waste Treatment and Disposal

Following evaporation, the concentrated liquid or slurry waste may undergo additional drying to further reduce waste volume.[5-9] The waste must then be solidified, encapsulated, or in some manner treated prior to disposal. The extruder-evaporator unit produces a solidified waste material, but other evaporator systems in this chapter require post-evaporative treatment. It is also possible that the evaporated water may still not be of sufficient quality for direct discharge to the environment, particularly if organics are present in the waste stream. Treatment/disposal technologies are described in other sections of this report.

5.5 Costs

Typical capital cost estimates, including labor, indirect costs, engineering, and construction management, for an evaporator crystallizer retrofit, an evaporator extruder facility, and a mobile thin-film evaporator are presented in Table 5-4, with operating and maintenance costs shown in Table 5-5.[5-10] Recent cost estimates for skid-mounted evaporators are around $500,000 for a 10 gpm system and $1,400,000 to $2,500,000 for a 100 to 250 gpm system.[5-11] Capital costs are highly dependent on the materials of construction.[5-12]

With any LLW volume reduction technology system reliability is an important concern with respect to maintenance. Maintenance costs are much higher in LLW systems because of the concentration of radioactive material in the liquids and solids in the system as well as its structural and operating components.

The operating cost of evaporators depends on the type of unit chosen. A comparison of the cost of steam, electricity, and water for a mechanical recompression unit and a multieffect evaporator system capable of evaporating 75,000 lb/hour (150 gpm) of water is shown in Table 5-6.[5-13] Table 5-6 shows that the cost of steam for the mechanical recompression is considerably less than that of a multieffect or, for that matter, a single-effect evaporator. The calculated pounds of water evaporated per

TABLE 5-4. CAPITAL COST ESTIMATES FOR SELECTED EVAPORATOR FACILITIES (1984 Dollars)

Cost Element	Evaporator Crystallizer Retrofit	Evaporator Extruder Facility	Mobile Evaporator
Capital Cost			
Major equipment	$2,500,000	$3,060,000	$3,000,000
Buildings and structures	65,000	712,000	3,000
Utilities	--	98,000	--
Site improvements	--	13,000	--
Piping	840,000	860,000	6,000
Instrumentation	144,000	113,000	--
Electrical	198,000	210,000	18,000
SUBTOTAL	$3,747,000	$5,066,000	$3,027,000
Labor	1,058,000	1,610,000	167,000
Indirect	1,345,000	1,817,000	562,000
Engineering and management	923,000	1,274,000	563,000
TOTAL CAPITAL COST	$7,073,000	$9,767,000	$4,319,000

TABLE 5-5. OPERATING AND MAINTENANCE COSTS FOR SELECTED EVAPORATOR FACILITIES (1984 Dollars)

Cost Element	Evaporator Crystallizer Retrofit	Evaporator Extruder Facility	Mobile Evaporator
Maintenance			
Maintenance materials	$ 74,000	$128,000	$90,000
Maintenance labor	75,000	75,000	50,000
TOTAL COSTS	$149,000	$203,000	$140,000
Operating labor	$125,000	$175,000	$175,000

TABLE 5-6. COST COMPARISON OF MECHANICAL RECOMPRESSION AND A MULTIEFFECT EVAPORATOR (1987 Dollars)

Cost Component	Mechanical Recompression	Multieffect Evaporator
Steam - cost	$8.58/hr	$39.60/hr
- quantity	2,600 lb/hr	12,000 lb/hr
Electricity - cost	$16.59/hr	$2.00/hr
- quantity	1,060 hp	85 hp
Water - cost	$0.10/hr	$1.65/hr
- quantity	65 gpm	1,400 gpm
TOTAL COST/HOUR	$25.27	$43.25
Water/steam ratio	29	6

pound of steam reaches a water-to-steam ratio of 29 for mechanical vapor recompression. Annual operating costs are also considerably lower.

In conclusion, the number of evaporator effects and the use of mechanical vapor recompression can reduce the operating cost of LLW evaporator systems, since they evaporate more water per pound of steam when compared to single-stage evaporation systems.

5.6 Mixed Waste

Just as evaporators can be used to reduce large volumes of liquid LLW, they can also be used to reduce volumes of dilute liquid mixed waste, provided the hazardous component(s) of the liquid are not volatile and remain with the evaporator bottoms for further treatment and disposal. An evaporator may be considered by the EPA or a delegated state program as a treatment facility requiring a RCRA Part B permit if the liquid undergoing treatment is considered to be "solid waste," as defined in 40 CFR 261. If an evaporator is part of an operational process, treating process water, it is likely that the evaporator will not be subject to RCRA permitting requirements. Further treatment or disposal of any mixed waste resulting from evaporator operations would, however, be subject to RCRA permitting and disposal requirements. These requirements would be in addition to satisfying NRC and/or Agreement State requirements under the Atomic Energy Act, as amended. Nuclear Management and Resources Council is currently studying the question of applicability of RCRA to the operations of nuclear power plants, and a report is expected in Spring, 1989.[5-14]

5.7 Vendors and Users

Numerous vendors manufacture and sell evaporators/crystallizers as well as complete systems that can be used for volume reduction of many waste types, including LLW. Some vendors specialize in a particular type of evaporator, while others supply a broad range of technologies. Reputable vendors will be more than willing to provide references and descriptions of past projects to permit a buyer to assess the performance of equipment currently in operation.

The selection of a vendor as well as the type of evaporator depends on the characteristics of the waste as well as site-specific factors such as electricity and fuel costs, space availability, availability of steam, and level of radioactivity in the LLW stream. Like incinerators, the evaporation characteristics of the waste, not its radiological characteristics, determine the type of evaporator. A properly designed shielding and containment system about the evaporation equipment provides for control of radioactive emissions and protection of employees at the facility. ALARA requirements are important since evaporation is actually concentrating the radioactivity.

A list of evaporator and crystallizer vendors by equipment type is presented in Table 5-7. The types of systems include crystallizers and forced circulation, rising film, falling film, multiple effect, and vapor recompression evaporation units.[5-15, 5-16] The listing needs to be qualified by the fact that many vendors avoid radioactive waste system installations. The order of vendors is alphabetical. The list is representative of vendors and does not constitute an endorsement of any particular vendor(s).

Many boiling water reactors and pressurized water reactors employ evaporators to treat process water. The following is only a partial list of facilities employing this technology:

1. BALTIMORE GENERAL ELECTRIC
   Calvert Cliffs Nuclear Plant
   Lusby, Maryland
   301-260-4436

2. COMMONWEALTH EDISON
   LaSalle County Nuclear Plant, Seneca, Illinois
   Dresden Nuclear Plant, Morris, Illinois
   312-450-5349

3. WISCONSIN ELECTRIC POWER
Kewaunee Nuclear Plant
Carlton, Wisconsin
414-221-2345

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TABLE 5-7. LIST OF EVAPORATOR VENDORS

Vendor	Crystallizers	Forced Circulation	Rising Film	Falling Film	Multiple Effect	Recompression
APV Crepaco 395 Filmore Ave. Tonawanda, NY 14150 (716) 692-3000	X	X	X	X	X	X
Alloy Fab. Inc. 200 Ryan St. P.O. Box 898 South Plainfield, NJ 07080 (201) 753-9393	X					
Aqua-Chem, Inc. P.O. Box 421 Milwaukee, WI 53201 (414) 962-0100)	X	X	X	X	X	X
Artisian Industries Inc. 73 Pond Street Waltham, MA 02154 (617) 893-6800	X	X	X	X	X	X
Corning Process Systems Big Flats Plant Big Flats, NY 14814 (607) 974-0299			X	X		
Dedert Corporation 20000 Governors Drive Olympia Fields, IL 60461 (312) 747-7000		X	X	X	X	X
Doyle and Roth Mfg. Co. 26 Broadway New York, NY 10004 (212) 269-7840				X		
Evaporator Technology Corp. 3435 Harlem Road Buffalo, NY 14225 (716) 876-5042	X	X	X	X	X	X
French Oil Mill Machinery Co. 1035 W. Greene Riqua, OH 45356 (513) 773-3420		X	X	X	X	X

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TABLE 5-7 (continued)

Vendor	Crystallizers	Forced Circulation	Rising Film	Falling Film	Multiple Effect	Recompression
Graver Co. 2720 U.S. Hwy 22 Union, NJ 07083 (201) 964-2600	X	X			X	
HPD, Inc. HPD Place Box 3032 Naperville, IL 60566 (312) 357-7300	X	X	X	X	X	X
Paul Mueller Co. Inc. P.O. Box 828 Springfield, MO 65801 (417) 831-3000				X		
Pfaudler-US, Inc. P.O. Box 1600 Rochester, NY 14692 (716) 235-1000				X		
Resources Conservation Co. 3101 N.E. Northup Way Bellevue, WA 98004 (206) 828-2400				X		X
Swenson Process Equip. Inc. 15700 Lathrop Ave. Harvey, IL 60426 (312) 331-5500	X	X	X	X	X	X

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6. HIGH-INTEGRITY CONTAINERS

The low-level radioactive waste (LLW) form stability requirements of 10 CFR 61.56(b) require that structural stability of the waste be achieved either by the waste form itself, by processing the waste to a stable form, or by placing the waste in a disposable container or structure that provides stability after disposal. A container that provides stability to the waste after disposal is called a high-integrity container (HIC). This chapter reviews the use of HICs, emphasizing the NRC topical review process.

Section 6.1 provides a general description of HICs. Section 6.2 reviews regulatory requirements, including design and performance criteria, NRC approval process, and approval status of various HICs. Descriptions of each type of HIC are presented in Section 6.3, and advantages and disadvantages of various HIC materials are presented in Section 6.4. Costs and a discussion of the applicability of HICs to mixed waste are provided in Sections 6.5 and 6.6, respectively. Vendors and users are listed in Section 6.7.

6.1 General Description

Use of a HIC can provide a convenient and economical means for handling, transporting, and disposing of low-level waste. HICs are most frequently used in conjunction with dewatering or drying systems for wet solids such as ion-exchange resins and filter sludges. Since the HIC eliminates the need to solidify wastes to achieve a stable waste form, the use of a HIC can reduce the total volume of waste disposed. Considering this advantage, the HIC may be considered a volume reduction as well as a stabilization technology.

HICs are used primarily for the disposal of Class B and C wastes and those Class A wastes which are required by Washington and South Carolina to be stabilized (wastes with half-lives greater than 5 years with concentrations in excess of 1 uCi/cm^3). Due to their cost, HICs are rarely used to stabilize other Class A wastes.

6.2 Regulatory Status

6.2.1 Design and Performance Criteria

In the Branch Technical Position on Waste Form (Reference 1-4), the U.S. Nuclear Regulatory Commission (NRC) outlined the following specific requirements for HICs:

1. Should contain less than 1 percent free liquid by volume of waste
2. Should endure a minimum lifetime of 300 years
3. Should resist the corrosive and chemical effects of both the waste contents and disposal environment
4. Should possess sufficient mechanical strength to withstand horizontal and vertical loads on the container equivalent to the depth of the disposal. [This requirement ensures that the HIC can withstand the structural forces imposed by the soil overburden. Soil produces a downward load on the top of a container and, in certain cases, soil loads are also imposed on the sides of a container. The HICs are subject to burial as deep as 7.6 meters (25 feet) at Barnwell, South Carolina, and 16.8 meters (55 feet) at Richland, Washington. Soil pressure at these depths can be significant.][6-1]
5. Should resist biodegradation
6. Should consider the thermal loads from processing, storage, transportation, and burial
7. Should use construction materials that provide radiation stability, assuming a maximum radiation level is 1×10^8 rads total dose
8. Should meet requirements for a Type A package including a 4-foot drop test onto an unyielding surface
9. Should not allow collection or retention of water on its top surfaces
10. Should provide a positive seal for the design lifetime of the container.

These requirements are defined in greater detail in Appendix A of this manual.

Two of the Agreement States also impose their own performance criteria. Washington and South Carolina impose a 7.6-meter (25-foot) drop test onto compacted sand. This test simulates a handling mishap and imposes additional constraints on the type of materials used to fabricate a HIC. For example, it effectively rules out or severely limits the use of brittle materials (Reference 6-1).

Although not a regulatory requirement, HICs should be relatively easy to fabricate and competitive in cost to other waste management alternatives. While this may be of secondary concern from a regulatory standpoint, it is of significant importance to the users.

6.2.2 Approval Processes

For most applications, HICs must be approved by both the disposal site regulator and the NRC. Since HICs may be used by a variety of waste generators and may be disposed of at several different disposal sites, the NRC has provided a means for submitting "generic" (albeit vendor-specific) HIC information for review and approval by the NRC staff. The process requires the development of a topical report that describes the HIC and how it meets the requirements and guidance of the NRC and the states that have LLW land disposal facilities.[6-2] Based on a review of the data contained in a topical report, the NRC decides whether the container meets the requirements of an HIC. Prior to the NRC decision, an Agreement State may independently review and approve a container as an HIC. Waste generators may use the container as an HIC until the NRC makes its determination. In most cases, approval of the NRC and disposal site regulator are coordinated.

Once an Agreement State has reviewed the topical report and is satisfied the container will perform as an HIC at a particular disposal site, the Agreement State issues a Certificate of Compliance for the HIC. A

Certificate of Compliance typically specifies conditions and restrictions of use of the HIC and serves as a communication vehicle for these restrictions to the waste generator, manufacturer, and disposal site operator. The issuance of the Certificate of Compliance by the Agreement State has not necessarily coincided with the approval of the topical report by the NRC; however, in most cases these independent approvals are coordinated.

South Carolina and Washington have issued Certificates of Compliance for HICs that have been approved by the NRC. In addition, South Carolina has issued Certificates of Compliance for other containers. Issuance of most of these other certificates predated 10 CFR 61. Certificates of Compliance issued after promulgation of 10 CFR 61 have been limited to containers made of materials comparable to those previously approved. The previously approved containers are currently under review by both the NRC and the states. Nevada usually accepts HICs that have been approved by South Carolina, Washington, or the NRC.

The Agreement States reserve the right to require stabilization of some wastes that are not required to be stabilized under 10 CFR 61. The most commonly encountered wastes of this type are filter media having concentrations greater than 1 uCi/cm^3 of radionuclides with half-lives in excess of 5 years. Much of the stabilized Class A waste received at a disposal site falls into this category. Since the Agreement States, not the NRC, impose this requirement, containers used for the purpose of stabilizing Class A waste do not require approval from the NRC, provided they are not disposed of in a way that would compromise the structural stability of a disposal unit containing Class B and C wastes. Many of the polyethylene containers received at the South Carolina and Washington disposal sites have received approval from the state agencies only.

6.2.3 NRC Approval Status

As of December, 1988, the NRC has approved only three topical reports that discuss HICs for shallow land burial of LLW, with an additional container provisionally approved. These are the Nuclear Packaging series of HICs made of a special stainless steel alloy (Ferralium Alloy 255), the Nuclear Packaging HIC made of steel-reinforced concrete, and the Chichibu Cement Co., Ltd. HIC made of steel fiber reinforced polymer impregnated concrete (SFPIC). The Nuclear Packaging steel reinforced concrete container was specifically designed to accommodate EPICOR-II liners containing low-level wastes from Three Mile Island and is not used for commercial applications. The LN Technologies container, a combination polyethylene and stainless steel, has only recently been provisionally approved by the NRC. Table 6-1 summarizes the status of NRC's review of topical reports on these and other HICs.

6.3 Technical Details

The following section contains brief descriptions of commercially available HICs under review by the NRC. The level of detail included in each description is dependent upon the information provided to Envirosphere by the vendor at the time of publication of this manual. Approvals of HICs by regulatory agencies can change. The reader is cautioned to consult with the applicable regulatory agency prior to packaging waste in a HIC.

6.3.1 Babcock and Wilcox

The Babcock and Wilcox line of HICs (ECOSAFE) are constructed of carbon steel that is encapsulated using the proprietary LOCK-BOND process developed by Advancer Technologies, Inc. The process involves the bonding to carbon steel of proprietary combinations of polymeric resins having high bonding capabilities and adhesive strengths. The LOCK-BOND process results in a surface that the manufacturer claims has an extremely long life in corrosive environments and is more resistant to failure from radiation damage than conventional polymeric materials. The use of thin-walled carbon steel shells makes the containers light in weight and cost-effective.

Babcock and Wilcox is the exclusive licensee of the LOCK-BOND process as applied to nuclear waste. The 55-gallon ECOSAFE HICs are currently offered in two exterior finishes. The ECOSAFE HIC-55EN is designed for normal handling conditions, whereas the ECOSAFE HIC-55P is designed for severe

TABLE 6-1. HIGH-INTEGRITY CONTAINER (HIC)
TOPICAL REPORT REVIEW SUMMARY

Vendor	Type of HIC	Disposition
Chichibu Cement	Steel fiber reinforced polymer impregnated concrete	Approved
LN Technologies	Stainless steel/ polyethylene	Approved
Nuclear Packaging	Ferralium/family	Approved
Nuclear Packaging	Reinforced concrete for EPICOR-II liners	Approved
Babcock and Wilcox	Polymer encapsulated carbon steel	Under review
Bondico Nuclear	Fiberglass/polyethylene	Under review
Chem-Nuclear	Polyethylene	Under review
Hittman	Polyethylene	Under review
TFC	Polyethylene	Under review

handling environments. Due to the design flexibility of carbon steel, custom designs of the container are available. The Babcock and Wilcox HIC is presently under review by the NRC. As of December 1988, it has not been approved for use at any disposal site.

6.3.2 Bondico Nuclear, Inc.

The Bondico Nuclear HIC is specially fabricated from a composite material that the manufacturer claims is resistant to a variety of environmental insults, including: chemical corrosion, gamma and ultraviolet radiation, biodegradation from fungi and bacteria, and temperature cycling. The composite material consists of an inner layer of medium density rotationally molded polyethylene (PE) enclosed in an outer casing of fiberglass reinforced plastic (FRP). The inner PE layer possesses exceptional corrosion resistance to a wide range of potential chemical contents and also resistance to radiation and biodegradation effects. The outer FRP layer provides physical strength characteristics that permit the HIC to meet or exceed the demanding conditions of burial trench environments and high structural strength requirements of the NRC and states.

Bondico Nuclear plans to develop and produce a family of HICs fabricated from this composite material. The overall program for this product is starting with the production of the smallest size unit, HIC-7, that will contain over 7.5 ft^3 of LLW. This will be followed by the development of other size HICs from a 10 ft^3 unit for enclosing standard 55-gallon steel drums up to a 200 ft^3 unit for handling spent nuclear reactor resins.

The Bondico Nuclear package is under review by NRC; as of December, 1988 it has not been approved for use at any disposal site.

6.3.3 Chem-Nuclear

The Chem-Nuclear HIC is fabricated of high-density, cross-linked polyethylene that the manufacturer claims offers strength, durability, radiation resistance, and chemical resistance for a burial life in excess of

300 years. The polyethylene matrix contains a proprietary ultraviolet light inhibitor, which in conjunction with administrative and procedural requirements for storage of the containers, eliminates the potentially embrittling effects of polyethylene from exposure to sunlight. Each HIC is fitted with a passive vent mechanism, a compressed HEPA filter, which allows the passage of gases while prohibiting the release of particulate material.

Chem-Nuclear provides two types of HICs. The first type is an efficient, large volume disposal container, available in five different sizes: 80 ft^3, 120 ft^3, 170 ft^3, 215 ft^3, and 300 ft^3 liners. Not only will they accept the direct containment of dry wastes, but these containers may also be fitted with dewatering internals to dewater particulate materials (bead resins, Powdex™, Ecodex™, diatomaceous earth, activated carbon, zeolites, etc.) to meet the acceptance criteria for disposal. In addition, these containers are fully compatible with Chem-Nuclear's industry-accepted radioactive waste transport cask fleet.

The second type is an HIC Overpack, available in small, medium, large, and 60-gallon sizes. Chem-Nuclear's HIC Overpacks accept the direct containment of dry wastes, one or two 55-gallon drums, and Chem-Nuclear's 24-inch-diameter pressurized demineralizers. The 60-gallon HIC can also replace the 55-gallon drum when direct containment of waste is required.

Chem-Nuclear's HICs are approved by the South Carolina Department of Health and Environmental Control (DHEC) for the disposal of Class A Stable, Class B and Class C wastes at the Barnwell Waste Management Facility. At the US Ecology Nevada Nuclear Center they are allowed as a strong tight container for the disposal of Class A Unstable waste. The US Ecology Washington Nuclear Center allows polyethylene HICs for the disposal of Class A Unstable waste and, combined with a concrete overpack, for the disposal of Class A Stable waste. Chem-Nuclear's topical report has been submitted to the Nuclear Regulatory Commission (NRC) under the NRC topical report program for referencing in licensing applications.

6.3.4 Chichibu Cement Co., Ltd.

The Chichibu Cement Co., Ltd. multiwalled HIC has been approved by the NRC for land disposal of low-level radioactive waste. The HIC is made of three basic barriers. The outer barrier is a standard steel drum or container fabricated of steel. This barrier is provided principally for predisposal conditions related to manufacturing, handling, and transportation. The second structural barrier is composed of a specially formulated concrete that contains Portland cement, aggregate, water, mixing agents, and steel fibers. This special concrete is designated by the acronym SFRC, which stands for steel fiber reinforced concrete. The vendor claims this specially formulated concrete adds to the structural integrity of the overall package and imparts longevity to the unit.

Additional barriers are provided on the inside of the concrete liner and between the concrete and the steel outer shell by impregnation with a monomer that is polymerized in place to provide coatings on the inside and outside of the concrete and to fill any voids in the concrete material. The manufacturer claims this further enhances the HIC's performance by providing corrosion resistance and improved impermeability of the liner. After completion, the concrete liner is called SFPIC, steel fiber polymer impregnated concrete.

This HIC is presently made in two sizes. The configurations are the same as a 200-liter (55-gallon) drum or a 400-liter (110-gallon) drum. Each unit has a fully opening lid that permits easy loading and sealing. These containers have been issued Certificates of Compliance from South Carolina and Washington and have an approved topical report from the NRC. Nevada is considering the specific approval of these containers.

6.3.5 Hittman Nuclear

The Hittman Nuclear line of HICs (RADLOCK) is constructed of high-density, cross-linked polyethylene. The RADLOCK containers come in three sizes, RADLOCK-100, RADLOCK-200, RADLOCK-500, and are sized to fit the cavity of

Hittman's HN-100, HN-200, and HN-500 transportation casks, respectively. The RADLOCK containers can be equipped with underdrain systems for *in-situ* dewatering of wet solid wastes or for use as a disposable demineralizer. All can receive dewatered material without an underdrain.

All RADLOCK containers feature a proprietary closure that does not require the use of additional sealants. The RADLOCK containers have been tested and have successfully met both South Carolina's requirements for HICs and the DOT requirements for Type A packaging. The RADLOCK containers are presently under review by the NRC. These containers are currently acceptable for disposal of Class B and Class C wastes in South Carolina. In Washington they may be used for Class A Unstable wastes or, when used in conjunction with a concrete overpack, for Class A Stable wastes. Nevada is considering approval of these containers.

6.3.6 LN Technologies

LN Technologies has combined polyethylene and stainless steel into a hybrid Barrier Plus™ HIC design. Polyethylene has low structural strength, but is highly resistant to corrosion. Stainless steel, on the other hand, has a high structural strength, but is subject to corrosion from the contained waste and burial environment. The manufacturer claims this hybrid container has high structural strength and excellent resistance to corrosion from contaminated wastes.

The hybrid Barrier Plus™ HIC is fabricated with a 316L stainless steel shell and a polyethylene lining that is rotomolded into the container. The wall thickness of the stainless steel is sufficient to withstand the burial overburden, currently 55 feet for the Richland, Washington facility and 25 feet for the Barnwell, South Carolina facility. The Barrier Plus™ HICs are available with a variety of internals for dewatering bead resins and powdered resins/filter sludges. An entire family of containers, ranging from a container with a disposable burial volume of 96 ft^3 to a container with a disposable burial volume of 179 ft^3, has been designed. The largest of these containers has been tested to certify the entire family. These containers have been conditionally approved for use by the NRC. The use of this family of containers is being considered by the states.

6.3.7 Nuclear Packaging, Inc.

Topical reports for two types of Nuclear Packaging HICs have been approved by the NRC for land disposal. The first type is made of Enviralloy, a duplex alloy of Ferralium-255. Enviralloy HICs are a metal fabrication designed for direct burial with a design life of 300 years. They may also be fitted with bead resin dewatering internals. The manufacturer claims that:

- Enviralloy HICs are highly resistant to any known or anticipated chemicals in boiling water reactor (BWR) or pressurized water reactor (PWR) radioactive waste streams, including oils, organics, acids, and caustics.
- Enviralloy is extremely resistant to corrosion, including intergranular stress corrosion.
- Enviralloy HICs are impervious to ultraviolet radiation and resist pitting.
- The Enviralloy family of HICs has an approved Topical Report from the NRC and Certificates of Compliance from Washington and South Carolina. Enviralloy HICs may also be acceptable for use in Nevada.

The second type of Nuclear Packaging HIC is not generally available for commercial use. It was designed for the transfer and burial of EPICOR II liners associated with the Department of Energy's research on LLRW from Three Mile Island. This type of HIC is constructed of steel reinforced concrete and was the first HIC to receive approval from the NRC. This HIC has only been received in Washington.

Nuclear Packaging also produces polyethylene HICs that are currently acceptable for disposal in South Carolina.

6.3.8 TFC Nuclear Associates, Inc.

The TFC Nuclear Associates, Inc. line of HICs (NUHIC) are constructed of high-density, cross-linked polyethylene and are approved for disposal at the Barnwell facility in South Carolina. In addition, the NUHIC-120 is the only HIC approved by DOE for use at their DOE Hanford facility. The NUHIC design contains a 16-inch diameter opening with one piece threaded cap, front lifting lugs, and a full circumference lifting band with steel cables. The cap is light enough that it may be installed by one worker or a remotely operated capping machine. The NUHIC containers are available with dewatering internals for bead resins, filter medias, or sludges. They are sized to fit several existing shipping casks and are approved for DOT Type 7A packaging. The NUHIC containers come in three sizes, the NUHIC-80, NUHIC-120, and NUHIC-136. The waste volumes for these containers are 80, 140, and 127 ft^3, respectively. The burial volumes for these containers are 90, 158, and 136 ft^3, respectively. The NUHIC containers are presently under review by the NRC.

6.4 Advantages/Disadvantages of HIC Fabrication Materials

Advantages and disadvantages of HIC fabrication materials are listed in Table 6-2. This table is not intended to demonstrate preference for a particular HIC vendor.

6.5 Costs

Vendors were reluctant to provide cost information on the HICs. Polyethylene HICs represent the least expensive type of container; they can range up to approximately $37.50/$ft^3$. The stainless steel and Ferralium HICs are the most expensive type of container, costing as much as $375/$ft^3$. Nevertheless, cost of the container is only one factor involved in the use and choice of an HIC. Transportation distances, regulatory requirements, and shielding requirements are also major factors. Economic factors are discussed in Chapter 1 of this manual.

TABLE 6-2. ADVANTAGES AND DISADVANTAGES OF HIGH-INTEGRITY CONTAINERS

Type of HIC Material	Advantages	Disadvantages
Enviralloy or Ferralium Alloy 255	o Resistant to corrosion o Rigid structure maintains shape even when pressurized o Several sizes and closure options	o Expensive (However, cost may be compensated by other factors.)
Fiberglass/polyethylene	o Resistant to corrosion o Rigid structure maintains shape even when pressurized o Family of sizes o Costs estimated to be comparable to or less than polyethylene HICs	o Too early in the review process to determine the disadvantages of the material
Polyethylene	o Relatively inexpensive o Lightweight o Multiple vendors o Most HICs in service o Resistant to corrosion o A decade of operational experience	o Nonrigid structure o Long-term structural integrity in burial trench is an outstanding issue due to structural creep and increased brittleness from gamma radiation o Limited disposal depths (e.g., no greater than 30 feet without structurally stable overpack) o Requires UV protection during outdoor storage
Polymer encapsulated carbon steel	o Resistant to corrosion o Rigid package o Lightweight o Inexpensive o Easily adaptable to many sizes	o Too early in the review process to determine the disadvantages of the material

TABLE 6-2 (continued)

Type of HIC Material	Advantages	Disadvantages
Stainless steel	o Rigid structure maintains shape even when pressurized	o Expensive o Difficult to fabricate due to the wall thicknesses required to provide adequate corrosion protection. (High cost may be compensated by other factors.) o Subject to stress corrosion and pitting
Steel fiber reinforced polymer impregnated concrete	o Rigid structure maintains shape even when pressurized o Relatively inexpensive	o Heavy container o Damage (e.g., cracking of cement) may be difficult to detect visually

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6.6 Mixed Waste

Existing regulations promulgated under RCRA do not provide for containerization of hazardous wastes as meeting either treatment or disposal requirements. Mixed wastes placed in a HIC must meet all applicable RCRA requirements without regard for any additional environmental protection provided by the HIC.

6.7 Vendors and Users

The following lists the addresses of vendors of HICs. The vendors will be pleased to provide a list of the users to buyers of their HICs. A partial list of users for NRC-approved HICs is shown below.

Vendors:

(1) Chichibu Cement Co., Ltd.
(Distributor: Scimarec Co., Ltd.)
1-1, Tsukimi-cho 2-chome,
Kumagaya-shi, Saitama 360
Japan

(2) Nuclear Packaging, Inc.
1010 South 336th Street
Federal Way, WA 98003
(206) 874-2235

(3) Babcock and Wilcox
3315 Old Forest Road
P.O. Box 10935
Lynchburg, VA 24506
(804) 385-2305

(4) Bondico Nuclear, Inc.
8760 Venice Boulevard
Los Angeles, CA 90034
(213) 559-5858

(5) Chem-Nuclear Systems, Inc.
220 Stoneridge Drive
Columbia, SC 29210
(803) 256-0450

(6) Hittman Nuclear
1256 North Church Street
Moorestown, NJ 08057
(609) 722-5700

(7) LN Technologies
1501 Key Road
Columbia, SC 29201
(803) 256-4355

(8) TFC Nuclear Associates, Inc.
425 Bridgeboro Road
Moorestown, NJ 08057
(609) 778-4529

Users:

(1) Chichibu Cement Co., Ltd.

9th Fl., Asahiseimi-Hibiya Bldg.
5-1 Yurakucho, 1-chome
Chiyoda-ku, Tokyo 100
Japan
03-593-2171

Local Agent: Pacific Nuclear Systems, Inc.
1010 South 336th St.
Federal Way, WA 98003
(206) 874-2235

Southern California Edison and San Diego Gas & Electric Company
San Onofre Station
(714) 368-3000

Pacific Gas & Electric Company
Diablo Canyon Station
(805) 595-4582

(2) Nuclear Packaging, Inc.

Arizona Public Service Company
Palo Verde Station
(602) 932-5300 x6887

GPU Nuclear Corporation
Three Mile Island Station
(717) 944-7621

Portland General Electric Company
Trojan Station
(503) 556-3713 x342

Southern California Edison and San Diego Gas & Electric Company
San Onofre Station
(714) 368-3000

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7. INCINERATION

Incineration refers to using high temperatures to burn and subsequently to reduce the volume of a variety of low-level radioactive wastes. Incinerators are available in a variety of designs, configurations, and sizes. Major incinerator technologies discussed in this chapter are rotary kilns, fluidized beds, and modular systems (also called controlled-air incinerators [CAI]). For modular systems, both starved-air and excess-air systems will be considered. The technologies discussed are applicable to other than low-level radioactive wastes; conventional incinerator technology has been used for municipal solid waste (MSW), institutional waste, industrial waste, and hazardous waste. Major differences in applying incinerator technology to low-level radioactive wastes involve shielding requirements, use of high efficiency particulate air (HEPA) filters, and methods of ash disposal.

This chapter discusses volume reduction of low-level waste by incineration. Section 7.1 describes types of incinerable wastes and types of incinerators. Section 7.2 evaluates performance of the various incinerators, while Section 7.3 summarizes regulations applicable to incinerating low-level wastes. Section 7.4 describes supporting systems required for a low-level waste incineration facility. Section 7.5 itemizes costs, while Section 7.6 discusses applicability of incineration technology to mixed waste, and Section 7.7 lists incineration vendors and users. Appendix C provides descriptions of some operating facilities.

7.1 General Description

Incineration of low-level waste, while primarily a volume reduction technique, has a secondary benefit in the destruction of hazardous organic chemicals often present in mixed waste. In all instances, however, incineration will produce a final product with a higher radionuclide concentration. Two important characteristics of the waste to be incinerated are the ultimate analysis and the heating value. Ultimate analysis is the percent, by dry weight, of carbon, hydrogen, oxygen, sulfur, nitrogen, chlorine, fluorine, and ash (noncombustibles) present in the waste. The heating value is the Btus per pound (energy content), which is a measure of the combustibility of the waste.

The goal of incineration is to maximize volume reduction and desirable reactions while minimizing undesirable reactions, which are dependent in part on the ultimate analysis of the waste. Descriptions of the desirable and undesirable reactions are presented in Table 7-1. Desirable reactions ultimately lead to innocuous products, while undesirable reactions result in acid gases, hazardous gases, or materials detrimental to the atmosphere. To achieve compliance with exhaust gas regulations, acid gases are typically removed by scrubbing. Maintaining proper temperature, residence time, and turbulence in the incinerator minimizes production of carbon monoxide and nitrogen oxide.

7.1.1 Incinerable Wastes

Low-level radioactive incinerable wastes from nuclear power plants include compactible dry active waste (compactible DAW), liquid organic waste, spent ion-exchange resins, and waste oil. Table 7-2 presents a typical ultimate analysis, while Table 7-3 presents typical heat contents of these materials. Nonincinerable wastes include noncompactible DAW (valves, pipe, etc.) and aqueous waste. Other liquid wastes and wet solids may be incinerable; however, more appropriate methods for handling these wastes may include evaporation, evaporative extrusion, and/or solidification. Filter sludges and cartridge filters are generally not incinerated because minimal volume reduction is achieved due to their high ash content.

One concern regarding compactible DAW is the large amount of plastics potentially present in the waste. Incineration of plastics can lead to the formation of acid gases that may require gas scrubbing equipment. At some incinerator facilities, plastics containing chlorine are separated from the DAW stream completely.[7-1] Alternatively, wastes are managed to limit the amount of plastics to less than 5 percent by weight.[7-2, 7-3]

Institutional wastes are expected to be similar to DAW generated at nuclear power plants in heating value. Extensive variability in the amount of inert

TABLE 7-1. DESIRABLE AND UNDESIRABLE COMBUSTION REACTIONS

Reactions	Comment
Desirable Reactions	
Carbon + oxygen = carbon dioxide	Innocuous product
Hydrogen + oxygen = water	Innocuous product
Undesirable Reactions	
Sulfur + oxygen = sulfur dioxide	Acid gas [a]
Chlorine + hydrogen = hydrogen chloride[b]	Acid gas [a]
Fluorine + hydrogen = hydrogen fluoride	Acid gas [a]
Carbon + oxygen = carbon monoxide	Indicates incomplete combustion, which leads to production of methane, benzene, and other products of incomplete combustion
Nitrogen + oxygen = oxides of nitrogen	Reactant in formation of ozone in the atmosphere

a. May require acid gas scrubbing depending on concentration.

b. The reaction of chlorine to hydrogen chloride is desirable in incinerators that have acid gas scrubbers because resulting hydrogen chloride can be easily removed from the off-gas system as compared to chlorine.

TABLE 7-2. ULTIMATE ANALYSIS OF INCINERABLE WASTES[7-4]

Incinerable Waste	Ultimate Analysis (percent dry weight)					
	Carbon	Hydrogen	Oxygen	Sulfur	Nitrogen	Ash
Spent ion-exchange resin	57.0	5.7	14.9	8.5	2.1	11.8
Compactible DAW (average)	63.8	9.3	23.6	0.1	0.2	3.0
Waste oil (average)	84.4	13.5	1.3	0.1	0.2	0.5
Liquid organic wastes	Variable					

TABLE 7-3. HEATING VALUE OF INCINERABLE WASTES (Reference 7-4)

Incinerable Waste	Heat Content (Btu/lb)
Spent ion-exchange resin	12,000
Compactible DAW (average)	14,500
Waste oil (average)	20,000
Liquid organic wastes	Variable

material and the moisture content of these wastes has been observed. In one hospital, plastics were reported at 40 percent by weight.[7-5]

With the above basis, the following describes the three major types of incinerators: the rotary kiln, fluidized-bed, and controlled-air systems.

7.1.2 Types of Incinerators

7.1.2.1 Rotary Kilns. Rotary kilns are large brick- (refractory-) lined, rotating steel cylinders set at a slight angle to the horizontal. Solids are fed into the elevated end of the kiln and move, by gravity and the rotational action of the kiln, to the lower or discharge end of the kiln. Depending on the heating value of the waste, auxiliary fuel may be required to ensure complete combustion of the waste. Auxiliary fuel is also required at startup and shutdown. Rotary kiln systems include a ram or screw feeder, a secondary combustion chamber (SCC) also called an afterburner, and air pollution control equipment. The SCC ensures complete destruction of the gases coming from the rotary kiln. Wastes with a high heating value do not require auxiliary fuel in the kiln, while wastes with a low heating value require auxiliary fuel firing. A schematic representation of a rotary kiln system is presented in Figure 7-1. As indicated in the figure, the complete kiln package includes a method of waste feed, the rotary kiln, the SCC, the gas cooling system, and the air pollution control equipment.

Rotary kilns are distinguished by the location of the burner and the state of the discharged ash. The kiln shown in Figure 7-1 is called a cocurrent kiln because the burner and waste feed are at the same end. If the burner and waste feed are at opposite ends it is called a countercurrent kiln because the gases and waste move in opposite directions. A kiln that discharges the ash in a solid state is known as an ashing kiln, while a kiln that discharges the ash in a molten or fluid state is known as a slagging kiln.

Important operating conditions for the rotary kiln and SCC include the feed rate, temperatures, residence time, and amount of combustion air required.

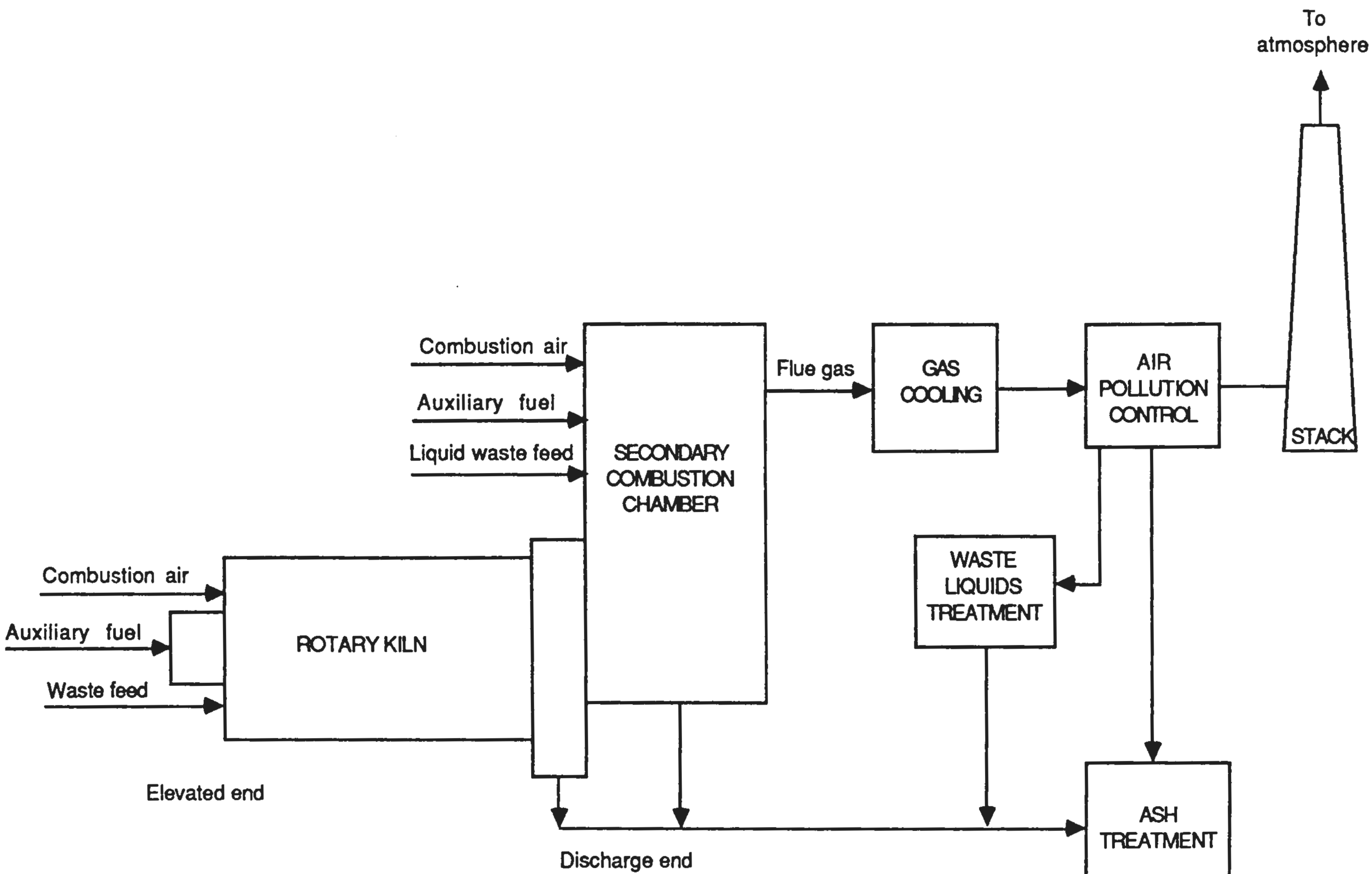

Figure 7-1. Schematic representation of a rotary kiln system.

Feed rates of kilns in radioactive waste and hazardous waste service range from less than 1 ton/hr to over 20 tons/hr. Ashing kilns typically operate at temperatures of 1,200°F to 1,800°F, while slagging kilns operate at 2,200°F to 2,400°F. Residence times of solids in the kilns typically range from 30 to 60 minutes for ashing kilns and in excess of 2 hours for slagging kilns. Residence times of gases range from 1 to 3 seconds. The quantity of air required is expressed as a percentage of the theoretical air required for complete incineration of the waste and auxiliary fuel. Kilns typically operate at 150 to 250 percent of the theoretical air required to minimize carbon monoxide emissions. The SCC operates in the temperature range of 2,000°F to 2,300°F, with a gas residence time of 1.5 to 3 seconds. Typical excess air requirements are on the order of 125 percent of the theoretical air.

Properly operated rotary kilns can convert 99.9+ percent of the carbon in the waste feed to carbon dioxide and can convert virtually 100 percent of the hydrogen to water. The required destruction efficiency of organics under the Resource Conservation and Recovery Act (RCRA) is 99.99 percent. For PCBs the required destruction efficiency is 99.9999 percent as required by the Toxic Substances Control Act (TSCA). These performance standards are obtainable with rotary kiln technology. Particulate and acid gas emissions are generated from incineration in rotary kilns. These emissions must be controlled prior to discharge of the flue gas to the atmosphere. Acid gases are formed from the sulfur, chlorine, and fluorine in the waste feed and auxiliary fuel (if used). Nitrogen oxide is generated from the nitrogen in the waste and the air. As a result, air pollution control equipment is required to remove these pollutants to the level required by local regulations.

The rotary kiln is the most versatile of the technologies described and can handle most types of incinerable wastes including LLW, municipal solid waste (MSW), and mixed wastes. Material may range in size from ion-exchange resin beads to boxes, and may include soils and 55-gallon drums. A slagging kiln will actually melt the drums. The various types of LLW previously described present no difficulty to a rotary kiln. For mixed wastes, the SCC requires auxiliary fuel to maintain the required temperatures necessary to ensure destruction of the hazardous organics. Waste oils and other combustible liquids can be used as auxiliary fuel in the rotary kiln or the SCC.

7.1.2.2 Fluidized Beds. Fluidized-bed combustors are large refractory-lined devices containing an inert bed material such as sand or limestone. Air is fed into the system under the bed material at sufficient velocity to raise the material and make it appear to boil, forming a fluidized bed. Waste is introduced into the bed, where it is burned by contact with the hot bed medium. The intimate contact between the bed medium and the feed ensures complete combustion, assuming that adequate quantities of air are available.

Fluidized beds have been used in industry for over 50 years. Some of the original coal gasification plants developed in the 1930s used fluidized-bed reactors. Fluidized-bed systems have been used for applications in petroleum refining, material drying and processing, chemical manufacture, and solid and liquid fuel combustion. Recently fluidized beds have been applied to the incineration of MSW, biomass fuels, hazardous waste, and LLW.

There are several types of fluidized-bed combustors. The most prominent types are the bubbling-bed and circulating-bed reactors. Schematic representations of bubbling-bed and circulating-bed reactors are shown in Figure 7-2. In the bubbling-bed reactor, the bed medium is held in the reactor by controlling the velocity of the combustion air. Every attempt is made to eliminate loss of bed material through the top of the bed. Typical air velocities in bubbling-bed systems are on the order of 5 ft/second. Circulating-bed reactors operate at higher air velocities (on the order of 15 ft/second) and control the loss of bed material by directing the flue gas through a cyclone (particulate removal device). Bed material is captured in the cyclone and reintroduced into the base of the fluidized-bed reactor. The fluidized bed has a significant advantage over the rotary kiln in that it requires no SCC for final waste destruction. The space above the fluidized bed acts as a secondary combustion chamber for the volatiles released in the bed. This is particularly important in mixed-waste applications where hazardous organics must be destroyed.

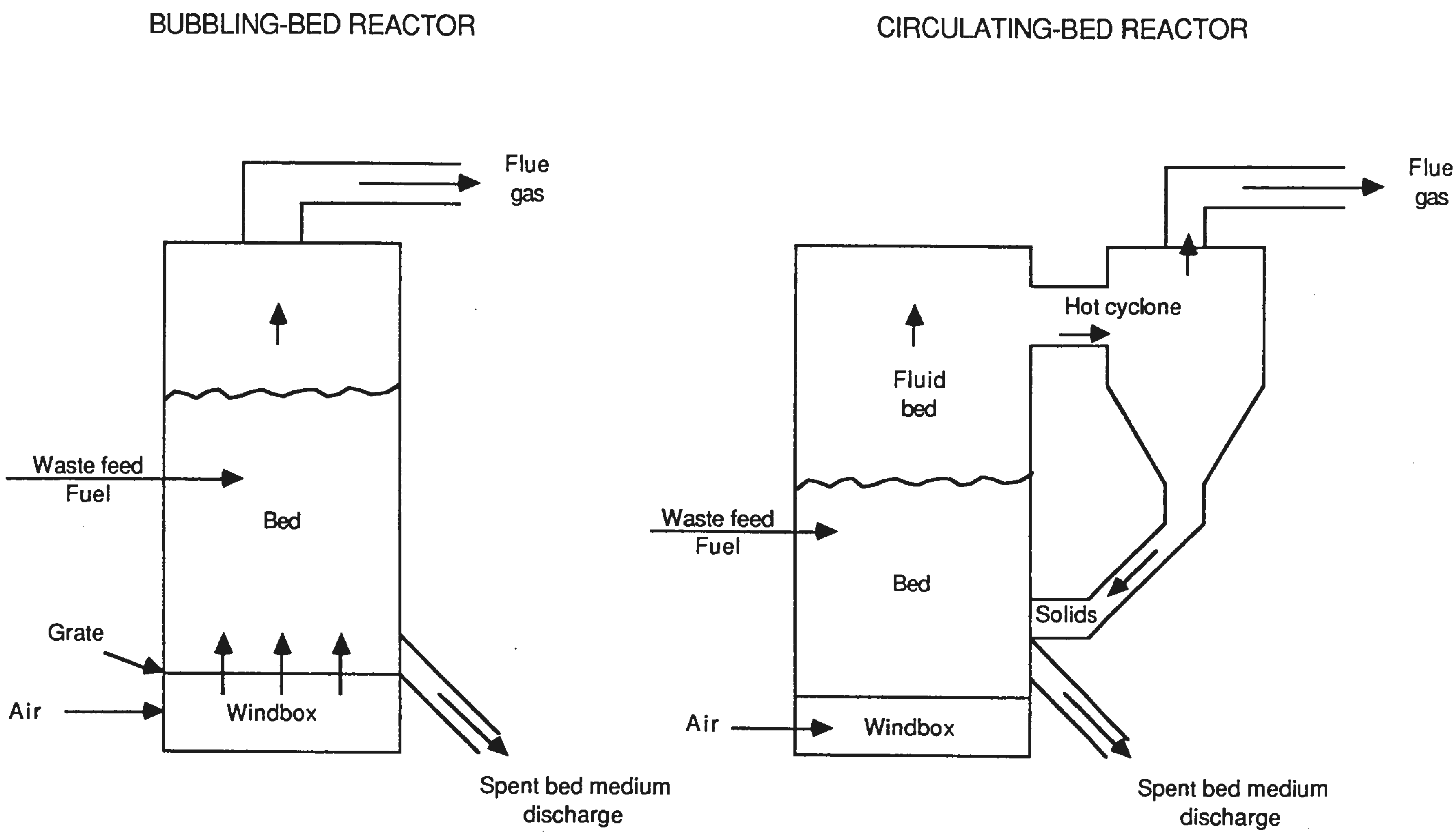

Figure 7-2. Schematic representation of bubbling and circulating fluidized-bed reactors.

Fluidized-bed combustors are designed to operate over a wide range of conditions. Typical MSW incinerators range in capacity from 4 tons/hr in Sundsvall, Sweden, to 20 to 30 tons/hr in the United States. Temperatures employed by fluidized-bed incinerators are in the range of 1,500°F to 1,800°F. The air required for good combustion in fluidized beds ranges from 135 to 200 percent of theoretical air.

Fluidized-bed systems have been demonstrated on MSW, hazardous waste, and LLRW. Conversion of carbon in the waste to carbon dioxide is accomplished at levels of 99.9+ percent. Destruction of organics in soils is achieved at levels greater than 99.9999 percent. Nonacid gas emissions from fluidized-bed reactors are similar to those generated from rotary kilns. One advantage of the fluidized bed is that limestone can be introduced into the bed for in-bed removal of acid gases; as a result, an acid gas scrubbing system may not be required. However, the introduction of limestone into the bed lowers the V: factor because higher molar ratios are required when compared to gas scrubbing equipment. Emissions of nitrogen oxide are minimized because the combustion temperatures are held at moderate levels.

The physical size of the waste that a fluidized bed handles is limited when compared to the rotary kiln. A fluidized bed requires size reduction for DAW, including hospital and other institutional and industrial wastes. Typically, the waste is sized so that 95 percent of the feed is less than 3 inches. As a result, shredding of the material is required, usually involving screening and the removal of metals. However, the fluidized bed is much better at handling wastes with a high moisture content, such as some ion-exchange resins and organic liquids. The ability to handle high-moisture-content material is a function of the large thermal mass that the bed medium supplies. Waste oils, solvents, and aqueous liquids are injected directly into the bed.

7.1.2.3 Modular Incineration Systems. Modular incinerators (sometimes referred to as controlled-air incinerators) represent a third type of unit that is used to incinerate LLRW. Modular incinerators discussed here are factory-assembled units that are classified either as starved-air or excess-air units. The starved-air units sometimes include pyrolysis units. Modular incineration systems have the following basic elements: a materials handling system, a refractory-lined primary chamber, a refractory-lined secondary chamber, air pollution control equipment, and an ash handling system. A schematic of a starved-air modular incinerator is shown in Figure 7-3.

Modular incinerators are used by small municipalities for MSW volume reduction; by commercial and industrial facilities to incinerate paper, plastics, wood, and other organics; and by hospitals for incineration of toxic and pathological wastes. They can also be used for the incineration of LLW and hazardous waste. Modular incinerators have the advantage of being inexpensive, shop-assembled, compact, and easy to operate.

As indicated above, there are two basic types of modular incinerators and a range of possible configurations. However, they are generally referred to as starved-air or excess-air systems. Both types are built to operate at feed rates from less than 250 lb/hr to 2 tons/hr. Larger units are available for higher capacities; however, the advantage of shop assembly is lost.

Modular incinerators typically operate with temperatures in the primary chamber from 1,200°F to 1,600°F and with temperatures in the secondary combustion chamber from 1,800°F to 2,000°F. The consumption of air distinguishes the excess-air from the starved-air system. Excess-air units employ 110 to 130 percent of theoretical air in the primary chamber. The starved-air units operate with 75 to 80 percent of the theoretical air required for combustion. In the starved-air units the primary chamber volatilizes the material into the gas stream for destruction in the secondary chamber. The secondary chamber of both the starved-air and excess-air systems operate as high as 150 percent of theoretical air. Another type of modular incinerator is the pyrolysis unit. Pyrolysis units operate with very little to no theoretical air.

Modular incinerators have a demonstrated record of reliability and efficient operation. Further, when used for hazardous waste incineration, they can

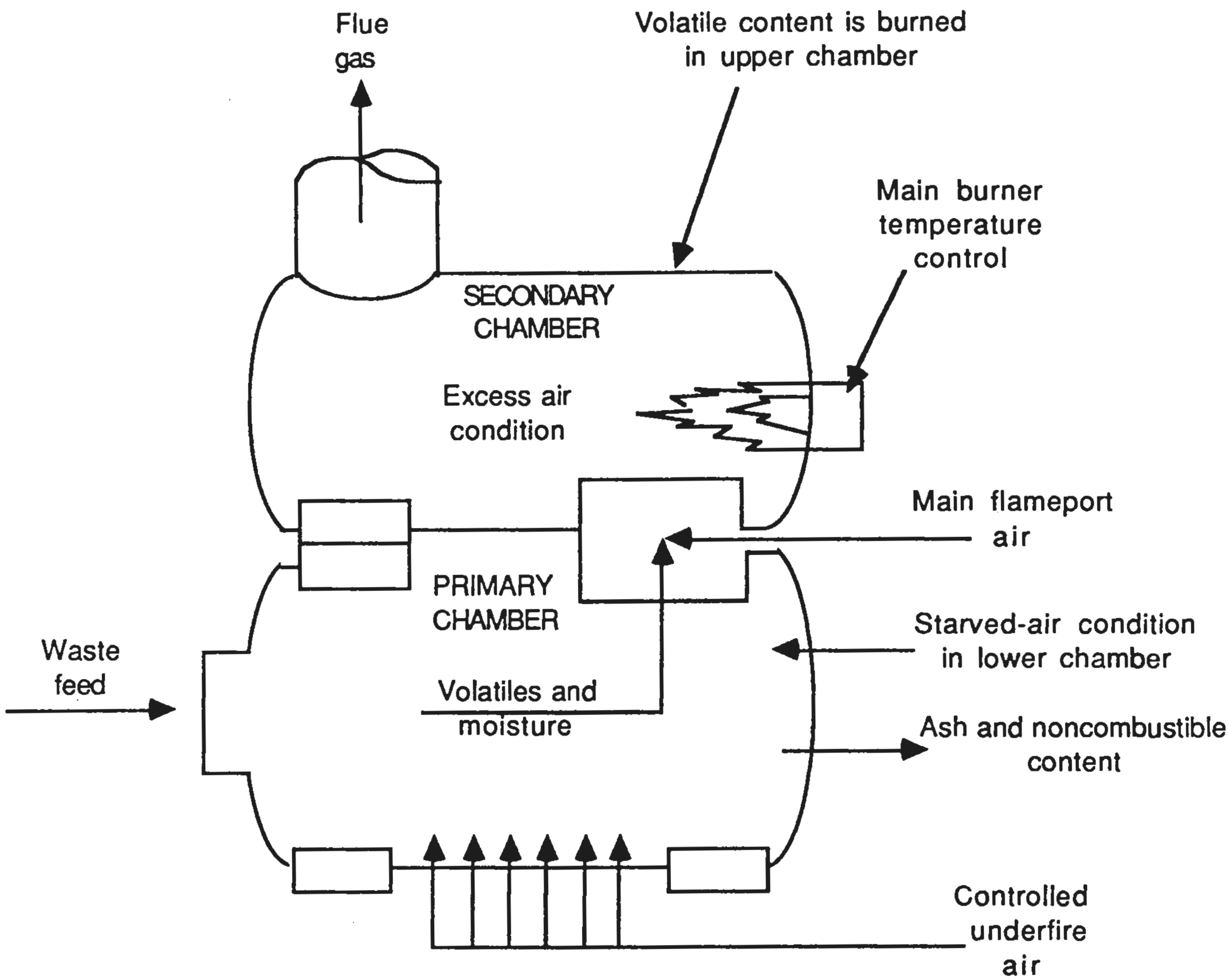

Figure 7-3. Schematic representation of a starved-air modular incinerator.

achieve a 99.99 percent destruction efficiency of hazardous organics. Generation of emissions is similar for the other technologies. However, the starved-air units have much lower gas velocities through the primary chamber and, as a result, generate less particulate emissions. Emissions of nitrogen oxide are controlled by maintaining appropriate temperatures in the combustion chamber. When operated beyond their design feed rate, modular incinerators, as do all technologies, emit large amounts of carbon monoxide and other unburned gaseous products.

Many designs of modular incinerators are available. The units are capable of being continuous or batch fed and being fed unprocessed or processed waste materials. For example, many units can burn MSW directly from the haul truck. A couple of units can accept drummed or boxed material. In general, modular incinerators can accept most of the LLRW types previously discussed.

7.1.2.4 Other Systems. Many other technologies are available for incineration. These include calcining furnaces, plasma torches, electric pyrolyzers, molten glass units, molten salt units, various electric furnaces, and others. These processes are used on aqueous wastes or wastes with a higher specific activity including transuranic (TRU) and alpha emitters from plutonium recovery. An example is the planned installation in 1992 of a pyrolysis furnace and rotary calciner for volume reduction and for the recovery of plutonium at the La Manche storage site near La Hague, France, by the Commissariat A L'Energie Atomique.[7-6] Idaho National Engineering Laboratory also has a calciner. Another example is the IOS (incineration with oxygen and steam) process being developed by Tokyo Electric Power Environmental Engineering Company for use on radwaste slurries.[7-7]

7.2 Performance Data

7.2.1 Existing Systems

The variety of incinerator technologies, associated emission control technologies, and differences in their applications provide little basis for comparative performance evaluations. However, a review of operatirg and future systems produced the following generalizations:

- The majority of incinerators currently used for volume reduction of radiologically contaminated materials are controlled-air incinerators

- Uses of rotary kiln or fluidized-bed incinerators are extremely limited

- Future incineration plans focus on the rotary kiln as the preferred system

- The use of calciners is limited to applications desiring recovery of plutonium.

Table 7-4 presents a summary of controlled-air incineration systems. Full abstracts for each system presented in the table are presented in Appendix C of this manual. These include systems used exclusively for low-level radioactive wastes as well as those used for biomedical wastes with little or no radiological components. As presented in the table, the incinerated wastes are principally solids. In some instances, sludges or ion-exchange resins are also treated. The throughput for controlled-air systems varies from 40 to 1,600 lb/hr, with the majority in the hundreds of pounds per hour range. Volume reduction factors are considerable, from a low of 40:1 to a high of 300:1. Operating temperatures are typically from 1,000°F to 2,000°F. The majority of problems occur not within the systems but at the point of emission of off-gases. Therefore, the problems are more in meeting emission standards than with the systems themselves. The second major class of problems concerns the ash or ash removal systems. These include clinker formation or slagging.

Only one rotary kiln system was reviewed, the Idaho National Engineering Laboratory's Process Experimental Pilot Plant (PREPP) (see Appendix C). This system is undergoing startup tests to incinerate waste contaminated with TRU. Data on volume reduction and other parameters were not available at this writing.

TABLE 7-4. SUMMARY OF REVIEWED CONTROLLED-AIR INCINERATION SYSTEMS

Facility	Type	Principal Wastes	Throughput	Volume Reduction	Operating Temperature	Performance Problems	Comments
Los Alamos National Laboratory	Dual chamber CAI	Liquid organics, sludges, DAW TRU contamination	100 lb/hr solids	Not provided	1,600°F primary 2,000°F SCC	No major problems reported	Demonstration unit for TRU and hazardous
Chalk River Nuclear Laboratories	Two-stage starved-air CAI	Low/intermediate solid wastes	2,200 lbs per 24-hour burn cycle	150	930°F primary 1,610°F secondary	Heat exchanger tubes cleaned/replaced periodically because of fouling/corrosion	--
Idaho National Engineering Laboratory Waste Experimental Reduction Facility	Two-stage CAI	DAW contact dose less than 20 mrem/hr, liquids	400 lbs/hr DAW	300	2,100°F	Premature failure of baghouse bags, clinkers in ash removal system	Liquid waste trial burns awaiting Part B
Bruce Nuclear Power Plant Radioactive Waste Operation Site	Two-stage CAI	Solid LLW	145,000 ft^3/yr	75	570°F-930°F primary 1,750°F SCC	Slagging in primary and uncombusted carbon in secondary chamber	---
Juëlich Nuclear Research Center (Germany)	CAI	Solid LLW, DAW, resins	110 lbs/hr	40 to 100	Data not available	10 years little maintenance	Accepts waste from a variety of sources
CEN-Cadarache Incinerator (France)	CAI starved-air	DAW including PVC	40 to 50 lb/hr	80	Data not available	Waste variety results in rapid filter clogging	---
Scientific Ecology Group	Partial Pyrolysis & CAI	Solid LLW, DAW	1,600 lb/hr DAW planned	Data not available	Similar to Studsvik facility	Under construction	Operational Sept. 1989, expects RCRA permit by 1990
Women's College Hospital	CAI semi-pyrolytic (starved-air)	Solid and biomedical waste	2,900 lb/day 370 lb/hr (capacity)	Data not available	Data not available	Slagging of glass corrected	---
Studsvik Energiteknik AB Radwaste Incinerator	CAI	Nuclear and institutional LLW	540 lb/hr	50	1,560°F primary	None noted	---
Swedish State Power Board Pilot Plant	Pyrolytic	Kerosene and spent resins	70 lb/hr	4	660°F in pyrolysis reactor 2,200°F in SCC	None noted	Pilot plant
Atomic Energy Commission of France	Pyrolytic and calcining	DAW	11 lbs/hr	Data not available	Not available	None noted	Prototype

1140K

As with rotary kilns, the use of fluidized-bed incinerators for waste incineration is severely limited. The one operating system is at the Oconee Nuclear Station (Duke Power) in South Carolina. The system (see Appendix C) is a fluidized-bed dryer and fluidized-bed incinerator. The system processes DAW, oil, resins, and evaporator concentrates at nominal rates of 60 lb/hr, 6 gal/hr, and 19 gal/hr (no data available for concentrates). Volume reduction factors were not available. The dryer system operates at a temperature of 950°F leading to the incinerator at 1,450°F. The most serious operating problem has been bed agglomeration during incineration of resins.

7.2.2 Future Systems

New incineration facilities for volume reduction and detoxification of LLRW, mixed wastes, and RCRA hazardous waste are planned at the Savannah River Plant (SRP) in South Carolina and the Los Alamos National Laboratory in New Mexico.

7.2.2.1 Savannah River Facility. The incinerator at the SRP, called the Consolidated Incineration Facility (CIF), will provide incineration capability for on-site generated boxed LLW, mixed wastes, and hazardous wastes. Boxed LLW is the largest stream generated, accounting for 97 percent of the solid material expected to be fed into the CIF. This waste stream consists of contaminated protective clothing such as cotton coveralls, rags, plastic suits, and PVC shoe covers. It has the following average composition:[7-8]

Waste Component	Weight Percent
Cellulose	40
PVC	8
Polyethylene	23
Latex rubber	19
Water	5
Ash	5

The CIF will use a rotary kiln for the primary chamber coupled to a horizontal, cylindrical SCC. Enclosures around the rotary kiln and SCC feeds will be ducted to high efficiency particulate air (HEPA) filters to prevent the release of radioactive material. Combustion gas leaving the SCC will be treated by a quench, an acid gas scrubber, a cyclone separator, and a mist eliminator. Following this, the flue gas will be reheated and will pass through a HEPA filter before being exhausted to the atmosphere (Reference 7-8). A flow diagram and project schedule for the CIF are presented in Figure 7-4. The unit is scheduled to be completed in 1991 and is expected to cost $30,000,000 (not including permits). It will have a capacity of 12 tons/day and a volume reduction factor of about 22. A RCRA Part B permit is expected to be obtained so the facility can burn mixed and hazardous waste.

7.2.2.2 Los Alamos Facility. Los Alamos National Laboratory is seeking to develop a more flexible feed system and expand its capacity to incinerate LLRW and mixed wastes on-site. The new system will most likely use a rotary kiln as the primary reactor, with a SCC designed with a long residence time. Although the rotary kiln is a likely selection for the primary chamber, concern has been expressed about the quality of the seals.[7-9] The facility is being designed to comply with RCRA permit standards in order to incinerate mixed and hazardous waste. The facility will incinerate only waste generated at the Los Alamos National Laboratory. Construction is expected to begin in 1989, with 1991 as the target completion date. The facility is expected to incinerate boxed LLRW at a rate of 300 lb/hr (3.6 tons/day).

7.2.3 Operating and Maintenance Concerns

As the case studies of existing facilities demonstrate (see Appendix C), there are operating problems that require routine maintenance. These problems include the following:

- o Heat exchanger tubes plug or corrode, necessitating cleaning or replacement

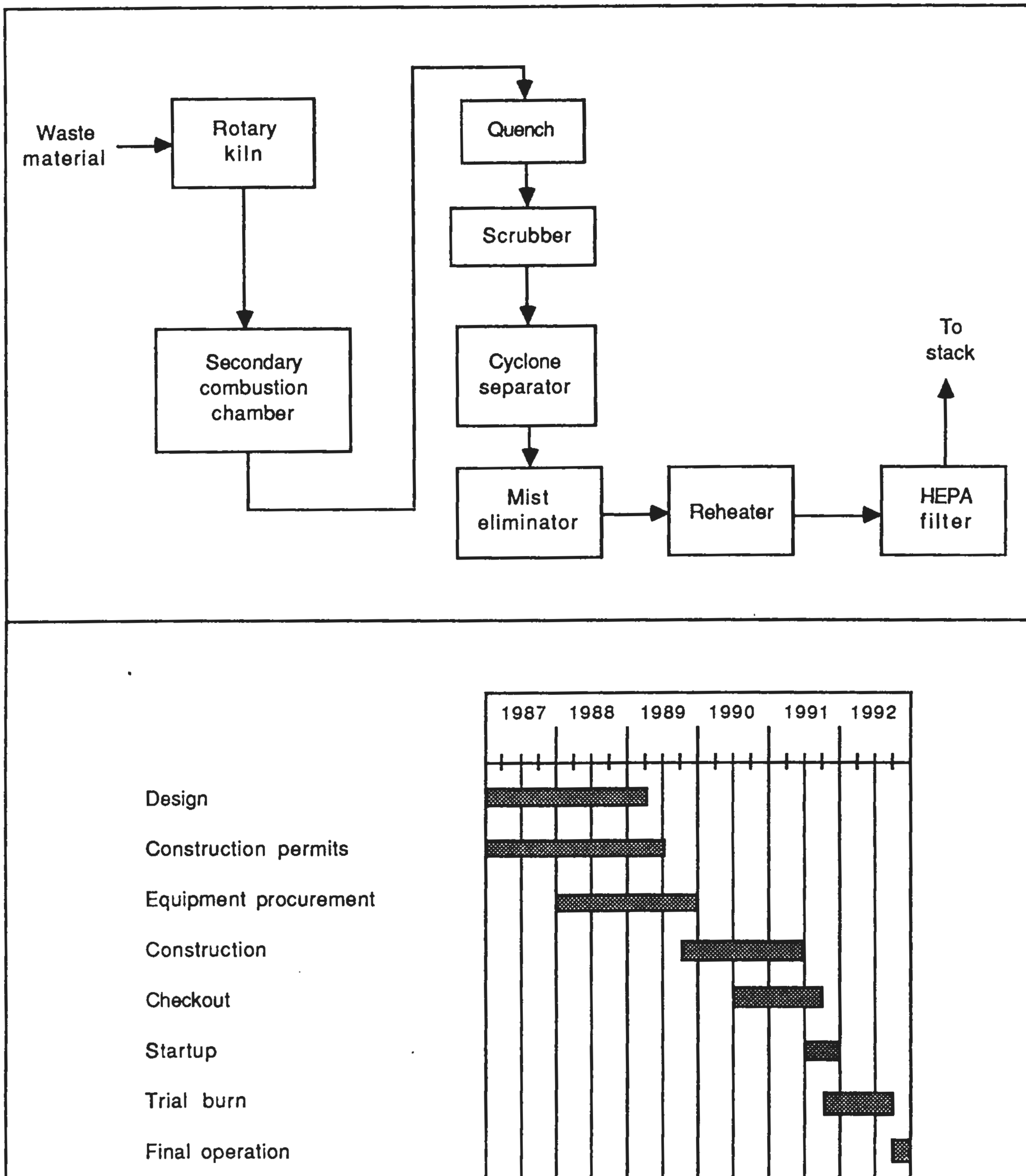

Figure 7-4. Savannah River Plant consolidated incineration facility flowsheet and project schedule.

- Refractory material is exposed to varying temperatures, chemical corrosion, and physical strain

- Baghouse filters corrode from excess amounts of acid gas

- Waste feed and preparation equipment break down

- Ash removal equipment is damaged by slagging

- Metal filter candles require frequent replacement

- Filter linings require frequent replacement.

Controlling the feed rate of materials containing chlorine, sulfur, and fluorine can reduce maintenance problems related to corrosion.

7.3 Regulatory Status

Incinerable LLW includes DAW, ion-exchange resins, waste oils and solvents, and other industrial and institutional wastes. Mixed wastes include material that is both radioactive and contains hazardous materials. LLW is regulated by the NRC, while mixed wastes are regulated by the NRC and the EPA. Local air pollution regulations must also be considered. A general review of the applicable regulations is presented below.

7.3.1 NRC Regulations for LLW Incinerators at Power Generating Stations

Initiation of NRC licensing reviews for a proposed LLW incinerator facility involves formal docketing of the planned vendor system and support facility into a plant's Final Safety Analysis Report.[7-10] The license is normally submitted as a technical evaluation report to substantiate modifications to the plant's operating license for the operation of an incinerator. NRC review involves an evaluation of the system's safety aspects, operability, and environmental releases. The NRC may then require an Environmental Impact Statement (EIS) under 10 CFR 51.5 and 40 CFR 1500.6. Operating plants could also petition under 10 CFR 50.59.

Current regulations, codes, and standards for radioactive waste treatment systems to process liquids, solids, and gaseous effluents are tabulated in Appendix A. There are no NRC guidelines for incinerators and ash transfer systems. Design guidance for incinerators and ash transfer systems is contained in ANS 40.35 (draft Volume Reduction of Low-Level Radwaste, May 1981). Safety features and redundancy are an important part of each system. Releases of radioactive isotopes are limited by 10 CFR 20, Appendix B, for each particular isotope or for unspecified beta-gamma emitters. In addition, 10 CFR 50, Appendix I, provides design objectives for power reactors to meet the "as low as reasonably achievable" (ALARA) criteria.

7.3.2 RCRA Regulations

Mixed wastes are regulated by the EPA under the RCRA program and by the NRC or an Agreement State under the Atomic Energy Act. In order to construct an incinerator for treatment of hazardous or mixed waste, a RCRA Part B permit must be completed. Applicable regulations are contained in 40 CFR 270 Subpart B - Permit Application. A RCRA Part B permit application must be submitted to the local authority, which may include a state department and/or an EPA regional office. This permit application includes a detailed description of site-specific factors, the waste, and the proposed incinerator and support facilities. The level of detail on the incinerator is equivalent to a traditional "50 to 70 percent" design. Once the permit is reviewed, a notice of deficiency is issued if the application is not complete. In this case, the permit application is returned for additional information. If the application is complete and accepted, a permit for construction is issued. A RCRA permit schedule for the Savannah River Plant Consolidated Incineration Facility is shown in Figure 7-5.

An incinerator treating mixed wastes must operate under 40 CFR 264, Subpart O - Incinerators for Hazardous Waste and 40 CFR 265 Subpart O - Interim Status for Nuclear and Other Facilities. These regulations include

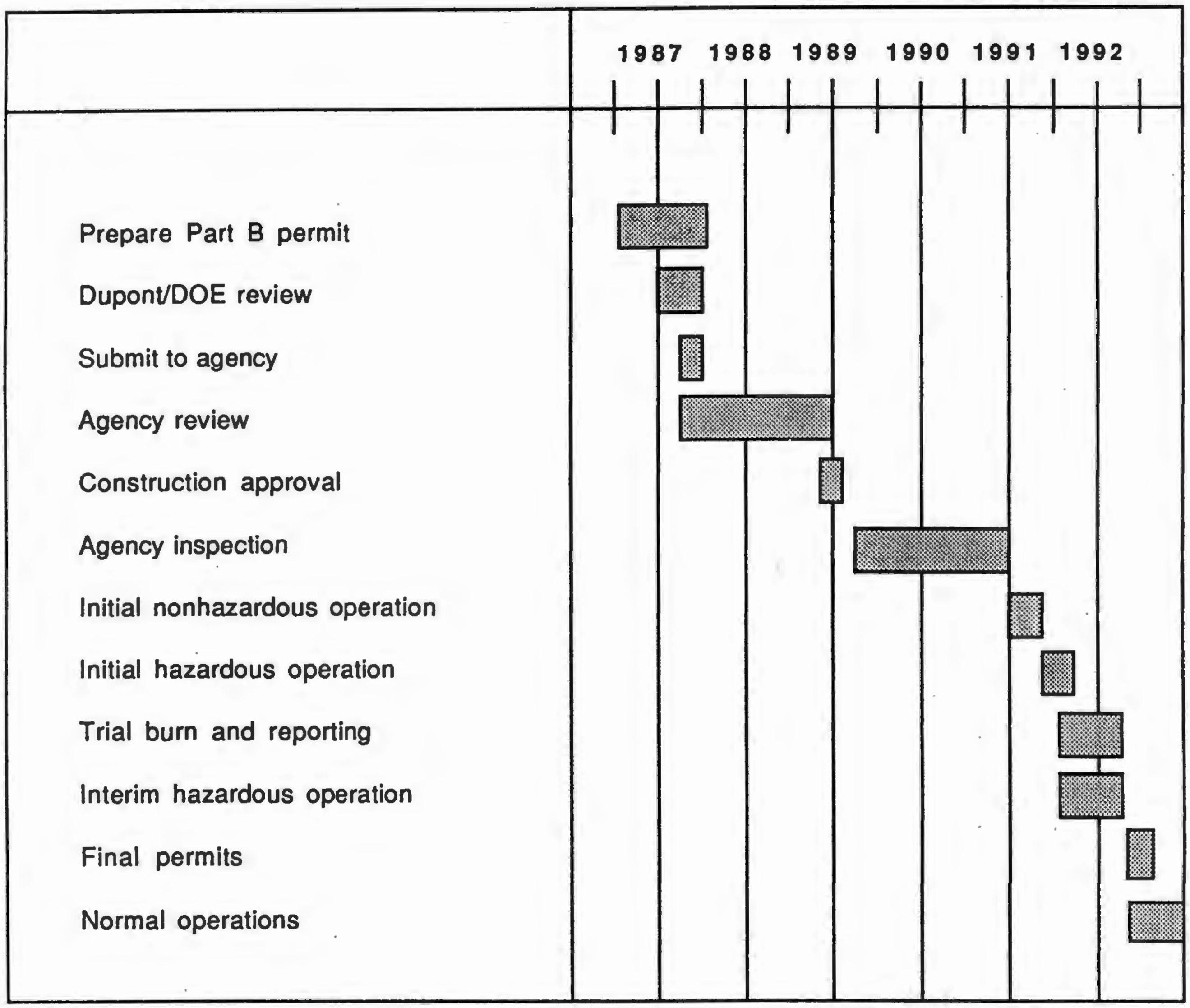

Figure 7-5. RCRA permit schedule for the Savannah River Plant consolidated incineration facility.

a trial burn on the fully constructed and operational incinerator. The trial burn must be conducted on wastes that are typical of the range of material to be incinerated. The results of the trial burn are used to establish operating conditions for the incinerator, including levels of theoretical air, temperatures, residence times, emissions, waste limitations, and other factors. Also, the trial burn sets conditions under which the incinerator must shut down because it is not destroying the wastes to the appropriate level; such conditions include deviations from the permit conditions. A RCRA incinerator must destroy or remove 99.99 percent of the hazardous component of the waste (this is called the destruction and removal efficiency, or DRE).

7.3.3 Other Regulations

Other important regulations include the local air emission standards and Clean Air Act emission standards for radionuclides. All incinerators must operate with emission levels in line with local regulations. Emissions of particulate and hydrogen chloride are set by RCRA. However, in some cases, the local standard is more stringent, and this level (not the RCRA level) should be the design point. Local air emission regulations include the following in most cases: particulate matter; nitrogen oxides; sulfur oxides; hydrogen chloride; carbon monoxide; hydrocarbons; volatile organics; certain metals such as lead, beryllium, and mercury; and certain parameters including level of theoretical air and stack opacity (the clarity of the stack). The level of final control required usually depends on whether the area is or is not an attainment area for a given pollutant. For example, in California most of the industrial areas are in nonattainment for nitrogen oxides. As a result, nitrogen oxides must be controlled to low levels when compared to rural areas that may be attainment areas for nitrogen oxides. Clean Air Act emission standards for radionuclides may also be enforceable at the local level. The EPA is currently revising these standards, which are likely to apply at the facility boundary, not the point of release.

7.4 Supporting Systems

The importance of supporting systems for incineration warrants the inclusion of a separate section. This section discusses supporting systems for a LLW incineration facility, which include material handling, fuel selection, ash handling, and air pollution control equipment.

7.4.1 Material Handling

The major constraining factor in designing a material handling system is the requirement to limit occupational exposure.[7-11] This is also a concern during routine maintenance where workers could be exposed in areas of the incinerator and supporting systems where materials may concentrate, such as in the ash handling and air pollution control systems. Waste segregation, inspections (radiation and visual), sorting, limits on types of waste, and other related concerns are important to assure that only compatible wastes enter the incinerator. Any sorting or administrative material segregation program would be required to comply with the facility's ALARA program.

In general, an incinerator can be fed LLW in several different ways: by screw feeder, ram feeder, chute, and liquid injection lances. For screw feeding, the material must be relatively small in size, like ion-exchange resins. Ram feeding is used for bulky material that is not too compressible. Ram and screw feeding may involve size reduction of the material. Size reduction is not desirable since it increases the likelihood of worker exposure and adds extra processing steps that must be properly shielded and protected from worker contact. Liquid injection can be used for waste oils and solvents or aqueous wastes. Waste oils and solvents may be used for auxiliary fuel firing. In some cases, the solvents may require an absorbent before incineration,[7-12] in which case they could be contained in boxes or bags and bulk fed or screw fed.

On the other hand, bulk feeding involves the direct feeding of waste as it is received at the facility. For example, at some facilities the waste is received in boxes. The safest way to handle this material is to place it "as is" directly into the incinerator. In this case, worker exposure is minimized. As indicated above, bulk liquids can be absorbed, placed in containers, or mixed with other wastes and bulk fed. A bulk-feed system usually includes some sort of elevator to raise the material over the incinerator. This can also be done by having a multilevel structure so that the feed level is on the second floor. The material then passes through air locks and a guillotine door. In bulk solids feeding, it is important to keep the incinerator under negative pressure. Negative pressure will assure that any contaminants are sucked into the incinerator when the feed chute is open. For example, in several Swedish hospitals the wastes are placed on carts around the hospital. Noncompatible wastes are sorted and placed on different carts. These carts are then brought to the incinerator and placed on a monorail. The monorail may contain 10 or more carts. The incinerator is then mechanically fed from carts on the circulating monorail. The carts are steam cleaned and returned to service.

The waste coming into the facility should be characterized. This should include x-ray, radiation assessment, and weighing. If sorting for PVC is required, this should be done at the point where the waste is generated. Another option is for the generator to reduce the use of chlorinated plastics. The actual degree of PVC removal required will depend on the local air pollution requirements for acid gases. However, if the incineration system includes acid gas scrubbing, chlorinated plastics can be directly incinerated.

7.4.2 Fuel Selection

In some cases auxiliary fuel may be required. Auxiliary fuel may include natural gas, propane, fuel oil, or waste solvents. If the incinerator does not have acid gas controls, and a large amount of auxiliary fuel is required, then natural gas should be used. The use of natural gas will minimize the formation of acid gases. However, fuel oil can be used if acid gas controls are present. Waste oils and solvents can also be used for auxiliary fuel, but in some cases the oils may require absorption in order to be shipped. The oil would be absorbed onto combustible media such as corn cobs, activated carbon, or other materials. If this is the case, the material will need to be fed into the incinerator mechanically. However, the oil can still act as an auxiliary fuel, since it increases the average heating value of the waste.

7.4.3 Ash Handling

Ash from incineration is a very light material and, as a result, is easily dispersed into the air. Volume reduction factors of over 150 have been reported for some feed materials. This means that the radioactivity in the ash may be concentrated by up to 150+ times its concentration in the initial waste fed to the incinerator. For this reason, the reliable transfer, feeding, and encapsulation of radioactive incinerator ash is highly important. Important criteria for an ash handling system are summarized below.[7-13]

- Has few moving parts
- Does not plug
- Is enclosed and shielded to prevent worker exposure
- Possesses minimal numbers of gasket joints to prevent leaks
- Can be completely emptied
- Can be easily decontaminated.

Prevention of plugging is an important concern because incinerator ash is highly compressible, which leads to plugups in bins and feeders. Research has shown that live bottom bins (live bottom bins are designed to mechanically assist the discharge of solids from a bin) and gravity feeders are the preferred means of storing and transferring ash. The selection of conveyors for transporting the ash between processes will depend on its exit temperature from the incinerator.

A generic ash handling system would include the following components: a conveyor to transfer the ash to a storage bin; a storage bin; a feeder from the storage bin to a conveyor; and a conveyor for transferring the ash to the encapsulation, solidification, or other processing areas.

7.4.4 Air Pollution Control Systems

There are many possible air pollution control systems that can be used on a LLW incinerator. However, it is recommended that a HEPA filter be the last treatment step. Other systems include quench chambers, acid gas scrubbers, and particulate control devices. Spray dryers are also discussed as a means of temperature reduction and volume reduction for LLW. Presented below is a general discussion of air pollution control equipment.

7.4.4.1 Gas Quenching. The flue gases from an incinerator are generally at temperatures in excess of 1,800°F. As a result, the gas must be quenched before it enters the downstream air pollution control equipment. Gas quenching can be accomplished by water sprays, cool ambient air, a heat exchanger, or a waste heat boiler. The most common methods are water sprays and air quenching. These methods are inexpensive, require little maintenance, and are simple to operate. A heat exchanger can be used if the flue gases require reheating before they are discharged. Wet scrubbers lower the temperature of the flue gas, and reheating prevents water from dropping out (raining) or forming an ice fog (frozen water droplets in cold climates) outside of the plant. A waste heat boiler can be used to reduce the gas temperature by producing low pressure steam. However, in most cases there is no use for this steam.

7.4.4.2 Acid Gas Scrubbers. If a large amount of chlorinated plastics are incinerated, an acid gas scrubber may be required. There are many types of acid gas scrubbers, including wet, dry, and dry-injection scrubbers. If a fluidized-bed incinerator is used, acid gases may be removed by injecting limestone into the incinerator.

Wet scrubbers use a circulating water stream to contact the flue gas. The circulating stream includes sodium hydroxide or other basic material, which reacts with the acid gases, forming salts. These scrubbers are relatively complex when compared to the others and have high maintenance requirements due to corrosion. Also, materials of construction are expensive. Dry scrubbers use a slurry of lime, limestone, or caustic and water that is sprayed into the flue gas in a reactor. The water is evaporated and the salts formed from the acid gases are removed in a dry state. Dry injection involves the injection of a dry reagent into the path of the flue gases. The dry reagent reacts with the acid gases, forming salts. These salts, in both dry and dry-injection scrubbers, are typically removed in a fabric filter (baghouse) located downstream. The dry scrubber and dry-injection scrubbers are usually selected because of their simplicity of operation and maintenance.

7.4.4.3 Particulate Removal. Particulate control equipment includes cyclones, multiclones, electrostatic precipitators, baghouses, ceramic filters, and HEPA filters.

In a cyclone the gas to be treated enters a cylindrically conical chamber at a high velocity. The particulate in the gas stream moves to the walls of the chamber by centrifugal action. The particulate-free gas exits the top of the cyclone, and the particulate is removed from the bottom of the unit. A multiclone is simply a group of cyclones placed together. Cyclones are inexpensive to install and operate. However, they have a limited collection efficiency.

In an electrostatic precipitator (ESP) the particulate passes between two charged plates, setting up a charge on the particulate. The particulate then migrates to the charged electrodes and is captured. Periodically, the electrodes are shaken and the particulate is removed from the unit. ESPs have a low operating cost but have a limited temperature range for operation. Also, the collection efficiency is low for submicron particulates. ESPs are typically not used for systems that use a dry scrubber or dry-injection scrubber.

A baghouse collects particulates by passing the flue gas through a fabric material. The particulate is collected on the dirty side of the bag and the gas exits on the clean side. Baghouses operate in temperatures from 200°F to 400°F on incinerator applications. They have high collection efficiencies for submicron particulates. Baghouses are also used for dry scrubber and dry-injection scrubber applications, since the baghouse provides additional reaction time for acid gas removal. Baghouses must be protected from hot particles so they do not catch on fire.

Ceramic filters are of a similar configuration to a baghouse except that they use ceramic candles to filter out the particulate. They have the advantage of being able to operate at temperatures up to 2,000°F. The units have a high collection efficiency. For a ceramic filter application in most cases the gases would not need to be cooled once they leave the incinerator.

HEPA filters are widely used in the general handling of radioactive materials. They have a very high collection efficiency on small particles. These filters consist of corrugated separators in a wood, particleboard, or metal box. The filters generally operate at low temperatures. They are expensive to install. The flue gas must be free of water droplets to avoid plugging the filters. HEPA filters are used on incineration systems and are also used to clean air used for fugitive dust control.

7.4.5 Spray Dryers

The nuclear power plant industry produces large amounts of aqueous LLW. The cost of disposal, transportation, and burial of these wastes has been increasing tremendously in the last few years and is expected to continue to increase in the future.[7-14] One way to dispose of this waste is to evaporate it in a spray dryer. A spray dryer is basically a vertical, cylindrical vessel in which the aqueous waste is sprayed into the hot flue gases. The water evaporates and the solids formed are removed in a dry state. A spray dryer can be used along with an incinerator or as a separate piece of standalone equipment. With an incinerator a spray dryer can be used for gas quenching, serving a dual benefit of quenching and waste concentration. Spray dryers have also been used as stand-alone units to dry resins[7-15] for the evaporation of the sodium sulfate wastes characteristic of BWRs, the boric acid wastes characteristic of PWRs (Reference 7-15), and for simulated LLW (Reference 7-14).

7.5 Costs

Few LLW incinerators are being constructed or contemplated, especially for nuclear power plant applications, as demonstrated by Commonwealth Edison's decision to indefinitely postpone its mobile incinerator project at two stations near Chicago.[7-16] Representative cost data for new or recent projects are therefore difficult to obtain. Costs can vary depending upon such factors as the amount of shielding required, type of waste to be incinerated, waste drying requirements, handling requirements, local regulations, and capacity of the facility. The following data provide comparisons among different types of systems of capital and operation and maintenance (O&M) costs for different types of incinerators. The basic assumptions include incineration of 85,000 lb/yr with the unit on-line 20 percent of the time.[7-17]

System	Capital Cost (million $)	O & M Cost (thousands $/year)
Electrically heated controlled-air	$6.9	$463
Gas-heated controlled-air	$7.0	$428
Rotary kiln	$8.8	$544

A more accurate picture of costs is obtained when the entire treatment scheme is analyzed and assorted options are compared. Chalk River Nuclear Laboratory analyzed its incineration program in conjunction with its compaction and baling project and compared the costs of different possible options. The results are presented graphically in Figure 7-6.

7.6 Mixed Waste

Incineration is a proven treatment for the destruction of some organic hazardous wastes regulated under RCRA and PCB wastes regulated under TSCA. Properly operated rotary kiln and fluidized-bed incinerators can convert 99.9+ percent of the carbon in the waste feed to carbon dioxide, can convert virtually 100 percent of the hydrogen to water, and can meet the specified

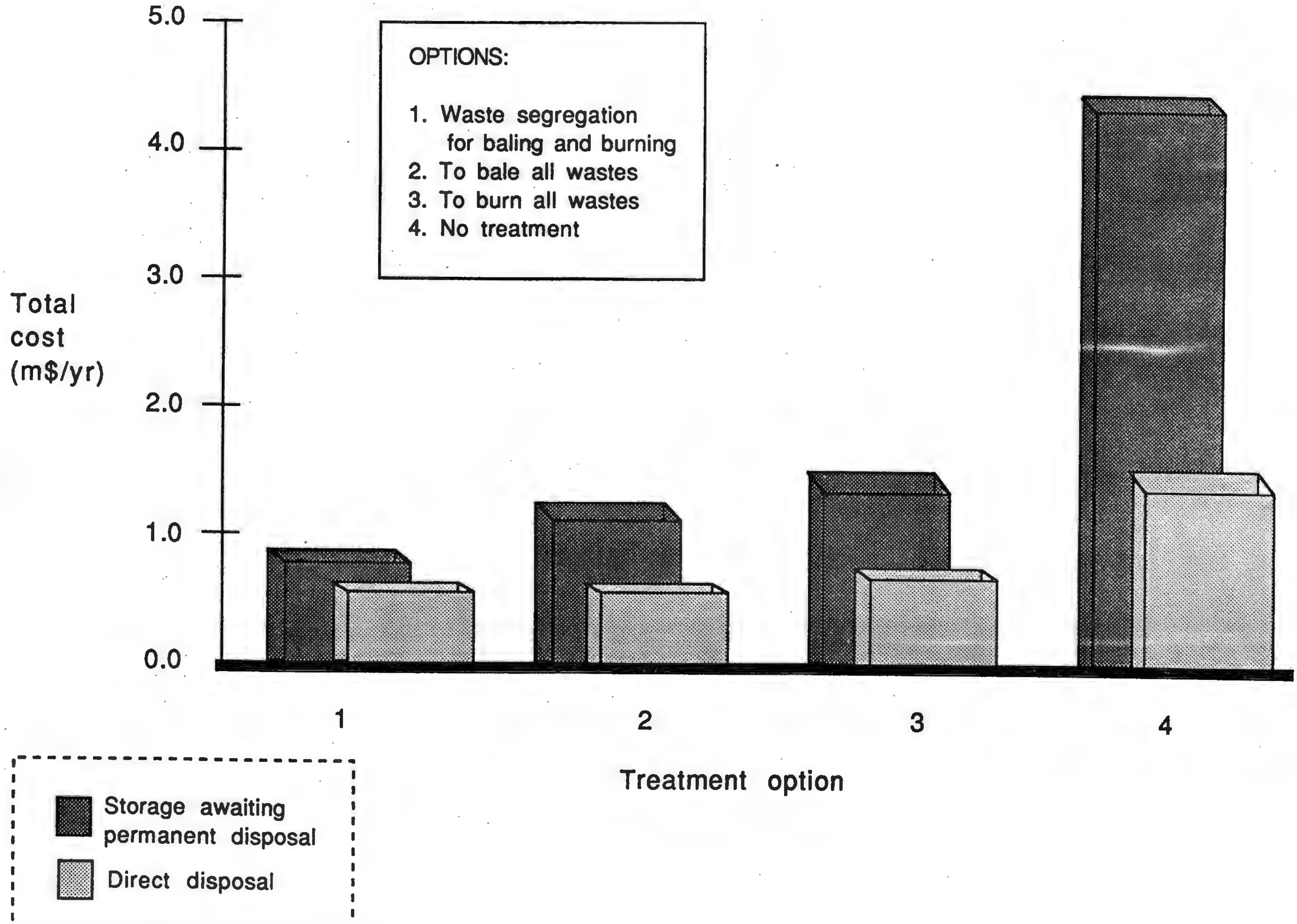

Figure 7-6. Economic analysis of treatment and disposal options for solid LLW at Chalk River Nuclear Laboratory.

destruction efficiencies in both RCRA and TSCA. Both the starved-air and excess-air type of modular incinerators are capable of 99.99 percent destruction efficiency for hazardous organic wastes, meeting or exceeding RCRA requirements. Incinerators treating mixed wastes must be permitted under 40 CFR 264, Subpart O - Incinerators, as well as licensed under 10 CFR 30 or applicable Agreement State requirements. In the case of an incinerator located at a nuclear power plant, licensure would be under 10 CFR 50. Under most circumstances, ash from an incinerator treating mixed waste would be required to be disposed of in a RCRA-regulated disposal facility. Exceptions to the requirements for RCRA-regulated disposal may include a successful de-listing petition to the EPA or a successful request for variance to the EPA or authorized state program.

Most mixed waste consists of liquid scintillation counting fluids.[7-19] These liquids are typically disposed of by adding the deregulated radioactive liquid to a fuel oil for energy recovery. This disposal takes advantage of deregulation of small quantities of radioactive liquids (10 CFR 20.306) and the ability to add small quantities of hazardous waste to fuel for energy recovery purposes (40 CFR 266), without having the ash be RCRA-regulated.

7.7 Vendors and Users of Incineration Systems

7.7.1 Vendors

Numerous vendors manufacture and sell incinerators and complete incineration systems that can be used for volume reduction of LLW. Some vendors specialize in a particular type of incinerator, while others provide a broad range of different incinerator types. Reputable vendors will provide references for a buyer to assess the performance of their equipment.

The selection of a vendor and type of incinerator depends upon the combustible properties of the waste rather than the waste's radiological characteristics (Reference 7-9). A containment system around the incinerator provides for control of radioactive emissions. For example, the Los Alamos National Laboratory extensively modified its LLW incinerator, acquired from Ecolaire Combustion Products, to control alpha-radiation.

A list of incinerator vendors with location, telephone number, and contact is included as Table 7-5. The type(s) of incinerator(s) available from each vendor is indicated in the columns at the right. The categories listed are fluidized bed, rotary kiln, and modular (starved or excess air) incinerators.[7-20, 7-21] The order of vendors is alphabetical. The list is not intended to be complete and does not constitute an endorsement of any particular vendor.

7.7.2 Users

Some of the users of incinerator technology are listed below. Additional information on these facilities is included in Table 7-4 and Appendix C.

(1) Scientific Ecology Group
P.O. Box 2530
1560 Bear Creek Road
Oak Ridge, TN 37830
(615) 481-0221

(2) Waste Treatment Center
Chalk River Nuclear Laboratories
Atomic Energy of Canada, Ltd.
Chalk River, Ontario, Canada K0J 1J0
(613) 584-3311 ext. 4908 or 4912

(3) E.I. duPont de Nemours & Company
Savannah River Laboratory
Aiken, SC 29808
(803) 725-6211 or
(803) 557-6299

(4) Idaho National Engineering Laboratory
Idaho Falls, ID 83415-8104
(208) 526-7527

(5) Studsvik Energiteknik AB
Nykoping, Sweden
+46 155 222 03

(6) Los Alamos National Laboratory
Waste Management Group
Los Alamos, NM 87545
(505) 667-4301

(7) Jeülich Nuclear Research Center
KFA Kuelich
Federal State of North Rhine - Westphalia
Germany

(8) CEN - Cadarache Incinerator
Comissariat a l' Energie Atomique CEN
Cadarache BP
France

TABLE 7-5. LIST OF INCINERATOR VENDORS

Vendor	Telephone Number	Incinerator Type: Fluidized Bed	Rotary Kiln	Modular
Allis Chalmers P.O. Box 512 Milwaukee, WI 53201	(414) 475-3862		X	
American Energy Waste Systems, Inc. 30 Indel Avenue Rancocus, NJ 08073	(609) 267-8833			X
Atlas Incinerators Inc. 277 Coon Rapids Blvd. Suite 102 Minneapolis, MN 55433	(612) 784-6701			X
Basic Environmental Engineering, Inc. 21 W. 161 Hill Street Glen Ellyn, IL 60137	(312) 469-5340			X
Cadoux 2010 Exeter Road Germantown, TN 38138	(901) 754-0676			X
C-E Raymond/Combustion Engineering 33 Quail Court #203 Walnut Creek, CA 94596	(415) 934-1071	X	X	X
Cleaver-Brooks P.O. Box 1336 Lynnwood, WA 98036	(206) 774-6602		X	
Comtro Division Sunbeam Inc. 180 Mercer Street Meadville, PA 16335	(814) 724-1456			X
Consertherm/Industronics 489 Sullivan Avenue S. Windsor, CT 06074	(203) 289-1551		X	
Consumat Systems, Inc. P.O. Box 9574 Richmond, VA 23228	(804) 764-4120			X

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TABLE 7-5 (continued)

Vendor	Telephone Number	Incinerator Type: Fluidized Bed	Rotary Kiln	Modular
Ecolaire Combustion Products Inc. P.O. Box 240707 11100 Nations Ford Rd. Charlotte, NC 28224	(704) 588-1620		X	X
Ensco 333 Executive Court Little Rock, AR 72205	(501) 223-4100		X	
Ford, Bacon and Davis 375 Chipeta Way Salt Lake City, UT 84108	(801) 583-3773		X	
Fuller Company 2040 Ave. C-LVIP Bethlehem, PA 18001-2040	(215) 264-6011	X	X	
International Technology Corp. (McGill Incorporated) 5800 W. 68th St. Tulsa, OK 74157	(918) 445-2437		X	
International Waste Energy Systems 2150 Kienlen Ave. St. Louis, MO 63121	(314) 389-7275		X	
John Zink Services 4401 S. Peoria Ave. Tulsa, OK 74170	(918) 747-1371		X	
Keeler/Dorr-Oliver P.O. Box 548 Williamsport, PA 17703-0548	(717) 326-3361	X		
Kelley Co., Inc. 6720 N. Tentonia Avenue Milwaukee, WI 53209	(414) 352-1000	X	X	X
Kennedy Van Saun P.O. Box 500 Danville, PA 17821	(717) 275-3050		X	

Vendor	Telephone Number	Incinerator Type: Fluidized Bed	Rotary Kiln	Modular
Midland Ross 2375 Dorr Street Toledo, OH 43691	(419) 537-6176			X
M and S Eng and Manufacturing Company Inc. 95 Rye St Broad Brook, CT 06016	(203) 627-9396	X	X	
Niro Atomizer Inc. 9165 Rumsey Rd. Columbia, MD 21045	(301) 997-8700	X		
Ogden Environmental Services Inc. P.O. Box 85178 San Diego, CA 92138-5178	(619) 455-2383	X		X
Procedair Industries, Inc. 10401 Linn Station Road Louisville, KY 40223	(502) 426-7793		X	
Process Combustion Corp. P.O. Box 12866 Pittsburgh, PA 15241	(412) 257-2080	X		
Simonds Manufacturing Corp. 304 Progress Road Auburndale, FL 33823	(813) 467-8566			X
Studsvik Energiteknik AB 5-611-82 Nykoping Sweden	46 155 222 03		X	
Thermal Inc. P.O. Box 1776-PE Peapack, NJ 07977	(201) 234-1776		X	
Trecan Combustion Ltd. Mississauga, ON	(416) 226-8631			X

TABLE 7-5 (continued)

		Incinerator Type		
Vendor	Telephone Number	Fluidized Bed	Rotary Kiln	Modular
Vesta Technology, Ltd. 2502 E. Commercial Blvd. Ft. Lauderdale, FL 33308	(305) 776-0330		X	
vonRoll Inc. 25 Commerce Dr. Cranford, NJ 07016	(201) 272-1555		X	

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8. SHREDDERS

This section discusses the use of shredders for reducing the size of each item of low-level radioactive waste. Shredding of radioactive wastes has been conducted for over 20 years in Europe and for over 10 years in the United States. Shredders are devices that tear, rip, shatter, and/or crush waste materials into smaller pieces. In nonradioactive waste applications, shredders are commonly used in conjunction with either incinerators, compactors, baling, or landfilling. For incineration, shredders are used to reduce particle size for feeding by rams, gravity, or stokers. Shredders are used in conjunction with compactors, balers, or landfilling to reduce void spaces between individual waste objects, thus reducing the volume of the disposed waste. For compaction, size reduction also reduces the amount of spring-back that occurs.

Sections 8.1 and 8.2 describe high- and low-speed shear shredders, respectively. Section 8.3 discusses regulatory concerns. Section 8.4 details what is required for a complete shredder and shredder/compactor installation/operation. Section 8.5 presents shredder costs, Section 8.6 discusses the applicability of shredders to mixed wastes, and Section 8.7 lists selected users and vendors of low-speed shear shredders.

8.1 General Description

There are two types of shredders used for size reduction: high-speed shredders and low-speed shredders. Each of these types of shredders are briefly discussed below.

8.1.1 High-Speed Shredders

High-speed shredders include hammermills and flailmills. The hammermill consists of pivoted or rigidly mounted hammers located on a horizontal or vertical rotating shaft. The shredding action is achieved by rotating the hammers against a breaker plate (a screen with perforations), with the distance between the hammers and the breaker plate being sufficient for clearance only. A flailmill is similar to a hammermill except that no breaker plate is used. As a result, attrition due to grinding of particles between the hammers and the breaker plate or screen can not occur. A flailmill relies on direct impaction between incoming material and the hammers or bars to reduce the particle size of the material. These high-speed shredders rotate at approximately 3600 rpm as compared to 10 to 80 rpm for the low-speed shear shredders. High-speed shredders are most commonly used to reduce municipal solid waste, to produce refuse derived fuel, and to reduce wood wastes.

High-speed shredders have several disadvantages in a nuclear environment:

1. Due to their high operating speeds, they are very susceptible to exploding when encountering unshreddable materials such as steel plates. Therefore, waste must be thoroughly sorted.

2. Hammermill installations require daily maintenance (hardfacing and/or replacement) of the hammers. Liners must also be periodically replaced. This level of maintenance is unacceptable in the nuclear environment where workers would be exposed to radiation during such maintenance.

3. In the smaller capacity range they have a limited open area for feeding waste material and are not amenable to the feeding of boxed or packaged wastes.

4. They require considerably more horsepower than a comparably sized low-speed shredder.

The first two concerns regarding explosions and maintenance eliminate high-speed shredders from use at nuclear facilities. Therefore, the remainder of this chapter only discusses the use of low-speed, shear-type shredders for low-level waste applications.

8.1.2 Low-Speed Shear Shredders

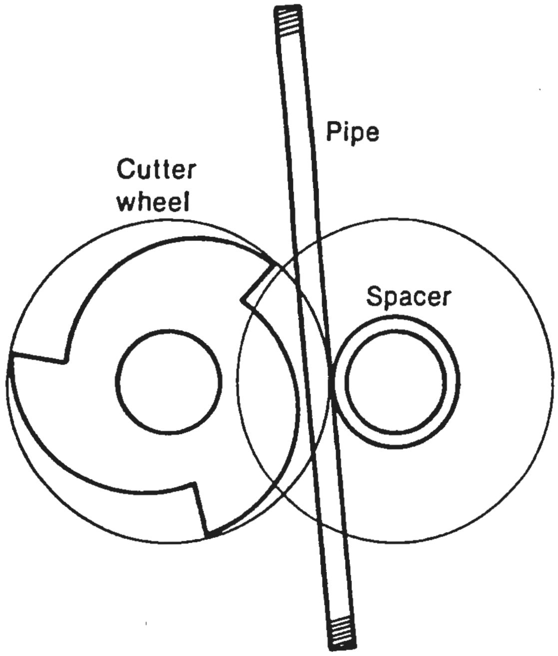
The rotary shear shredder works using low speeds and high torque (torque is a measure of the force applied at the cutter wheels). A low-speed shear shredder operates using two counter-rotating shafts with cutter wheels and spacers as shown in Figure 8-1.[8-1] One of the shafts rotates faster than the other, providing the following advantages:[8-2, 8-3]

- Improved shredding efficiency
- Prolonged cutter wheel life from distributing the wear
- Improved cutter cleaning
- Improved tearing and ripping (shearing).

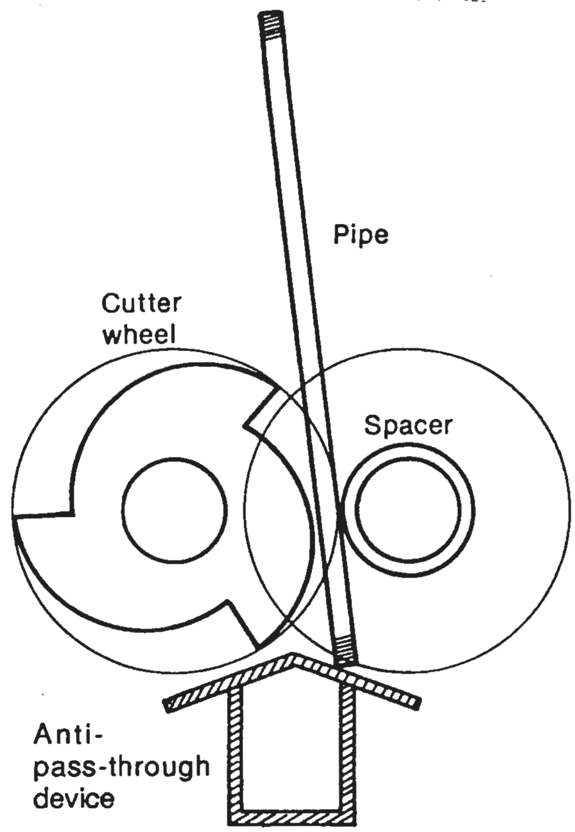
The cutter wheels contain one or more teeth that intermesh with the cutter wheels on the adjacent shaft. Each cutting wheel either has one, two, or three teeth depending on the specific vendor system used. The cutter configuration is described as the number of adjacent cutters plus the number of adjacent spacers plus the number of adjacent cutters (Reference 8-2). The low-speed shear shredder shown in Figure 8-1 has a 2 + 2 + 2 configuration. The term "single spiral" means that each cutter tooth is offset from the adjacent tooth so that it takes the full length of the cutter shaft to make one complete revolution of the cutter tooth position (Reference 8-2). As a result, only one tooth at a time is in position to shear the waste, and the full torque of the shaft is then applied to this tooth. For the in-line configuration all the teeth are lined up; therefore, the shaft torque is divided among all the teeth.

Depending on design, some materials will fall directly through the cutters without being reduced in size. A typical example for a length of pipe is shown in Figure 8-2 (Reference 8-1). To prevent this, an antipass-through device is used; however, long pieces of sheet metal or flexible conduit may still pass through.

Figure 8-1. Typical view of a low-speed shear shredder (Shred Pax 80 hp).

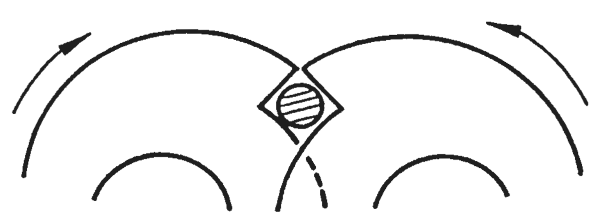


A pipe falling through the gap between a cutter wheel and the opposing spacer.



A pipe blocked from falling through by an anti-pass through device. Long pieces of flexible material like sheet metal might not be blocked.

A waste item (round bar) trapped and cut by one tooth against a non-tooth edge of the opposite cutter wheel.



A waste item (round bar) trapped and ready to be cut by one tooth against another tooth of the opposite cutter wheel.

Figure 8-2. Selected operating conditions of low-speed shear shredders.

The gearing of the shredder is also an important factor. Two situations for shredding a steel bar are shown in Figure 8-2. In the position where only one tooth is contacting the waste, only the power from one shaft is applied to the tooth or teeth on that shaft (an example is the Saturn shredder). Other designs are geared so that the full power of both shafts are applied to this tooth or teeth (an example is the Shred Pax). When both teeth contact the steel bar, all shredder configurations apply full power.

Production rate in tons/hour and particle size are a function of many design and operational factors as summarized below:[8-4]

- Cutter Blades: The greater the thickness of the cutter blades the greater the production rate. The cutter blades should also control and meter the waste through the shredder.

- Hook Height: The hook or cutter height refers to the height of the tooth above the rotating disc. The higher the hook the more material the cutter will grab and the higher the production rate. In general particle size increases with hook height.

- Type of Material: The harder and more dense the material, the more power will be required. Shredder applications are determined by vendors on a case-by-case basis, which usually includes pilot testing.

- Method of Feeding: Continuous feeding is the best way to operate a shredder if the intent is to maximize throughput.

The feeding method is an important concern for low-level waste. Continuous feeding is best accomplished by a conveyor. However, batch feeding, particularly in the case of boxed or drummed low-level waste, may be the only practical method. Batch feeding results in more shredder reversals (when an overload situation is sensed the shredder shafts reverse direction for a predetermined amount of time to clear the obstruction). However, this can be offset to a degree by oversizing the unit.

Another important design parameter is the source of power for the unit--hydraulic verses electromechanical. Advantages and disadvantages of hydraulically and electromechanically operated shredders are presented in Table 8-1. Electromechanical units are more amenable to glove box and hot cell applications on low-level waste.

8.2 Performance Data

The effectiveness of a shredder depends on the composition of waste being shredded and the desired method of processing or disposal of the waste after shredding. Requirements for a shredder will vary depending on whether the shredded waste is next compacted, incinerated, or loaded directly into drums for disposal. This section explains the parameters for determining shredder performance and describes the types of waste that can be processed and those that cannot be shredded. Examples of operating shredders are also described.

8.2.1 Performance Parameters

Throughout this manual, the VR factor for a certain technology has been used to evaluate its performance in reducing the volume of waste. This is true for shredders in some instances; however, other criteria may be more important depending on the application and whether compactors or incinerators are included with shredders in a multistep system. The VR factor for shredders or a composite system including shredders can be measured in two principal ways. Volume reduction calculated from density rather than burial volume is the preferred method based on experience in comparing technologies.[8-6] A comparison of the density of uncompacted waste, compacted waste, shredded and compacted waste, and supercompacted waste is presented in Figure 8-3. The density of shredded and compacted waste approaches that of supercompacted waste. A VR factor of 6.2 can be calculated for the shredded and compacted waste versus a VR factor of 7.7 for supercompacted waste.

TABLE 8-1. ADVANTAGES AND DISADVANTAGES OF ELECTROMECHANICALLY AND HYDRAULICALLY POWERED SHREDDERS

Advantages	Disadvantages
Hydraulic Drive	
o Fast reversing cycle on the order of 2 seconds, which protects the shredder from damage[8-6]	o Require large amounts of space for the pump stands
o Hydraulics can withstand high shock loadings since shock is absorbed by the fluid not the gearbox	o Dirty systems to operate if not properly maintained
o Virtually instantaneous response of hydraulics	o Require large amounts of horsepower
o Shredder hydraulic pump stand can be used to power ancillary systems	o Higher priced units
Electromechanical Drive	
o Requires little space	o Shock loadings are absorbed by the shaft gearboxes
o 30 percent more energy efficient than hydraulic drives	o Reversal times are on the order of 30 seconds (Reference 8-5)
o Cleaner units to operate	
o Lower priced units	

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DENSITY COMPARISONS

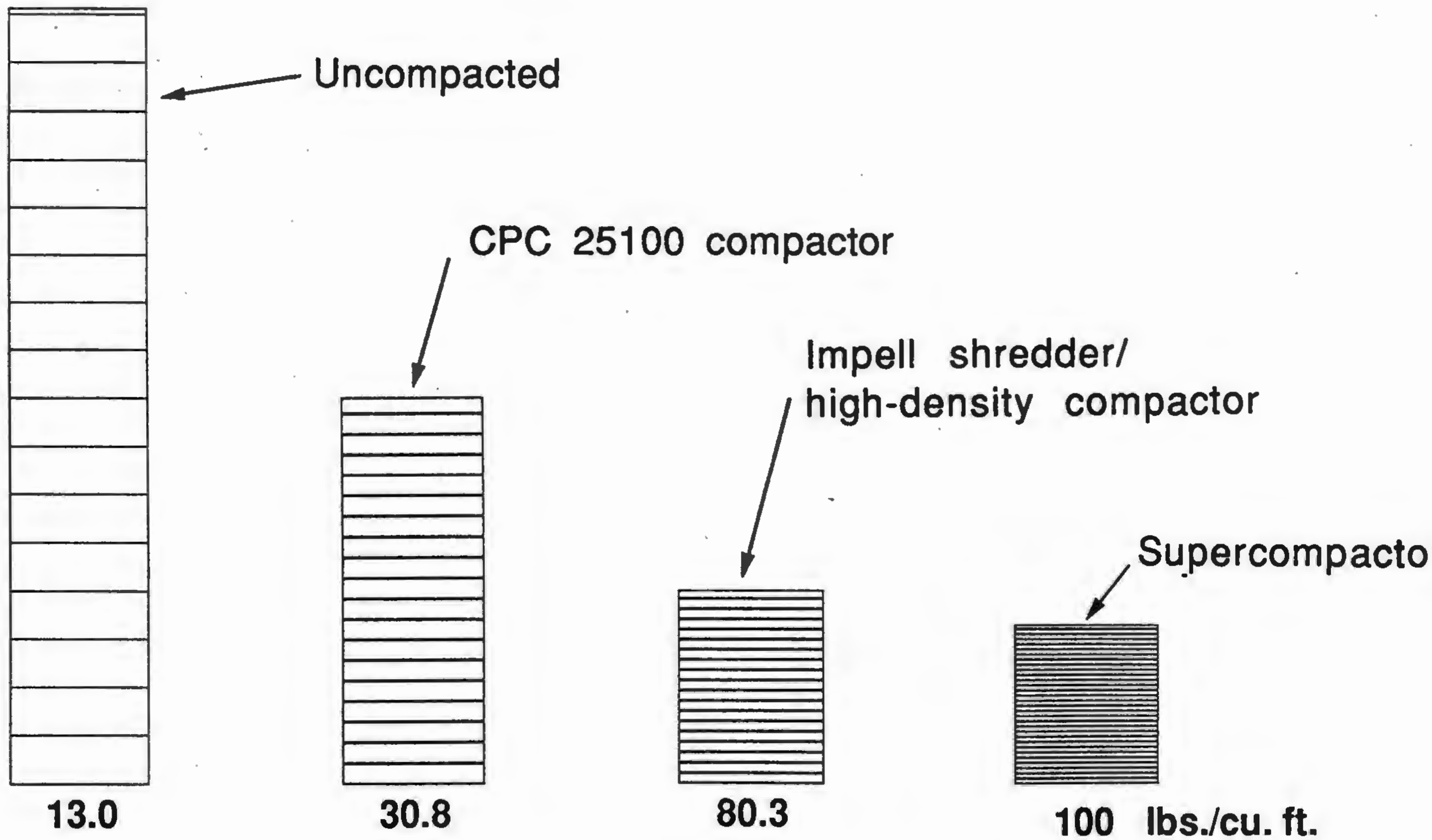

Figure 8-3. Density comparisons of shredders and compactors using simulated 1981 EPRI waste mix.

In addition to the VR factor, there are two other parameters that are important for judging the performance of a shredder. One of these parameters is piece size, or particle size. The size of material exiting the shredder would be the most important requirement, regardless of VR factor, if the shredded waste is disposed of in drums without further processing.[8-7] The parameter for evaluating shredder performance is the process rate, or throughput. Throughput and piece size are usually considered to be tradeoffs. The rate of material processing varies considerably between different types of waste for a given shredder model. Throughput of a particular waste type increases with both horsepower and maximum shredder inlet opening. Shredder throughput is discussed in detail in Section 8.4.1.

8.2.2 Waste Shreddability

Most items contaminated with low levels of radioactivity can be shredded, although there are some limitations. The limits of shreddability depend on the width of the cutter, the waste configuration, and the orientation of the waste when it hits the cutter teeth (Reference 8-1). See Figure 8-2 for an example of problems due to waste orientation. The heaviest materials that can generally be shredded include the following:

- 1/4-inch plate steel (using 1-1/2 inch cutters)
- 1-1/4-inch rebar
- 1-1/4-steel rebar
- 4-inch Schedule 40 pipe

Standard 55-gallon steel drums can be easily handled in low-speed shredders.

Plywood boxes can also be handled with proper feed controls. Waste must be sorted to remove hardened steel, which could damage the cutter teeth if automatic reversal is not used on the shredder. Unshreddable items that will not damage equipment need not be sorted because they can be removed by a grappler. Some materials such as uniformly shaped pieces of flat wood and metal will increase in volume when shredded. Paper and especially plastic bags become very fluffy when shredded alone and will not compress well unless mixed with denser material prior to shredding.[8-8] Material containing large amounts of loose contamination (e.g., used HEPA filters) should not be shredded because the shredder containment system's HEPA filters are quickly loaded, which could cause build up of high levels of contamination within the system (Reference 8-6).

8.2.3 Operating Experience

Low-speed shredders have been used for LLW volume reduction alone or in combination with other devices for about a decade in the United States. The following examples provide the results from tests and operating systems. Additional users of shredders may be found in Section 8.6.

8.2.3.1 U.S. Department of Energy (DOE) Test. A test conducted for the DOE was performed to prove the viability of low-speed shredders for sizing drummed and boxed waste. Five sets of test waste were used to determine the limits of shreddability and were tested in four different types of shredders. All four shredders--the Blower Application Shredder, Triple/S Dynamics MSW 75, Saturn Model 50, and Shred Pax AZ-80--were found to be excellent. However, the Shred Pax model was best suited for the transuranic waste at that particular DOE facility. All of the shredders accomplished a process rate of better than 90 tons/day with only minor problems in waste feeding (Reference 8-1).

8.2.3.2 Pacific Northwest Laboratory Test. Electric-drive, low-speed shredders manufactured by Shredding Systems, Inc. and Shred Pax Corporation were tested and compared in terms of waste throughput, cutter force, cutter configuration, and fragment size. Waste throughput and shredder reversal data for the test are presented in Table 8-2. The 2+2+2 single spiral configuration had the highest waste throughput and lowest number of reversals. One problem encountered was that filters loaded with particulate released dust during shredding (Reference 8-2).

8.2.3.3 Chalk River Atomic Energy Laboratory. A Shred Pax AZ-7 is currently being used in evaluation of a shredder/compactor waste management system. A VR factor of 1.5 has been determined for the shredder alone, while shredding followed by compaction has produced a VR factor of 8. Motor

TABLE 8-2. SHREDDER PERFORMANCE COMPARISON

Waste Material	Shredder Model	Configuration	Throughput Rate, kg/min	Reversals per 100 kg
GPT[a]	1600	2+2+2 single spiral	60	0
GPT	AZ-80	2+2+2 single spiral	80	1.4
GPT	AZ-80	1+1+1 in line	19	14
SAC[b]	1600	2+2+2 single spiral	70	1.6
SAC	AZ-80	2+2+2 single spiral	40	6.7
Wood HEPAs	1600	2+2+2 single spiral	ND[c]	0
Wood HEPAs	AZ-80	2+2+2 single spiral	ND	0
Wood HEPAs	AZ-80	1+1+1 single spiral	ND	0
Metal HEPAs	1600	2+2+2 single spiral	50	4.1
Metal HEPAs	AZ-80	2+2+2 single spiral	34	9.3

a. General process trash. Mostly combustible with a small fraction of tramp metal.

b. Sample and analytical cell waste. Contains 40 percent by weight or more noncombustibles.

c. ND - No data are reported. Wood HEPA filters had to be manually repositioned at regular intervals to facilitate shredding. Throughput was dependent on the manual repositioning and not the shredder capacity.

reversal from material jamming has been high. Replacement of broken cutter teeth has been frequent, and more intensive waste separation is now being considered.[8-9]

8.2.3.4 Savannah River Laboratory. Savannah River Laboratory operates a Shred Pax AZ-160 for processing transuranic wastes, which can include wood, metal, and sealed boxes. It can shred a box 4 feet square in about 45 minutes. A Shred Pax AZ-80 has been tested and is being recommended to replace the existing model. The AZ-80 will be operated with a recycle feature for material that is too large on the first pass through the shredder. A greater portion of the total VR occurs during the second pass through the shredder. Final particle size is the most important parameter because the shredded waste is sealed in drums for disposal (Reference 8-7).

8.2.3.5 Carolina Power & Light Company. A shredder/compactor system developed by Impell Corporation was installed at Carolina Power & Light Company's Brunswick Steam Electric Plant in October 1984. It has been used to process DAW efficiently and cost-effectively. The shredder alone has reduced the volume of hard plastics, wood, glass, and metals that contain void spaces. An average VR factor of 5 over completely untreated and packaged waste has been realized (Reference 8-8).

8.3 Regulatory Status

There are no specific regulations applicable to the licensing or preapproval of shredder installations at nuclear facilities by a federal regulatory agency. However, a 10 CFR 50.59 safety evaluation is required to ascertain if a change to the facility would result in an unreviewed safety question or if it would result in a change of the plant's Final Safety Analysis Report (Reference 8-6). The shredder or shredder/compactor installation is required by the "As Low As Reasonably Achievable" (ALARA) principal in 10 CFR 20 to minimize radiological exposure to the system operating and maintenance personnel. Also, the shredder or shredder/compactor installation must meet the requirements of the Occupational Safety and Health Administration presented in 29 CFR 1910. Of primary concern is the generation of airborne contamination as a result of shredding. This concern can be reduced by containing the shredder unit in a glove box or hot cell and maintaining the shredder system under negative pressure. Only the shredder (or other support processing equipment) needs to be remotely located; the shredder shafts or hydraulics can extend through the wall into the clean environment (Reference 8-1). The negative air handling system would include an exhaust fan, a roughing filter (which may include a baghouse), and a HEPA filter. A listing of potentially applicable regulations, codes, and standards is presented in Appendix A.

8.4 Technical Details

This section discusses technical details, which include system throughput, operational factors, and typical systems.

8.4.1 Shredder Throughput

As discussed in Section 8.1.2, shredder throughput is a function of many design and operational parameters. Shredders are marketed generally on their open area at the cutters, which is selected based on the physical size of the expected waste materials. The horsepower requirement for a specific shredder is determined by one or all of the following.

- The characteristics of the material to be handled
- Past experience with other systems on the same type of waste material
- Actual shredder testing in vendor pilot or laboratory shredders.

Pilot testing using actual low-level waste in vendors' facilities is not possible due to radiation concerns. However, the radiological content of low-level waste does not affect shreddability. As a result, composite samples of simulated low-level waste can be assembled using nonradioactive materials.

To illustrate the importance of testing, a comparison was made between two different models of Saturn shredders on various materials.[8-10] A description of the two shredders is presented in Table 8-3. Estimated throughput for Model 72-46 and Model 96-50 for various types of waste materials is presented in Table 8-4, some of which would be included in low-level waste. Shredder capacity is highly dependant on the type of material or combination of materials to be processed.

The information indicated above shows that the two units are capable of processing approximately 25 to 60 tons/hour of garbage. This seems to be a very large capacity when compared to the smaller amounts of low-level waste that require shredding. However, if full drums and boxes are going to be shredded, the unit will operate in a batch mode. As a result, the shredder will instantaneously see a much larger flow of material than the calculated average hourly flows. In batch feeding of drums or boxes, the shredder size will be determined by the required feed opening, while capacity will be a function of material shredded and horsepower.

8.4.2 Operational Features

The shredder itself includes the shredder body, cutters, shafts, and gearing. Other required equipment includes the feed system, the support structure, and the controls for the prevention of jamming.

The shredder itself is mounted above grade to allow access for the discharge system, which may include collecting the material in steel drums, dropping the material onto a conveyor for feeding to an incinerator, or dropping the material directly into a gravity feed hopper of a compactor. In low-level waste installations the shredder may have a hood to control dust or alternatively the hot cell could be kept under negative pressure. Particulate in the air stream would be ducted to a roughing filter and finally to a HEPA filter before being discharged to the atmosphere. For incinerator applications it may be possible to use the ventilation air as combustion air.

TABLE 8-3. COMPARISON OF SATURN SHREDDER MODELS (Reference 8-10)

Parameter	Model 72-46	Model 96-50
Feed opening at cutters	72" by 46"	96" by 50"
Horsepower	200	400
Shredder size	144" x 59" x 42"	174" x 70" x 46"
Hydraulic unit size	98" x 78" x 86"	96" x 78" x 86" 2 units
Number of motors	2	4
Shaft speed		
Fast shaft	42.8 rpm	42.8 rpm
Slow shaft	27.2 rpm	33.6 rpm
Cutter diameter	24.5 inches	26.5 inches
Shaft torque		
Fast shaft	30,700 ft/lb	30,700 ft/lb
Slow shaft	48,200 ft/lb	39,000 ft/lb
System total weight	35,000 lb	52,000 lb
Unit cost F.O.B factory less hopper and stand	$180,000	$300,000

TABLE 8-4. SHREDDER THROUGHPUT AS A FUNCTION OF MATERIAL (Reference 8-10)

Material Type	Model 72-46	Model 96-50
Garbage	25 - 35 tph	35 - 60 tph
Paper and cardboard	5 - 6 tph	7 - 10 tph
Aluminum scrap	4 - 5 tph	5 - 7 tph
Ferrous	3 - 4 tph	4 - 5 tph
White goods	1 - 3 tph	3 - 5 tph
Wire and cable	3 - 4 tph	4 - 6 tph
Loose steel cable	2 - 3 tph	3 - 4 tph
Wood pallets	100 - 150/hr	200 - 250/hr
55-gallon drums	100 - 125/hr	150 - 200/hr

A feed system must be designed to properly feed and align the waste as it enters the shredder. The feed system must be designed to operate in a hot cell or other enclosure to minimize direct human contact with the waste. Feed to the shredder would consist in most cases of materials in some sort of container. Containers most likely would include plywood boxes or steel drums. These containers would then be shredded intact. In some cases, the contents of the containers (concrete storage containers in this case) could be opened and the waste sorted before shredding.[8-11] In this case the material could enter the shredder on a conveyor. To feed containers, a remotely operated platform or roller conveyor could be used. Because of the low profile of the cutters on low-speed shear shredders, flat-bottom or flat-sided containers require some assistance to allow the cutters to properly bite into the container to initiate shredding. A remotely operated grappler or a hydraulically operated ram could be used to force the waste into the cutters. The downward movement of the grappler and ram should be limited by proper interlocks to avoid engaging the cutters. Provisions must also be made for material that is unshreddable (e.g., thick steel plates, liquids, spent solvent containers) and for recovery of material that passes through the unit unshredded. This unshredded material must be remotely collected and fed back into the shredder. Material passing through the shredder will most likely include long pieces of pipe, semirigid conduit, or flat pieces of sheet metal or aluminum.

The support structure of the shredder must adequately support the shredder and its drive mechanisms. For hydraulically operated units, the power unit can be located outside of the hot cell or enclosure. It is important to design the system with sufficient rigidity to absorb shock loadings including shaft reversals. If hot cells are used, access should be provided for an overhead crane to remove the shafts if required for repair. Sufficient access must be provided to allow cutter rebuilding and/or hardfacing and other maintenance. Also, remote lubrication is recommended.

It is important to use antijamming devices to extend shredder life and to protect workers. When a shredder encounters a material that cannot be shredded or its orientation prevents shredding, the power unit senses this and reverses the direction of rotation of the shafts. In hydraulic units shaft reversal is virtually instantaneous, while in electromechanical units the shafts must stop rotating before reversal. In either case an overload is sensed by pressure in the hydraulic unit (usually 2800 psi) or a current overload in the case of the electromechanical system. The duration of the reversal period is adjustable. During reversal, provisions need to be made to discharge the item plugging the unit. This can be accomplished by the grappler. Alternatively, some shredders have hydraulically operated gates that open and allow the cutters to eject the material.

8.4.3 Typical System

In low-level waste applications, there is no such thing as a typical installation. However, most installations have the following aspects in common: minimization of worker exposure, limitation of fugitive dust emissions, and containment of the system. Shredders for low-level waste are used for the following purposes:

- Feed preparation for incineration
- Feed preparation for a compactor
- Shredding to reduce bulk density for direct packaging into containers.

In shredder systems coupled to an incinerator, the material would likely be removed from the containers and shredded. Removal from the containers would assure destruction of the material, since shredding drums trap material in the metal (Reference 8-1). The complete system would then include a feed conveyor, feed hopper, shredder, discharge chute and level indicator, feed conveyor to the incinerator, power unit, air filtration system, and control system.[8-12]

For a shredder/compactor installation the best configuration would be the mounting of the shredder above the feed box of the compactor. This would result in the gravity feed of the material into the compactor. The complete shredder/compactor installation would then include the following components: a feed system consisting of a grappler and/or conveyor, the shredder and its feed hopper, a discharge hopper with high- and low-level indicators, a high-density compactor, an air filtration system, a box or container handling system, an incidental liquid collection system, the shredder and compactor power supplies, and the control system.[8-13]

The components of a stand-alone shredder installation are basically the same as that described for the incinerator. Discharge from the unit could be onto a conveyor or directly into a collection container.

8.5 Costs

Capital costs for shredders are listed below in 1988 dollars:

Blower Application, 300 hp	$400,000
Triple/S Dynamics, 400 hp	$460,000
Saturn 72-46, 200 hp	$180,000
Saturn 96-50, 400 hp	$300,000
Shred Pax AZ 80, 80 hp	$135,000

It is not possible to estimate general system costs because of the effect of site-specific concerns and required ancillary equipment. A cost evaluation in 1987 dollars of alternative volume reduction systems including operating costs, is presented in Table 8-5. The systems that include shredders have a longer payback period but a lower ten-year cost than a comparable system without a shredder. The annual cost of operating a shredder/compactor system is significantly less than the operating cost of a conventional drum compactor. Reduced labor cost translates into a reduced potential for worker exposure. Some limited application, low-volume shredders can be purchased and installed for as little as $15,000. These small shredders may be useful by generators of small quantities of LLW.

8.6 Mixed Waste

Shredders can be used to pre-treat mixed waste, prior to application of other volume reduction treatment. Shredders, however, do not render mixed waste less hazardous, nor does the shredding of waste change the regulatory status of the mixed waste. As stated previously, shredders are most often

TABLE 8-5. SUMMARY OF ALTERNATIVE DAW VOLUME REDUCTION SYSTEMS EVALUATION (Reference 8-5)

Alternative Systems	Disposal Container Cost ($)	Burial Cost ($)	Shipping Cost ($)	Labor Cost ($)	Total Annual Operating Cost ($)	Initial Cost ($)	Ten Year[a] Cost (1987 Dollars)	Payback Period (Years)
Conventional drum compactor	52,000	373,600	9,000	40,900	475,500	50K	2.97M	Base case
Box compactor	49,400	318,600	9,000	8,300	385,300	150K	2.52M	1.1
Shredder/ box compactor	41,500	227,500	8,000	11,750	288,800	450K	2.22M	2.1
Shredder/ high-pressure compactor	55,100	143,650	8,000	16,500	223,250	480K	1.85M	1.7
Super compactor	32,000	106,000	8,000	47,500	193,500	900K	2.09M	3.0

a. Present worth factor 6.1446 - (10 percent for 10 years).

2374K

9513383.0641

used in conjunction with other treatment or volume reduction technologies. Care must be exercised to assure that mixed waste materials are not reactive or incompatible with the shredder or the forces involved with the shredding action. If a shredder is used to treat mixed waste, it may be required to be permitted under RCRA as a treatment facility (40 CFR 264). Shredded mixed waste must be disposed of or further treated in accordance with RCRA requirements whether or not the shredder is permitted under RCRA.

8.7 Vendors and Users

Numerous vendors provide shredders and complete volume reduction systems that include compactors, which can be used for LLW applications. Some vendors specialize in a particular type of shredder, while others provide low-speed shredders and other types not used for LLW. A reputable vendor will be willing to provide references to allow a buyer to assess the performance of their equipment that is currently in operation.

There are thousands of shredder users. For this manual, the pertinent users are those that shred LLW or more highly radioactive transuranic waste. Users with these applications can provide insights about any special requirements and unique problems encountered when shredding radioactively contaminated wastes. However, the physical properties, shape, and size of waste has a greater effect on the operation of shredders than do the radiological properties of the waste.

The list provided below does not constitute an endorsement of any particular vendor nor is it intended to be inclusive.

Shredder Vendors:

(1) American Pulverizer Company
5540 West Park Avenue
St. Louis, MO 63110
(314) 781-6100

Shredder Vendors (Continued):

(2) Bepex Corporation
333 N.E. Taft Street
Minneapolis, MN 55413
(612) 331-4370

(3) Blower Application Co.
N. 114 W. 19125 Clinton Dr.
Germantown, WI 53022
(414) 255-5580

(4) Carthage Machine Company
571 West End Avenue
Carthage, NY 13619
(315) 493-2380

(5) Hi-Torque Shredder Company
Division of Jersey Stainless, Inc.
230 Sherman Avenue
Berkeley Heights, NJ 07922
(201) 464-2002

(6) Impell Corporation
Division of Combustion Engineering
333 Research Court
Norcross, GA 30092
(404) 449-7840

(7) Montgomery Industries International
Jacksonville Blow Pipe Division
2017 Thelma Street
P.O. Box 3687
Jacksonville, FL 32206
(904) 355-5671

Shredder Vendors (Continued):

(8) Saturn Shredders/MAC Corporation
201 East Shady Grove Road
Grand Prairie, TX 75050
(214) 790-7800

(9) Shred Pax Corporation
136 West Commercial Avenue
Wood Dale, IL 60191-1304
(312) 595-8780

(10) Shredding Systems Inc.
P.O. Box 869
Wilsonville, OR 97070
(503) 682-3633

(11) Triple/S Dynamics
1031 South Haskell Ave
Dallas, TX 75223
(800) 527-2116

(12) Williams Patent Crusher & Pulverizer Co.
2701 North Broadway
St. Louis, MO 63102
(314) 621-3348

Shredder Users:

(1) Baltimore Gas and Electric Co.
Calvert Cliffs Nuclear Plant
Lusby, MD
(301) 260-4009

Shredder Users (Continued):

(2) Boston Edison Co.
Pilgrim Nuclear Plant
Plymouth, MA
(508) 747-8117

(3) Carolina Power & Light Co.
Brunswick Nuclear Plant
Southport, NC
(919) 457-2263

(4) Chalk River Atomic Energy Laboratory
Chalk River, Ontario
(613) 584-3311

(5) Nebraska Public Power District
Cooper Nuclear Plant
Brownsville, NE
(402) 825-3811

(6) Oak Ridge National Laboratory
Oak Ridge, TN
(615) 574-9007

(7) Savannah River Laboratory
Aiken, SC
(803) 557-6428

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9. OTHER MEANS OF SOLIDIFICATION

Other less common but commercially available solidification techniques utilize various polymers. Two polymer solidification agents that have been successfully tested and are ready for commercial application are vinyl ester-styrene and the "AZTEC" polymer system. Other polymeric solidification agents, including polyester-styrene and epoxy, are still in the developmental stages and will not be discussed here.

9.1 Polymeric Solidification Systems - Overview

Chemical processes associated with polymeric solidification are somewhat complicated. In general, the processes involve mixing liquid monomeric chemicals that react with a catalyst and linking individual molecules to form long-chain hydrocarbon molecules. This process is called polymerization. Sometimes, a promoter is also added to the process, causing the catalyst to decompose and accelerating polymerization. These processes are usually carried out at room temperature and require no additional heat. The wastes themselves do not participate in the chemical reaction of polymerization. Polymers solidify the liquid waste by entrapping waste elements among complex linkages of the long-chain molecules.

Of the many commercially available solidification agents, polymeric systems were found to achieve among the highest waste loading factors. Vendor test data have shown samples with waste loading factors as high as 60 to 67 percent by weight that are still able to meet all six BTP stability criteria (reference 1-4). In contrast to cement, polymeric systems do not require water to solidify. Consequently, these systems often result in significant volume reduction. Polymer-solidified wastes possess compressive strengths of 1,500 to 9,000 psi and exhibit good leach resistant characteristics. Test results presented to the NRC in vendors' topical reports demonstrate that polymer-solidified wastes remain impervious to the effects of radiation, temperature fluctuation, water immersion, and microbial attack.[9-1, 9-2]

While polymeric systems possess all the favorable characteristics required to meet the NRC's stability requirements, they are slightly more expensive than other stabilization systems. Preparation procedures also require precise measurement, handling, and mixing of chemical ingredients. Lastly, the potential for explosions, fires, and releases of toxic fumes caused by some of the chemicals used in the process requires serious consideration in the design and operational procedures of a system. Overall advantages and disadvantages of polymeric systems are summarized in Table 9-1.

The following discussion describes two types of commercially available polymer solidification systems: the vinyl ester-styrene system and the "AZTECH" polymer system.

9.2 Vinyl Ester-Styrene System

In the vinyl ester-styrene system, three or four proprietary monomer chemicals are generally used in the polymerization process, depending on the waste to be solidified. After the waste and chemical compounds are mixed together, a catalyst is added to start the polymerization process. Within one hour, the process is completed and the mixture is hardened with waste entrapped inside the solidified matrix. The entire process is conducted at room temperature, without the addition of heat. Although actual operating experience with this process is limited, test results indicate the binding chemicals are generally insensitive to the chemical composition of most waste streams, provided the pH is within an acceptable range. Waste streams such as those containing boric acid must be pretreated to an acceptable pH for solidification. In general, waste-to-binder ratios of 1.5 to 2.0 can be expected, depending on the waste types (Reference 9-1).

The Dow Chemical Company is the only company actively marketing the vinyl ester-styrene solidification process. This process does not yet have a commercial performance record. The NRC has approved the DOW topical report, pending satisfactory completion of thermal cycling tests.

TABLE 9-1. ADVANTAGES AND DISADVANTAGES OF POLYMERIC SOLIDIFICATION SYSTEMS

Advantages	Disadvantages
o Adaptable to many waste streams both solid and liquid	o Limited shelf life for binding chemicals
o No free-standing water	o Release of toxic fumes, potential explosive and fire hazard for the handling of catalyst and promoter
o Extremely low leachability	
o High compressive and impact strength	o Relatively expensive materials
o Good radiation stability	o Requires careful handling and mixing
o Ease of working with liquid components	
o Available in both in-container and mobile mixing systems	

9.3 AZTECH Polymeric System

The other commercially available polymeric solidification agent is the AZTECH polymeric system developed by the General Electric Company. Much of the information regarding the details of the system and chemical process of solidification are proprietary and are not available. However, the general process can be described.

Waste solution and vinyl toluene are introduced and mixed in a mixer-evaporator where an azeotropic[a] distillation process takes place to remove the water in the liquid or wet solid waste. When the vinyl toluene coated residue is free of water, it is discharged into a 55-gallon drum where a catalyst and a polyester polymer are added to initiate the polymerization process. This mixture must either be heated and maintained at 180°F, or a promoter must be added to allow the solidification process to proceed properly. The solidification process takes approximately 2 to 3 hours. The resulting product is a dense, hard, and water-resistant solid monolith. The AZTECH system is suitable for the solidification of most low-level waste streams. A review of the AZTECH waste form test data indicates that the solidified waste form possesses the highest structural strength of all stabilization media tested, greatly exceeding the NRC acceptance criteria, and generally exceeds all other stability requirements (Reference 9-2). However, this system is sensitive to the mixing process and the handling of chemicals in the mixture. Field application of this system requires strict adherence to design and procedural requirements so that the chemicals will be properly mixed and the polymerization process will be complete. The NRC has approved the topical report for the AZTECH polymeric system.

While the AZTECH system was first developed by General Electric Company, this company has since sold the entire technology, the equipment, and the process to Pacific Nuclear of Federal Way, Washington. The AZTECH system was once

a. An azeotrope is a liquid mixture that maintains a constant boiling point and that produces a vapor of the same composition as the mixture.

marketed to Pennsylvania Electric and Power Company. However, the system has never functioned in a full-processing mode. The maintenance contract on the unit was recently terminated due to operational difficulties. As a result, there are no commercial AZTECH users.

The AZTECH system is available as both a mobile unit and an on-site permanent installation. The cost for solidifying power plant liquid waste using a mobile AZTECH system is estimated at approximately $16 to $20 per gallon, with a minimum monthly volume of 5,000 gallons. The cost for installing an entire system on-site is estimated at approximately $3 to $5 million.

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10. REFERENCES

10.1 References for Chapter 1

1-1. National Low-Level Radioactive Waste Management Program, The 1986 State by State Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites, DOE/LLW-66T, December 1987.

1-2. B. Bede, "US Ecology's Remarks before The House Subcommittee on Nuclear Affairs," Washington State Legislature, at Olympia, Washington, September 29, 1988.

1-3. M. Magleby, private communication, EG&G Idaho, Inc., November 8, 1988.

1-4. U.S. Nuclear Regulatory Commission, Branch Technical Position on Waste Form, May 1983.

1-5. J. W. Voss and B. D. Guilbeault, "The Mixed Economics of Volume Reduction," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 43-48.

10.2 References for Chapter 2

2-1. WasteChem Corporation, WasteChem Corporation's Volume Reduction and Solidification (CRS) System for Low-Level Radwaste System, DOE/ID/12636-TI.

2-2. Oak Ridge National Laboratory, Volume Reduction Techniques in Low-Level Radioactive Waste Management, ORNL/NFW-84/5, September 1981.

2-3. Nuclear Management and Resources Council, Inc., A Technical Basis for Meeting the Waste Form Stability Requirements of 10 CFR 61, NUMARC/NESP-002, April 1988.

2-4. U.S. Nuclear Regulatory Commission, Waste Solidification System Topical Report Review Status Summary, June 30, 1988.

2-5. American Nuclear Society, Measurement of the Leachability of Solidified Low-Level Radioactive Wastes by a Short-Term Test Procedure, ANS.16.1, February 1986.

2-6. M. Kaczmarsky, private communication, Waste Chem, December 6, 1988.

10.3 References for Chapter 4

4-1. S. Love, Babcock and Wilcox, private communication, August 17, 1988.

4-2. H. Baudisch, "DAW Volume Reduction (VR) Using the Newly Developed 20-MN (2,200 ton) SUPERPACK - A New Generation of Supercompacting Equipment," Proceedings of the Symposium of Waste Management, Tucson, Arizona, March 24, 1985, Volume 2, pp. 513-515.

4-3. L. C. Oyen and R. F. Tucker, Jr., Advanced Low Level Radwaste Treatment Systems, EPRI NP-1600, October 1980.

4-4. D. A. Zigelman, "Volume Reduction - A Solution to The Low-Level Radioactive Waste Policy Act Amendment of 1985," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986.

4-5. D. N. Enegess, "High Force Compaction - Its Capabilities and Limitations for Dry Active Waste Processing," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984.

10.4 References for Chapter 5

5-1. G. Trigilio, Volume-Reduction Techniques in Low-Level Radioactive Waste Management, NRC FIN B6413, 1981.

5-2. P. Dejonghe, W. Blommaert, V. D. Voorde, "Treatment and Conditions of Aqueous Effluents from LWRs Optimization in Volume Reduction and Insolubilization," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - 5, 1987.

5-3. R. H. Perry, C. H. Chilton, Chemical Engineers' Handbook, 5th Edition. New York: McGraw-Hill Book Company, Inc., 1973.

5-4. HPD Incorporated, "Crystallization for Radwaste Service" Reactor Radwaste Management Workshop at New Orleans, Louisiana, January 12 - 14, 1977.

5-5. B. B. McKercher, C. C. Miller, N. D. Naughton, "Operational Experience of the Palisades Station Volume Reduction System: The First Two Months," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984.

5-6. R. L. Jolley, L. R. Dole, H. W. Godbee, A. H. Kibbey, L. C. Oyen, S. M. Robinson, B. R. Rodgers, R. F. Tucker, Low-Level Radioactive Waste from Commercial Nuclear Reactors, DE86 012480, 1986.

5-7. L. Rutland, N. C. Papaiya, M. D. Naughton, "Current Status and Future Potential for Advanced Volume-Reduction Technologies," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984.

5-8. HPD Incorporated, "Operating Experience with Radwaste Evaporators," ASME Joint Power Generation Conference, September 1977.

5-9. G. Quinn, J. Hofmann, E. Schlich, "Volume Reduction for Low-Level Radwastes," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 8 - March 11, 1982.

5-10. L. Rutland and N. C. Papaiya, Long-Term, Low-Level Radwaste Volume-Reduction Strategies Volume 3: Characterization of Low-Level Radwaste Volume-Reduction Installations, EPRI, 1984.

5-11. R. Vandenberg, private communication, Resource Conservation Company, 1988.

5-12. F. Bella, private communication, Swenson Process Equipment, Inc., 1988.

5-13. APV, Evaporator Handbook, Chicago, Illinois: APV Crepaco, Inc., 1987.

5-14. Nuclear Management and Resources Council, 1776 Eye Street NW, Suite 300, Washington, D.C., 20006-2496, (202) 872-1280.

5-15. Miller Freeman, Buyers Guide 1988, San Francisco, California: Miller Freeman Publications, 1988.

5-16. Chemical Engineering, Chemical Engineering Equipment Buyers Guide 1989 Issue, New York: McGraw-Hill Publishers, Inc., 1988.

10.5 References for Chapter 6

6-1. S. B. McCoy, W. M. Poplin, T. A. Jur, "A Hybrid High Integrity Container for Disposal of Low-Level Radioactive Wastes," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 571-574.

6-2. H. Lowenberg, "Development of a Composite Polyethylene-Fiberglass Reinforced Plastic High Integrity Container for Disposal of Low-Level Radioactive Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 569-570.

10.6 References for Chapter 7

7-1. G. W. Csullog and S. Kupca, "Waste Characterization Studies at CRNL," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984.

7-2. F. Hetzler, private communication, Studsvik Energiteknik AB, Sweden, May 2, 1988.

7-3. F. Hetzler, "The Studsvik Incinerator - Ten Years After," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

7-4. M. S. Terrell, "Incineration Test Results of a Fluidized Bed Incinerator System," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

7-5. S. H. King, K. L. Miller, G. L. Zook, "Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

7-6. R. Hopper, Thermal Systems for Conversion of Municipal Solid Waste, ANL/CNSV-TM-120, Volume 3, July 1983, 162 pp.

7-7. M. Hoshino, M. Hayashi, I. Oda, N. Nanaka, K. Kuwayama, T. Shigeta, "Progress on Radioactive Waste Slurry Incineration with Oxygen and Steam (IOS Process)," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

7-8. D. A. Weber, "The Savannah River Plant Consolidated Incineration Facility," Proceedings of the Symposium on Incineration of Low-Level Radioactive and Mixed Wastes at St. Charles, Illinois, April 22 - April 24, 1987.

7-9. L. Borduin, private communication, Los Alamos National Laboratory, June 14 to June 17, 1988.

7-10. F. S. Farinoso and R. B. Wilson, Radwaste Incinerator Experience, EPRI NP-3250, October 1983.

7-11. F. S. Farinoso, C. P. Deltete, R. B. Wilson, "Spent Resin Incineration: Should Radioactivity Preclude It?" Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987.

7-12. E. M. Steverson, D. P. Clark, J. N. McFee, "Addition of Liquid Waste Incineration Capability to the INEL's Low-Level Waste Incinerator," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986.

7-13. W. J. Klein, "Development of Process Systems for Radioactive Incinerator Ash," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983.

7-14. R. F. Abrams and J. P. Monat, "Spray Drying of Liquid Radioactive Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984.

7-15. R. L. Gay, L. F. Grantham, D. E. McKenzie, "Volume Reduction of Reactor Wastes by Spray Drying," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983.

7-16. M. Vincent, private communication, Commonwealth Edison, 1988.

7-17. K. H. Oma, J. H. Westsik, W. A. Ross, Shredder and Incinerator Technology for Treatment of Commercial Transuranic Wastes, PNL-5632, October 1985.

7-18. V. T. Le, N. V. Beamer, L. P. Buckley, "Experience with Radioactive Waste Incineration at Chalk River Nuclear Laboratory," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

7-19. B. S. Bowerman, C. R. Kemf, D. R. MacKenzie, B. Siskind, P. L. Piciulo, An Analysis of Low-Level Wastes: Review of Hazardous Waste Regulations and Identification of Radioactive Mixed Wastes, NUREG/CR-4406, 1985.

7-20. R. A. Young, "Environmental Control Telephone Directory," Pollution Engineering, October 1987.

7-21. C. R. Brunner, D. R. Dean, F. A. Erickson, "Site Remediation by Incineration/Thermal Treatment," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

10.7 References for Chapter 8

8-1. G. R. Darnell and W. C. Aldrich, Low-Speed Shredder and Waste Shredability Tests, U.S. Department of Energy, April 1983.

8-2. K. H. Oma, "Shredder and Incinerator Technology for Volume Reduction of Commercial Transuranic Wastes," American Nuclear Society International Topical Meeting on Waste Management, Niagara Falls, New York, September 15, 1986.

8-3. Hi-Torque Shredders, Brochures, Berkeley Heights, New Jersey, 1988.

8-4. Shredding Systems, Brochures, Wilsonville, Oregon, 1988.

8-5. J. Beasley, private communication, Shredding Systems, November 30, 1988.

8-6. U.S. Department of Energy, Documentation on Currently Operating Low-Level Radioactive Waste Treatment Systems, November 1987.

8-7. S. Simpson, private communication, Savannah River Laboratory, November 29, 1988.

8-8. J. D. Henderson and R. W. Marshall, Operating Experience with Dry Active Waste Shredder/Compactor at a Nuclear Power Plant, Carolina Power and Light Company and Impell Corporation, 1986.

8-9. J. Torok, private communication, Waste Management Division of Chalk River Atomic Energy Laboratory, 1988.

8-10. Saturn Shredders, Brochures and Technical Information, 1986.

8-11. D. B. Burns, private communication, Interim Waste Technology Division, E.I. du Pont De Nemours & Company (Incorporated), Savannah River Laboratory, 1988.

8-12. M. A. Christie, J. W. Cammann, R. S. McBeath, H. H. Rode, Waste Receiving and Processing Facility Engineering Study, DE86 004019, September 1985.

8-13. Impell Corporation, Technology Update - High Density Shredder/Compactor System, 1988.

10.8 References for Chapter 9

9-1. Envirosphere Company, A Technical Basis for Meeting the Waste Form Stability Requirements of 10 CFR 61, NUMARC/NBSP-002, April 1988.

9-2. U.S. Nuclear Regulatory Commission, Waste Solidification System Topical Review Status Summary, June 30, 1988.

APPENDIX A

BACKGROUND INFORMATION

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CONTENTS

TABLES

1. INTRODUCTION

This appendix provides background information on volume reduction and stabilization of low-level waste applying to several technologies. Regulatory requirements and characteristics and sources of low-level waste are discussed. This appendix is intended as a convenient reference to assist in developing an understanding of factors influencing choice and use of volume reduction and stabilization technologies.

2. REGULATORY REQUIREMENTS

Regulations or regulatory guidance affecting volume reduction and solidification of low-level waste are principally in the areas of waste form, transportation, health, and safety. In this section, specific stability requirements of the U.S. Nuclear Regulatory Commission (NRC) are presented for wastes treated by solidification or placed in high-integrity containers. Requirements of the Department of Transportation (DOT) are also briefly discussed. These regulations determine packaging and shielding requirements. The section also discusses the application of solidification processes such as cement to mixed hazardous and low-level radioactive waste and provides an overview of health and safety requirements for radioactive waste systems, with an emphasis on power reactor systems.

2.1 NRC Waste Form and Stability Requirements

The NRC recognized that 10 CFR 61 provided insufficient guidance to waste generators, vendors, regulators, and disposal site operators. Consequently, NRC issued two Branch Technical Position Papers in May 1983 explaining in greater detail what was meant by waste form and stability and how to classify waste.[A-1, A-2] Branch Technical Positions (BTPs) are not regulations; however, they describe acceptable method(s) of meeting the regulations. The Branch Technical Position (BTP) on Waste Form (Reference A-2) and 10 CFR 61 assume that stability can be achieved in four general ways. First, the waste itself could be stable. Second, the waste could be processed into a form that would meet stability requirements. Third, the waste could be placed in high-integrity containers (HICs) that would provide the necessary stability. Last, structures could be built at the disposal facility that would provide the required stability. The first three options address techniques generators can use to obtain stable wastes. The most frequently used techniques are discussed in this report. The fourth option deals with efforts at the disposal facility. This last option is not encountered as frequently as stabilization by generators. The BTP on Waste Form provides detailed descriptions of criteria and testing procedures for demonstrating waste form stability.

2.1.1 Requirements for Processed Wastes

The following stability requirements pertain to wastes that have been processed to achieve stability:

- Stability guidance for processed wastes should be implemented through the qualification of the individual licensee's process control program. Generic test data may be used for qualifying these process control programs. Through the use of a well designed and implemented process control program, frequent requalification to demonstrate stability is expected to be unnecessary. However, process control programs should include provisions to periodically demonstrate that the solidification system is functioning properly and waste products continue to meet the 10 CFR 61 stability requirements. Waste specimens should be prepared based on the proposed waste streams to be solidified and based on the range of waste stream chemistries expected. The tests identified may be performed on radioactive or nonradioactive samples.

- Solidified waste specimens should have compressive strengths of at least 50 psi when tested in accordance with ASTM C39.[A-3] Compressive strength tests for bituminous products should be performed in accordance with ASTM D1074.[A-4]

  Many solidification agents will be easily capable of meeting the 50 psi limit for properly solidified wastes. For these cases, process control parameters should be developed to achieve the maximum practical compressive strengths, not simply to achieve the minimum acceptable compressive strength.

- The specimens for each proposed waste stream formulation should remain stable after being exposed in a radiation field equivalent to the maximum level of exposure expected from the proposed wastes to be solidified. Specimens for each proposed waste stream formulation should be exposed to a minimum of 10^8 rads in gamma irradiator or equivalent. If the maximum level of exposure is expected to exceed 10^8 rads, testing should be performed at the expected maximum accumulated dose. The irradiated specimens should have a minimum compressive strength of 50 psi following irradiation as tested in accordance with ASTM C39 or ASTM D1074.

- Specimens for each proposed waste stream formulation should be tested for resistance to biodegradation in accordance with both ASTM G21[A-5] and ASTM G22.[A-6] No indication of culture growth should be visible. Specimens should be suitable for compression testing in accordance with ASTM C39 or ASTM D1074. Following the biodegradation testing, specimens should have compressive strengths greater than 50 psi as tested using ASTM C39 or ASTM D1074.

  For polymeric or bitumen products, some visible culture growth from contamination, additives, or biodegradable components on the specimen surface that do not relate to overall substrate integrity may be present. For these cases, additional testing should be performed. If culture growth is observed upon completion of the biodegradation test for polymeric or bitumen products, remove the test specimens from the culture, and wash them free of all culture and growth with water and only light scrubbing. An organic solvent compatible with the substrate may be used to extract surface contaminants. Air dry the specimen at room temperature and repeat the test. Specimens should have observed culture growth rates no greater than 1 in the repeated ASTM G21 test and compressive strengths greater than 50 psi. The specimens should have no observed growth in the repeated ASTM G22 test and a compressive strength greater than 50 psi. Compression testing should be performed in accordance with ASTM C39 or ASTM D1074.

If growth is observed following the extraction procedure, longer term testing of at least six months should be performed to determine biodegradation rates. The Bartha-Pramer Method[A-7] is acceptable for this testing. Soils should be representative of those at burial grounds. Biodegradation extrapolated for full-size waste forms to 300 years should produce less than a 10 percent loss of the total carbon in the waste form.

- Leach testing should be performed for a minimum of 90 days in accordance with the procedure in ANS 16.1.[A-8] Specimen sizes should be consistent with the samples prepared for the ASTM C39 or ASTM D1074 compressive strength tests. In addition to the demineralized water test specified in ANS 16.1, additional testing using other leachants specified in ANS 16.1 should also be performed to confirm the solidification agents' leach resistance in other leachant media. The synthesized sea water leachant should also be tested. In addition, radioactive tracers should be utilized in performing the leach tests. The leachability index, as calculated in accordance with ANS 16.1, should be greater than 6.

- Waste specimens should maintain a minimum compressive strength of 50 psi as tested using ASTM C39 or ASTM D1074, following immersion for a minimum period of 90 days. Immersion testing may be performed in conjunction with the leach testing.

- Waste specimens should be resistant to thermal degradation. The heating and cooling chambers used for the thermal degradation testing should conform to the description given in

ASTM B553, Section 3.[A-9] Samples suitable for performing compressive strength tests in accordance with ASTM C39 or ASTM D1074 should be used. Samples should be placed in the test chamber and a series of 30 thermal cycles carried out in accordance with Section 5.4.1 through 5.4.4 of ASTM B553. The high temperature limit should be 60°C and the low temperature limit -40°C. Following testing the waste specimens should have compressive strengths greater than 50 psi as tested using ASTM C39 or ASTM D1074.

o Waste specimens should have less than 0.5 percent by volume of the waste specimen as free liquids when measured using the method described in ANS 55.1.[A-10] Free liquids should have a pH between 4 and 11.

o If small, simulated laboratory-size specimens are used for the above testing, test data from sections or cores of the anticipated full-scale products should be obtained to correlate the characteristics of actual-size products with those of simulated laboratory-size specimens. This testing may be performed on nonradioactive specimens. The full-scale specimens should be fabricated using actual or comparable solidification equipment.

o Waste samples from full-scale specimens should be destructively analyzed to ensure that the product is homogeneous to the extent that all regions in the product can expect to have compressive strengths of at least 50 psi. Full-scale specimens may be fabricated using simulated nonradioactive products, but should be fabricated using actual solidification equipment.

2.1.2 Special Considerations for Radiation Stability of Organic Ion-Exchange Resins

To ensure that organic ion-exchange resins will not produce adverse radiation degradation effects, resins should not be generated that have loadings which will produce greater than 10^8 rads total accumulated dose. For Cs-137 and Sr-90 a total accumulated dose of 10^8 rads is approximately equivalent to a 10 Ci/ft^3 concentration. This position is applicable to resins in the unsolidified, as-generated form. If the waste generator considers it necessary to load resins higher than 10^8 rads, it should be demonstrated that the specific resin will not undergo radiation degradation at the proposed higher loading. The test method should adequately simulate the chemical and radiologic conditions expected. A gamma irradiator or equivalent should be utilized for these tests. There should be no adverse swelling, acid formation, or gas generation that will be detrimental to the proposed final waste product.

2.1.3 Requirements for High-Integrity Containers (HICs)

The BTP on Waste Form (Reference A-2) also outlines specific requirements for HICs:

- The maximum allowable free liquid in an HIC should be less than 1 percent of the waste volume as measured using the method described in ANS55.1.[A-11] A process control program should be developed and qualified to ensure that the free liquid requirements in 10 CFR 61 will be met upon delivery of the damp solid material to the disposal facility. This process control program qualification should consider the effects of transportation on the amount of drainable liquid that might be present.

- HICs should have a minimum lifetime of 300 years. The HIC should be designed to maintain its structural integrity over this period.

- The HIC design should consider the corrosive and chemical effects of both the waste contents and the disposal trench environment. Corrosion and chemical tests should be performed to confirm the suitability of the proposed container materials to meet the design lifetime goal.

- The HIC should be designed to have sufficient mechanical strength to withstand horizontal and vertical load on the container equivalent to the depth of proposed burial assuming a cover material density of 120 pounds per cubic foot. The HIC should also be designed to withstand the routine loads and effects from the waste contents, waste preparation, transportation, handling, and disposal site operations, such as trench compaction procedures. The mechanical design strength should be justified by conservative design analysis.

- For polymeric material, design mechanical strengths should be conservatively extrapolated from creep test data.

- The design should consider the thermal loads from processing, storage, transportation, and burial. Proposed container materials should be tested in accordance with ASTM B553 (Reference A-9). No significant changes in material design properties should result from this thermal cycling.

- The HIC design should consider the radiation stability of the proposed container as well as the radiation degradation.

  Radiation degradation testing should be performed on proposed container materials using a gamma irradiator or equivalent. No significant changes in material design properties should result following exposure to a total accumulated dose of 10^8 rads. If it is proposed to design the HIC to greater accumulated doses, testing should be performed to confirm the adequacy of the proposed materials. Test specimens should be prepared using the proposed fabrication techniques.

- o Polymeric HIC designs should also consider the effects of ultraviolet radiation. Testing should be performed on proposed materials to show that no significant changes in material design properties occur following expected ultraviolet radiation exposure.

- o The HIC design should consider the biodegradation properties of the proposed materials and any biodegradation of wastes and disposal media. Biodegradation testing should be performed on proposed container materials in accordance with ASTM G21 and ASTM G22 (References A-3 and A-4, respectively). No indication of culture growth should be visible. The extraction procedure may be performed where indications of visible culture growth can be attributable to contamination, additives, or biodegradable components on the specimen surface that do not affect the overall integrity of the substrate. It is also acceptable to determine biodegradation rates using the Bartha-Pramer Method (Reference A-7). The rate of biodegradation should produce less than a 10 percent loss of the total carbon in the container material after 300 years. Test specimens should be prepared using the proposed material fabrication techniques.

- o The HIC container should be capable of meeting the requirements for a Type A package as specified in 49 CFR 173.398(b). The free drop test may be performed in accordance with 10 CFR 71, Appendix A, Section 6.

- o The HIC container and the associated lifting devices should be designed to withstand the forces applied during lifting operations. As a minimum the container should be designed to withstand a 3g vertical lifting load.

- o The HIC container should be designed to avoid the collection or retention of water on its top surfaces to minimize accumulation of trench liquids that could result in corrosive or degrading chemical effects.

- HIC container closures should be designed to provide a positive seal for the design lifetime of the container. The closure should also be designed to allow inspections of the contents to be conducted without damaging the integrity of the container. Passive vent designs may be utilized if needed to relieve internal pressure. Passive vent systems should be designed to minimize the entry of moisture and the passage of waste materials from the container.

- Prototype testing should be performed on HIC designs to demonstrate the container's ability to withstand the proposed conditions of waste preparation, handling, transportation, and disposal.

- HICs should be fabricated, tested, inspected, prepared for use, filled, stored, handled, transported, and disposed of in accordance with a quality assurance program. The quality assurance program should also address how wastes that are detrimental to HIC materials will be precluded from being placed into the container. Special emphasis should be placed on fabrication process control for those HICs that utilize fabrication techniques such as polymer molding processes.

2.1.4 Topical Reports

The NRC determined that products used to achieve stability should have a coordinated regulatory review to provide reasonable assurance of long-term performance. The NRC thus began to formally review topical reports submitted by the vendors of the equipment or processes designed to achieve stability. Prior to 1983, this review system was almost exclusively applied to safety analyses of reactor-associated components and was not often used to describe waste forms. When 10 CFR 61 was promulgated, NRC encouraged vendors to use the topical report process as a regulatory review and approval system for those processes, media, and containers intended to meet the new waste form requirements.

To assure market acceptance of their products, vendors generally submit topical reports to the NRC for review and approval in concert with their marketing efforts. Topical reports dealing with low-level wastes submitted thus far have fallen into four categories: process systems, computer codes, solidification media, and high-integrity containers. The topical reports provide justification and test results to demonstrate compliance with 10 CFR 61 waste form stability safety and recordkeeping requirements. A waste form or product that is not the subject of an approved topical report may still be acceptable for use; however, the generator must maintain test results and other documentation substantiating that the stability and other applicable requirements of 10 CFR 61 have been met. Because of the extensive testing and documentation requirements, most generators look to the topical report process to serve this function.

As of June 30, 1988, 26 topical reports had been received by the NRC. Of these, 7 were approved, 3 were discontinued, 6 were withdrawn, and 9 were under review, and 1 was given a conditional verbal approval. Table A-1 lists the status of each solidification and HIC topical report received by the NRC.

2.2 Licensing Requirements

A license amendment may be required if the volume reduction or solidification system component in any way threatens the safety systems of an operating reactor or other licensed facility. In general, an amendment is required for the installation and operation of an incinerator, evaporator, or solidification system. Amendments are usually not required for the installation and operation of ancillary equipment such as compactors or shredders at facilities that are already licensed. However, if the facility is primarily licensed to process waste, an amendment to the operating radioactive materials license would probably be required for installation and operation of any volume reduction or solidification equipment.

TABLE A-1. TOPICAL REPORT REVIEW STATUS SUMMARY - SOLIDIFIED WASTE FORM AND HIGH-INTEGRITY CONTAINERS (HICs)

Vendor	Docket No.	Type	Disposition
Waste Chem	WM-90[a]	Solidification (bitumen)	Approved
General Electric	WM-88	Solidification (polymer)	Approved
U.S. Gypsum	WM-51[a]	Solidification (gypsum)	Approved[b]
Chichibu	WM-81	HIC (poly impreg/concrete)	Approved
Nuclear Packaging	WM-45	HIC (ferralium/FL-50)	Approved
Nuclear Packaging	WM-85[a]	HIC (ferralium/family)	Approved
DOW	WM-82[a]	Solidification (polymer)	Approved[c]
ATI	WM-91[a]	Solidification (bitumen)	Discontinued
VIKEM	WM-13	Solidification (cement)	Discontinued
Stock	WM-92[a]	Solidification (cement)	Discontinued
Nuclear Packaging	WM-71	Solid/encap (cement/gypsum)	Withdrawn
LN Technologies	WM-57	HIC (polyethylene)	Withdrawn
Chem-Nuclear	WM-47	HIC (fiberglass/poly)	Withdrawn
Chem-Nuclear	WM-19[a]	Solidification (cement)	Withdrawn
Chem-Nuclear	WM-96[a]	Solidification (cement)	Withdrawn
Hittman	WM-79[a]	Solidification (SG-95)	Withdrawn
Chem-Nuclear	TBD[d]	Solidification (cement #1)	Under review
Chem-Nuclear	TBD	Solidification (cement #2)	Under review
Chem-Nuclear	TBD	Solidification (cement #3)	Under review
LN Technologies	WM-20	Solidification (cement)	Under review
Hittman	WM-46	Solidification (cement)	Under review
TFC	WM-76	HIC (polyethylene)	Under review
Nuclear Packaging	WM-83	HIC (316-stainless)	Under review
LN Technologies	WM-93	HIC (stainless/poly)	Under review[e]
Bondico	WM-94	HIC (fiberglass/poly)	Under review
Babcock & Wilcox	WM-95	HIC (coated carbon steel)	Under review

a. Actions completed in calendar year 1988.
b. Approved for single waste stream for one year.
c. Approved pending satisfactory completion of thermal cycling tests.
d. TBD = to be determined.
e. Verbal approval received fall 1988.

The use of mobile systems is a special licensing situation. In the case of mobile systems at a nuclear power plant, the mobile system would operate under the reactor's license. In the case of mobile systems at nonreactor facilities (e.g., hospitals and universities), the mobile system would be issued a license by the NRC or an Agreement State. Use of the mobile system would be determined by the terms and conditions of the mobile system's license, and reciprocal recognition of the operating license would be necessary if the system were to operate outside of the jurisdiction of the agency issuing the license.

Equipment for volume reduction and solidification of LLW would be evaluated by the NRC against the standards and guidance documents outlined in Table A-2. Agreement States must evaluate such systems in a manner that is compatible with the requirements of the NRC. In many cases standards and codes of manufacturing for design and delivery are adequate for fans, pumps, and pipes. However, if they contain radwaste products, the specific codes of R61.143 are required as summarized in Table A-3.[A-12]

2.3 Agreement State Requirements

Agreement States exercise considerable latitude in administering their radioactive materials licenses authorizing low-level radioactive waste disposal operations. To remain compatible with the NRC, the Agreement States with existing disposal sites must require adherence to the minimum classification, waste form, and recordkeeping requirements of 10 CFR 61.

Many Agreement States use the NRC waste form tests as part of their own regulations or license conditions for waste stability. Agreement States' requirements, however, can differ slightly from those of 10 CFR 61. Where federal requirements require only Class B and C wastes to be stabilized, some Agreement States require that a small portion of Class A waste streams must be stabilized also. Usually these are Class A wastes containing oils, chelating agents, and high concentrations of short-lived radionuclides. In general, all the stabilization media acceptable to the NRC are also acceptable to the Agreement States.

TABLE A-2. SUMMARY OF RELEVANT NRC REQUIREMENTS APPLICABLE TO VOLUME REDUCTION AND SOLIDIFICATION SYSTEMS

Regulation/Document/Code	Title
10 CFR 50.34a[a]	Design Objectives for Equipment to Control Releases of Radio-active Material in Effluent
10 CFR 50.36a[a]	Technical Specifications on Effluents from Nuclear Power Reactors
10 CFR 50.59a[a]	Influence of Modification on Plant Safety Systems
10 CFR 50[a] (Appendix A)	General Design Criterion for Nuclear Power Plants
10 CFR 50[a] (Appendix I)	Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low As is Reasonably Achievable" for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents
Criterion 60	Control of Releases of Radioactive Materials to the Environment
Criterion 64	Monitoring Radioactivity Releases
10 CFR 51[a]	Licensing and Regulatory Policy and Procedures for Environmental Protection
10 CFR 20	Standards for Protection Against Radiation
10 CFR 20 (Appendix B)	Concentrations in Air and Water Above Material Background
10 CFR 20.101	Radiation Dose Standards for Individuals in Vertical Areas
10 CFR 20.103	Exposure of Individuals to Concentrations of Radioactive Materials in Air in Restricted Areas
10 CFR 20.105	Permissible Levels of Radiation in Unrestricted Areas

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TABLE A-2 (continued)

Regulation/Document/Code	Title
10 CFR 20.106	Radioactivity in Effluents to Unrestricted Areas
10 CFR 20.302	Method for Obtaining Approval of Proposed Disposal Procedures
10 CFR 20.305	Treatment of Disposal by Incineration
10 CFR 71.5	Transportation of Licensed Materials
40 CFR 190[a]	Environmental Radiation Protection Standards for Nuclear Power Operations
49 CFR 170-189	Guidelines and Procedures for Transportation of LLW; including Categorization, Packaging, Labeling, and Transportation Dose Rates.
Regulatory Guide 1.109[a]	Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR 50, Appendix I
Regulatory Guide 1.110[a]	Cost Benefit Analysis for Light-Water-Cooled Nuclear Power Reactors
Regulatory Guide 1.111[a]	Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors
Regulatory Guide 1.112[a]	Calculation of Releases of Radioactive Material in Gaseous and Liquid Effluents from Light-Water-Cooled Power Reactors
Regulatory Guide 1.113[a]	Estimating Aquatic Dispersion of Effluents from Accidental and Routine Releases for the Purpose of Implementing Appendix I

TABLE A-2 (continued)

Regulation/Document/Code	Title
Regulatory Guide 1.143[a]	Design Guidance for Radioactive Waste Management Systems Structures and Components Installed in Light-Water-Cooled Nuclear Power Plants
Regulatory Guide 1.21[a]	Measuring, Evaluating, and Reporting Radioactivity in Solid Wastes and Releases of Radioactive Materials and Liquid and Gaseous Effluents from Light-Water-Cooled Nuclear Power Plants
Regulatory Guide 1.120[a]	Fire Protection Guidelines for Nuclear Power Plants
Regulatory Guide 1.140[a]	Design, Testing, and Maintenance Criteria for Normal Ventilation Exhaust System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants
Regulatory Guide 1.143[a]	Seismic Design and Quality Assurance Requirements for Structures or Systems Used to Collect or Store Liquid or Solid Radwaste
Regulatory Guide 8.8	Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations will be As Low As Is Reasonably Achievable
Regulatory Guide 8.10	Operating Philosophy for Maintaining Occupational Radiation Exposure As Low As Is Reasonably Achievable
ANS 40.35 (draft)	Volume Reduction of Low-Level Radwaste
ANSI/ASME N509 (1976)	Nuclear Power Plant Air Cleaning Units and Components
ASTM G4-68	Conduct of Plant Corrosion Tests

TABLE A-2 (continued)

Regulation/Document/Code	Title
IEEE 383	The IEEE Standards for Type Test of Class IE Electrical Cables, Field Splices, and Connections for Nuclear Power Generating Stations
NEMA Standards	National Electrical Manufacturers Association Standards
NFPA Standards	National Fire Protection Association Standards

a. These system design and release control requirements are applicable solely to waste processing systems installed or to be installed at nuclear power plants.

TABLE A-3. DESIGN GUIDANCE FOR RADWASTE SYSTEMS

	Codes			
Equipment	Design and Fabrication	Materials[a]	Welder Qualification and Procedures	Inspection and Testing
Pressure vessels	ASME, Sect VIII, Div 1	ASME, Sect II	ASME, Sect IX	ASME, Sect VIII, Div 1
Atmospheric tanks	ASME,[b] Sect III, Class 3 or API 650 or	ASME, Sect III AWWA D-100[c]	ASME, Sect IX	ASME,[b] Sect III, Class 3 or API 650 or AWWA D-100[c]
0-15 lb/in²g tanks	ASME,[b] Sect III, Class 3 or API 620[c]	ASME,[c] Sect II	ASME, Sect IX	ASME,[b] Sect III, Class 3 or API 620[c]
Heat exchanger	ASME, Sect VIII, Divl	ASME, Sect II and TEMA	ASME, Sect IX	ASME, Sect VIII, Div 1
Piping and valves	ANSI B31.1	ASTM and ASME, Sect II	ASME, Sect IX	ANSI B31.1
Pumps	Mfgr's Stds[d]	ASME, Sect II or Mfgr's	ASME, Sect IX (as reqd)	ASME,[b] Sect III, Class 3 or Hydraulic Institute

a. Manufacturer's material certificates of compliance with material specifications may be provided in lieu of certified material.

b. ASME Code stamp, material traceability, and quality assurance criteria of Appendix B to 10 CFR 50 are not required. Therefore, these components are not classified as ASME Code Class 3.

c. Fiberglass-reinforced plastic tanks may be used in accordance with appropriate articles of Section 10, ASME Boiler and Pressure Vessel Code, for applications at ambient temperature.

d. Manufacturer's standards for intended service. Hydrotesting should be 1.5 times design pressure.

Acceptance of HICs is not, however, uniform among the three Agreement States and the NRC. These differences are because of the comparatively limited experience with HICs prior to promulgation of 10 CFR 61; the relatively large differences in operations, depth of disposal, and soil chemistry among the three sites; and the relatively complex testing requirements for HICs.

Waste generators must consider the final destination of their waste in determining how it is to be treated or packaged, as differences exist among the requirements of the three disposal sites. A summary of pertinent Agreement State requirements is presented below. The three states with currently operational facilities are discussed first. These states are Washington, Nevada, and South Carolina. Because the disposal sites in these states predated promulgation of 10 CFR 61, not all of the provisions of 10 CFR 61 may be applicable to these disposal sites.

Washington State has recently completed an extensive revision of the disposal license for facility operations and waste acceptance at the Richland commercial LLW facility. The new license specifies a number of Class A waste streams that require solidification or stabilization. Table A-4 lists stabilization media approved by the State of Washington as part of the Richland commercial LLW disposal license, dated January 21, 1987. The current Richland license expires November 30, 1990. Operator licenses typically are renewed every five years. The State of Washington has required adherence to the classification and waste form criteria continued in the May 1983 BTP (References A-1 and A-2) for this 1987 license revision.

The Barnwell, South Carolina license was renewed on August 25, 1986. The State of South Carolina has adopted substantial portions of 10 CFR 61 and the waste form guidance in the BTP. Table A-5 shows approved stabilization media as part of the renewed license. Before this license renewal, the State of South Carolina did not accept bitumen

TABLE A-4. APPROVED STABILIZATION MEDIA AT RICHLAND, WASHINGTON[A-12]

Excerpts from Washington Radioactive Materials License:

"Only those stabilization media which have been evaluated or are in the process of being evaluated and are used with the stability guidance requirements of the U.S. Nuclear Regulatory Commission's Low-Level Waste Licensing Branch, Technical Position on Waste Form or are specifically approved by the Department are considered acceptable stabilization media. The approved stabilization media are:

1) Aztech (General Electric)
2) Bitumen[a] (ATI and Waste Chem)
3) Chem-Nuclear Cement
4) Concrete[b]
5) Dow Media (Vinyl Ester Styrene)
6) Envirostone (U.S. Gypsum Cement)
7) LN Technologies Cement
8) Stock Equipment Cement
9) Westinghouse-Hittman Cement
10) Other stabilization media and processes which have been reviewed and approved by U.S. NRC and/or the Department as meeting waste form stability criteria."

a. Oxidized bitumen only.

b. Concrete, when used as an encapsulation medium around a small volume of radioactive material (e.g., a sealed source centered in a 55-gallon drum containing concrete) shall have a formulated compressive strength greater than or equal to 2500 psi.

TABLE A-5. APPROVED STABILIZATION MEDIA AT BARNWELL, SOUTH CAROLINA[A-13]

Excerpts from Barnwell License:

"This licensee is allowed to receive aqueous liquids and other applicable waste forms which have been solidified or otherwise stabilized with one of the following solidification media:

1) Vinyl Ester Styrene
2) Cement
3) Bitumen
4) G. E. Aztech

For bitumen, the license stated the following additional conditions:

"The licensee shall only receive for disposal, full formula, oxidized bitumen (asphalt) solidified waste, and certified as such by the waste generator. Regardless of the waste classification, bitumen solidified waste received for disposal shall be a free-standing monolith and shall not demonstrate the characteristics of a free flowing, viscous fluid.

The licensee shall dispose of bitumen solidified waste in trenches commensurate with the applicable waste classification, and in all cases, provide sufficient backfill material to fill all voids around the waste to provide structural stability and minimize trench subsidence. The licensee may construct segregated trenches for disposal of bitumen waste provided approval is granted by the Department.

Prior to receiving bitumen solidified waste, the licensee shall establish specific handling, placement and backfilling procedures to assure exposure to workers is maintained in accordance with ALARA requirements."

stabilization media at Barnwell. In October 1986, Barnwell began accepting "full formula oxidized bitumen" waste, provided it met the criterion of a free-standing monolith.

The Beatty, Nevada, license is undergoing renewal at this time. Amendments to the existing license have required no additional Class A wastes to be stabilized and have generally allowed HICs acceptable at either of the two other operating disposal sites.

Several Agreement States without operating disposal sites are amending their regulations to include requirements compatible with 10 CFR 61. In Illinois, the State Department of Nuclear Safety is sponsoring a study on appropriate waste form and acceptance criteria. Promulgation of LLW regulations will occur after completion of this study. The Departments of Health in California, New Hampshire, Colorado, New York, Washington, Nevada, and Texas have adopted regulations consistent with 10 CFR 61 and the BTP.

In North Carolina, the State Department of Human Resources, Radiation Protection Section, is currently preparing draft LLW regulations for public comment.

Nonagreement states are also preparing to promulgate 10 CFR 61 compatible regulations. In Pennsylvania, the State Department of Environmental Protection is in the process of developing NRC compatible LLW regulations in preparation for becoming an Agreement State for LLW only.

2.4 Other Requirements

2.4.1 Transportation

Transportation requirements can play an important role in determining how much waste can be put into a package, how heavy the package can be, and what type of shielding is necessary.

Transportation requirements are established by federal, state, and local authorities. The principal federal agencies responsible for regulating the transportation of radioactive wastes are the NRC and the U.S. Department of Transportation (DOT). The NRC is responsible for the safety, design, and performance of packages for fissile materials and large quantities of radioactive materials, called Type B packages. The DOT is responsible for assuring safe transport of all radioactive materials by air, water, rail, or highway with specific responsibility for transit safety, packaging, manifests, loading, unloading, handling, driver qualification, and package tie-down requirements. Limitations on the gross weight of trucks and intrastate routing are controlled and regulated by each individual state and local authority.

The disposal package and waste form are regulated by the NRC or the Agreement State. The final waste form after volume reduction or solidification must meet the applicable packaging requirements of DOT regulations presented in 49 CFR 171 through 178 and NRC regulations presented in 10 CFR 71. In many cases the package and waste form requirements for disposal are in excess of what is required for transportation alone. Most low-level radioactive wastes are transported in strong tight containers as low specific activity (LSA) materials. Strong tight containers are the least expensive container for transport. As concentrations or total activity in a package increase, waste may need to be transported in Type A or Type B containers. Type A packages are regulated by the DOT, are designed to withstand the normal rigors of transportation, but are not necessarily designed to withstand transportation accidents. Consequently, the quantities and concentrations of materials that can be transported in Type A containers are limited. Type B packages are regulated by the NRC, designed to retain their effectiveness even in a severe accident, and used when total activity in a package is in excess of that allowed in a Type A package. Type B packages, because of their design, shielding, and testing, are generally more expensive to use and transport.

The packaging regulations for waste transport are complex, waste specific, and beyond the scope of this manual. Transportation requirements can play a major role in assessing cost-effectiveness of a volume reduction technology if application of the technology would require a more expensive package (e.g., Type B packaging) or would require heavy load restrictions (e.g., stabilization using cement). Section 1.7 of the manual briefly discusses some of these competing economic factors.

2.4.2 Mixed Waste

A small volume of low-level radioactive waste is classified as hazardous waste under the Resource Conservation and Recovery Act (RCRA). Under RCRA, a waste is considered hazardous if it has certain characteristics such as ignitability, corrosivity, reactivity, and toxicity as described in 40 CFR 261, Subpart C - Characteristics of Hazardous Waste. If a waste passes all of these tests, it can still be designated as a hazardous waste by containing materials listed in the tables provided in Subpart D - Lists of Hazardous Waste. In addition, some states have additional test procedures, modifications to RCRA tests, or additional table listings that may make a waste hazardous. If a waste is determined to be a hazardous as well as a LLW, it is classified as a mixed waste.

The NRC and the EPA have issued joint guidance on the definition of mixed waste.[A-13] The NRC and the EPA contend that they know of no instances where regulation of mixed waste by the EPA is in conflict with NRC requirements. In case of a conflict, variances to RCRA requirements can be granted by the EPA in favor of compliance with NRC or Agreement State regulations in accordance with Section 1006 of RCRA. The joint NRC/EPA guidance document recommends that potential inconsistencies should be discussed with the NRC to verify the Atomic Energy Act requirements and to ensure that the reasons for the variance are technically sound.

The EPA requires that persons who treat, store, or dispose of hazardous waste do so under a RCRA permit. Generators of hazardous or mixed waste must register with the EPA or a delegated state program carrying out the provisions of RCRA.

Sources of mixed wastes can include boiling water reactors (BWRs) and pressurized water reactors (PWRs), hospitals, industries, and some commercial laboratories. Mixed wastes are regulated by both the state or federal agency implementing RCRA and the state or federal agency implementing the Atomic Energy Act (NRC or Agreement State). Some stabilization and volume reduction techniques can be used in the treatment of mixed wastes. For example, incineration of flammable mixed wastes can destroy the hazardous component of the waste. A stabilization medium such as cement can render the resulting product less harmful to the environment. Regulations implementing RCRA (40 CFR 264 and 265) require that treatment facilities operate under interim status or a RCRA Part B permit. Disposal of the treated waste product (ash in the case of an incinerator or a free-standing monolith in the case of waste solidified with cement) will continue to be regulated under RCRA as a hazardous waste unless the waste product can be delisted, or it can be demonstrated to the EPA that the waste is no longer hazardous.

2.4.3 Environmental Releases

Effluents from waste processing and treatment technologies must also comply with all other environmental laws. These laws may be enforced by the EPA or a state or local agency, depending on delegation of authorities and local laws. Most notable are the requirements for a National Pollution Discharge Elimination System Permit (NPDES Permit) for discharges of treated liquids to surface water and Clean Air Act emissions of radionuclides and other substances.

2.4.4 Occupational Safety and Health Act

Standard industrial safety requirements of 29 CFR 1910 must be followed at all times for all systems and technologies. These requirements are in addition to, not in substitution for, all Atomic Energy Act requirements administered by the NRC or an Agreement State.

3. LOW-LEVEL WASTE SOURCES AND CHARACTERISTICS

The following section describes sources and characteristics of low-level waste streams undergoing typical volume reduction and/or solidification prior to disposal at a commercial disposal site. In general, there are three major sources of low-level wastes:

- Nuclear power plants
- Industries and institutions
- Government research and defense activities

The primary sources of commercial low-level waste streams are operations of nuclear power plants and their supporting fuel cycle facilities. Industrial manufacturers of radioactive materials and commercial research and testing institutions are the second major LLW source. Low-level waste from government research, defense programs, and weapon production are primarily the responsibility of the DOE and are handled, treated, and disposed of at DOE-owned facilities. These DOE waste streams are not subject to NRC or Agreement State license authority and are not discussed in this manual.

Commercial low-level waste streams exhibit highly variable physical, chemical, and radiological characteristics. Section 3.1 discusses power reactor waste streams, while Section 3.2 describes waste streams from industrial and institutional generators.

3.1 Power Generation Wastes

LLW from power generation can be divided into power reactor wastes and fuel cycle facility wastes. Power reactors are responsible for the largest volume of LLW. Fuel cycle plants, such as fuel enrichment plants and fuel fabrication plants, produce small volumes of LLW relative to power plants. Fuel cycle facility wastes include calcium fluoride generated from hydrogen fluoride gas scrubbers, filter sludges, contaminated equipment, and trash.

Power reactor wastes are generated from two types of reactors: pressurized water reactors (PWRs) and boiling water reactors (BWRs). The majority of power reactor wastes can be classified as liquid radioactive wastes, wet solids (including slurries), dry active solid wastes (DAW), and liquid organic wastes. Only liquid and wet solid wastes must be solidified prior to transportation and disposal. DAW is typically Class A waste and therefore does not usually require stabilization.

3.1.1 Liquid Radioactive Wastes

Liquid radioactive wastes are typically composed of fluids with dissolved or suspended radioactive compounds, gases, or dust particles. Liquid radioactive wastes are produced from recycled reactor core fluids, hydraulic fluid from equipment repairs, housekeeping activities, and laundering. All liquid wastes are treated to remove the maximum amount of radioactive contamination. The treated liquids are then typically recycled or discharged to the environment under the control of the plant operating license and federal, state, and local environmental regulations. Liquid radioactive wastes can be treated by filtration, centrifugation, dehydration, or evaporation. The remaining concentrated waste is commonly referred to as evaporator bottoms, liquor, or concentrates. These concentrates are then typically stabilized with cement, bitumen, or other binder materials into free-standing solid monoliths for disposal.

Typical BWR liquid wastes include sodium sulfate solutions resulting from recycling demineralizer filters on ion-exchange processors. After an incident involving an exothermic reaction of regenerated ion-exchange media, sodium sulfate waste volumes have decreased substantially. PWR liquid wastes primarily consist of boric acid solutions generated from the purification of the primary reactor coolant. Boric acid is used as a neutron moderator in PWRs. The solidification of sodium sulfate and boric acid solutions are discussed in Chapters 2 and 3 of this manual dealing with the use of bitumen and cement as solidification media, respectively.

Another liquid waste type common to both PWR and BWR reactors is decontamination (decon) solutions. Decon solutions are generated from the periodic decontamination of equipment and the cleaning of machine parts. The purpose of in-plant decontamination is to reduce occupational exposure to workers. Decontamination solutions can include a wide variety of solvents such as oxalic acid, citric acid, crud, and small amounts of chelating agents (e.g., EDTA).

3.1.2 Wet Solid Wastes

Wet radioactive solid wastes consist of solid wastes containing a relatively high proportion of liquid. Most radioactive wet solid wastes are produced from cleaning aqueous processing systems at power reactors. Most power plants generate wet solid wastes that are either spent ion-exchange resins, filter sludge, or cartridge filters. Wet solid waste types generated at a plant vary depending on the type of cleaning processes employed at the plant. Precoat filtration systems produce filter cartridges and filter sludge wastes. Demineralizer systems produce spent bead resins or powdered resins. Class A wet solids may be dewatered or dehydrated and disposed in standard containers. Class B or C wet solid wastes require stabilization or containerization using an HIC. The following section describes the characteristics and sources of these three types of wet solid wastes.

3.1.2.1 Spent Ion-Exchange Resins. Spent ion-exchange resins are generated from the use of ion-exchange media to filter water. Ion exchange is a reversible filtration method where radioactive ions in the wastes are exchanged for nonradioactive ions in the filter material. Ion-exchange resins are used extensively in both BWRs and PWRs. The resins are made from organic polymers in the form of small beads 1 mm in diameter or powder packed into cylindrical tanks. As the liquid waste flows through the resin bed, dissolved radioactive contaminants chemically replace or exchange with the positive or negative ions in the resins. This process continues until the nonradioactive and radioactive ions are in equilibrium, the ion-exchange capacity of the resin is exhausted, and the spent resin is either replaced or regenerated.

Spent resins are removed from the filtration tanks and placed into shipping containers in a slurry form, which is then either dewatered or solidified. Spent resins can be regenerated by washing with sulfuric acid and sodium hydroxide. Wastes resulting from regeneration of resins reduced in concentrates for stabilization are high in sodium sulfate and are treated as liquid wastes.

3.1.2.2 Filter Sludge. To extend the life of filter cartridges and to increase efficiencies, filters may be precoated. Filter sludge waste is produced from this coating material, consisting of a thin layer of diatomaceous earth mixed with powdered cation- and anion-exchange resins and high purity cellulose fibers. In this case, the filter medium is usually made of a wire mesh or metal disk with the ion-exchange material sprayed on. This precoating removes suspended solids and dissolved solids. When the filtering capacity of the precoat filter is exhausted, the precoat material is scraped or rinsed off for disposal as wet solid waste.

3.1.2.3 Cartridge Filters. Spent cartridge filters are a common type of wet solid waste that requires solidification prior to disposal. Cartridge filters may contain one or more disposable filter elements. These elements can be woven fabric, wound fabric, pleated filter paper supported with stainless steel mesh, or pleated or mottled paper supported by an external stainless steel or plastic basket. Paper filter elements are often impregnated with epoxy. Woven fabric filters are typically constructed of cotton and nylon. Cartridge filters are effective in removing suspended solids but not dissolved solids.

3.1.3 Dry Active Solid Wastes

Dry active solid wastes (DAWs) are industrially produced wastes containing traces of radioactivity. Table A-6 presents typical types of DAWs. This waste category represents the largest volume of LLW and includes the most varied waste streams. DAWs are generated from nuclear power plants, industrial manufacturers, and institutions and include a wide variety of materials from paper towels to irradiated metals. Although most of this material contains only very low levels of radioactivity, a small fraction can contain sufficiently high radioactivity to require special handling. DAWs are typically the type of wastes that are suitable for volume reduction by compaction, incineration, or shredding. The application of these volume reduction technologies to DAW is discussed in Chpaters 4, 7, and 8 of this manual, describing compactors and supercompactors, incinerators, and shredders, respectively.

DAWs are divided into compactible and noncompactible wastes. Within these two classes, some DAWs are combustible. As a general rule, compactible DAWs have an average density of 8 lb/ft^3, and noncompactible DAWs have an average density of 22 lb/ft^3. With the introduction of supercompactor systems, DAWs that were previously considered noncompactible can now be compacted. Details regarding supercompactors are presented in Chapter 4 of this manual.

3.1.3.1 Compactible Wastes. Compactible wastes are typically composed of cloth, paper, plastics, rubber articles, wood chips, and thin-gauged metal contaminated with traces of radioactivity. In general, most compactible wastes are also combustible and therefore lend themselves well to incineration. Although incineration has been a widely used volume reduction technology in Europe, it has not been a common volume reduction technology in the United States due to its high cost and due to public concerns over environmental impacts. More detailed discussion of incineration is presented in Chapter 7 of this

TABLE A-6. LIST OF TYPICAL DRY ACTIVE SOLID WASTES (DAWs)

Anticontaminant clothing	Miscellaneous metal Aerosol cans Buckets Crushed 55-gallon drums Fittings Pipes and Valves
Cloth (rags, mops, gloves)	Miscellaneous wood
Conduit	Paper
Contaminated dirt	Plastic Bags, gloves, shoe covers Sample bottles
Contaminated tools and equipment Hand tools Eddy current equipment Vessel inspection equipment Ladders Lighting fixtures Spent fuel racks Scaffolding Laboratory equipment	Rubber
Filters Filter cartridges HEPA filters Respiratory cartridges	Sweeping Compounds
Glass	Irradiated metal alloys Flux wires Flow channels Fuel channels In-core instrumentation Poison channels Shim rods
High density concrete block	

manual. Most compactible DAWs are currently compacted and packaged into large boxes or drums for disposal at commercial LLW facilities as low specific activity wastes (LSA wastes). Noncombustible compactible wastes include waste metals such as thin metal sheets and small metal tools.

3.1.3.2 Noncompactible Wastes. Noncompactible wastes include radioactive building materials and metal components such as valves, piping, grating, tools, large pieces of wood, large equipment components such as tanks and parts of heat exchangers, and soil contaminated by spills or equipment leaks. Some noncompactible wastes are combustible. Contaminated building materials such as concrete, rubble, and bricks, and hardware such as contaminated valves, pipes, and tools are not combustible. Combustible but noncompactible wastes are mostly wood items such as wood crates, ladders, and scaffoldings. Most noncompactible wastes are placed into large boxes or drums for disposal as DAW. Void spaces can be a problem with these wastes. Many generators place compacted or uncompacted DAW in the disposal container to fill these voids. Contaminated soil can also be disposed of in the same container to fill voids.

3.1.4 Liquid Organic Wastes

This category of liquid organic wastes includes pump oil, lubricating oils, organic resins, liquid scintillation counting solutions, and decontamination solutions containing organic chelating agents. Liquid organic waste volumes are very small when compared to the total volume of LLRW generated nationwide. Liquid organic wastes are generally difficult to treat or solidify for disposal. Waste oils can sometimes be stabilized with cementitious agents or emulsifiers such as Envirostone, but the amount of oil must be carefully controlled. Waste oils can also be solidified with polyester binder agents such as General Electric's Aztech system (see Chapter 9 of this manual), but this agent is generally more expensive than cement. Liquid scintillation wastes and some oils are mixed wastes; that is, they are considered to be both radioactive and chemically hazardous wastes regulated under both the Atomic Energy Act and the Resource Conservation Recovery Act (RCRA).

Since radioactive contamination levels of most liquid organic wastes are usually extremely low, the industry is preparing an application to the NRC to allow these wastes to be disposed as nonradioactive wastes (Below Regulatory Concern [BRC] wastes). While regulations on BRC wastes are still being developed, many generators of liquid organic waste (not including most liquid scintillation wastes) are currently storing these wastes on site. BRC mixed waste would still be required to be disposed as hazardous waste. Liquid scintillation wastes are usually incinerated as a fuel additive.

3.2 Institutional and Industrial Wastes

Institutional wastes are wastes produced at laboratories, hospitals, clinics, medical schools, and research facilities. Radioactive materials are used for diverse applications including analytical instruments, diagnosis and therapy, research, and classroom instructions. Industrial wastes are generated by firms involved in the production of radioisotopes for medical research, industrial research, and development activities; quality control and testing applications; and manufacturing and distribution of products containing radioactive materials.

These wastes fall into the following categories:

- Liquid radioactive wastes
- Dry active solid wastes (DAWs)
- Liquid organic wastes
- Biological wastes
- Sealed sources.

Institutional and industrial wastes are similar in form to their counterpart wastes generated by reactor systems; however, they are far less homogeneous and predictable.

Liquid institutional wastes are typically produced in small chemically unique batches precluding processing or treatment with typical ion-exchange and filtration systems. Since liquid institutional wastes generally have low concentrations of radioactive material, they are usually treated with enough approved absorbent material to absorb twice the amount of liquid present. They may also be solidified with cement, although this treatment is usually reserved for liquids requiring stabilization.

Dry active solid wastes are generated by institutional users. However, this waste also reflects the diverse nature of the generator. Laboratory glassware and used syringes represent occupational as well as radiological hazards in institutional waste.

Liquid organic wastes from institutional and industrial generators are largely composed of liquid scintillation fluid, a toluene- and xylene-based mixture used in measuring radioactivity. Most scintillation wastes are mixed waste, but qualify for disposal as nonradioactive hazardous material under an exemption for small amounts of carbon-14 and tritium, 10 CFR 20.306. As such, most scintillation wastes are incinerated. They are disposed as a supplemental fuel and are exempt from most RCRA requirements. Liquid scintillation wastes are estimated to account for no more than 4 percent of the nation's low-level waste volume.

Biological wastes consist of tissue and cell cultures, animal carcasses, excreta, and animal bedding material. These wastes, produced in biological and medical research and nuclear medicine, can represent an infectious hazard if not properly pretreated prior to disposal.

Sealed sources are primarily used in industry in quality or process control applications or measuring instrumentation. According to the BTP on Waste Classification and NRC guidance, sealed sources can be stabilized in small packages of concrete meeting stability requirements. The concentration of the resulting waste package can be calculated using the entire volume or weight of the stabilizing concrete. The Agreement States regulating disposal sites may not agree in all cases with this provision of the BTP. Specific confirmation should be made with the regulator of the disposal site prior to stabilizing sealed sources.

3.3 Mixed Wastes

Mixed wastes are low-level wastes that are also subject to the requirements of the Resource Conservation and Recovery Act (RCRA) (see Section 2.3.2 for a discussion of the regulatory requirements for mixed waste. These wastes either exhibit a hazardous characteristic (ignitability, corrosivity, reactivity, or toxicity) or are specifically listed by the EPA or a state. There is debate and concern over the amount of mixed wastes actually being generated. Estimates based on generator shipping reports indicate that no more than 5 percent[A-14] of the volume of waste received in 1983 could qualify as mixed waste, but the records were not sufficiently detailed to determine the actual amount of mixed waste generated. Since that time, land disposal of liquid scintillation wastes used in counting radioactivity has been halted. These wastes are now often incinerated as a fuel additive under RCRA. Generation of small volumes of mixed wastes is still believed to occur throughout industry, medicine, and research. The EPA is in the process of determining how much of which types of mixed waste is routinely generated exclusive of Department of Energy operations.

4. REFERENCES

A-1. U.S. Nuclear Regulatory Commission, Technical Position on Radioactive Waste Classification, Rev. 0, May 1983.

A-2. U.S. Nuclear Regulatory Commission, Technical Position on Waste Form, Rev. 0, May 1983.

A-3. American Society for Testing and Materials, ASTM C39 - Compressive Strength of Cylindrical Concrete Specimens, 1979.

A-4. American Society for Testing and Materials, ASTM D1074 - Compression Strength of Bituminous Mixtures, 1980.

A-5. American Society for Testing and Materials, ASTM G21 - Determining Resistance of Synthetic Polymeric Materials to Fungi, 1970.

A-6. American Society for Testing and Materials, ASTM G22 - Determining Resistance of Plastics to Bacteria, 1976.

A-7. R. Bartha and D. Pramer, "Features of a Flask and Method for Measuring the Persistence and Biological Effects of Pesticides in Soils," Soil Science, 100, 1, 1965, pp. 68-70.

A-8. American Nuclear Society Draft Standard, ANS 16.1 - Measurement of the Leachability of Solidified Low-Level Radioactive Wastes, April 1981.

A-9. American Society for Testing and Materials, ASTM B553 - Thermal Cycling of Electroplated Plastics, 1979.

A-10. American Nuclear Society, ANS 55.1 - American National Standard for Solid Radioactive Waste Processing System for Light Water Cooled Reactor Plants, 1979.

A-11. Washington Department of Social and Health Services, Radioactive Materials License #WN-I019-2, January 21, 1987.

A-12. South Carolina Department of Health and Environmental Control, Radioactive Materials License issued to Chem Nuclear Systems for Barnwell facility, August 25, 1986.

A-13. J. G. Davis and J. W. Porter, Guidance on the Definition and Identification of Commercial Mixed Low-Level Radioactive and Hazardous Waste, January 5, 1987.

A-14. B. S. Bowerman, C. R. Kemf, D. R. MacKenzie, B. Siskind, P. L. Piciulo, An Analysis of Low-Level Wastes: Review of Hazardous Waste Regulations and Identification of Radioactive Mixed Wastes, NUREG/CR-4406, 1985.

APPENDIX B

ANNOTATED BIBLIOGRAPHY FOR LOW-LEVEL RADIOACTIVE WASTE VOLUME REDUCTION AND STABILIZATION RESOURCE MANUAL

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TABLE OF CONTENTS

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1. INTRODUCTION

This annotated bibliography is divided into three sections. The first section lists documents cited in the bibliography. Many of these documents are symposia containing numerous articles relevant to LLW volume reduction and stabilization. The second section lists the references cited in the bibliography according to LLW volume reduction or stabilization technology. The third section contains the annotations for each reference in alphabetical order by the first author.

2. DOCUMENTS CITED

Application of a Glass Furnace System to Low-Level Radioactive and Mixed Waste Disposal, MLM-3351-OP.

Assessment of Power Reactor Waste Immobilized by Vitrification, EPRI-NP-3225.

Cements in Radioactive Waste Management-Characterization Requirements of Cement Products for Acceptance and Quality Purposes, EUR 10803.

Characterization of INEL Compactible Wastes, Compactor Options Study, and Recommendations, EGG-WM-7176.

Department of Energy Documentation of Currently Operating Low-Level Radioactive Waste Treatment Systems - Shredder/Compactor Report, DOE/ID/12635.

Documentation on Currently Operating Low-Level Radioactive Waste Treatment System, DOE/ID/12568.

Evaluation of Emerging Technologies for the Destruction of Hazardous Wastes, EPA/600/2-85/069.

Incineration Systems: Selection and Design.

Innovative Thermal Hazardous Waste Treatment Processes, EPA/600/2-85/049.

Long-Term Low-Level Radwaste Volume-Reduction Strategies, Volumes 1-5, EPRI-NP-3736.

Low-Level Radioactive Waste From Commercial Nuclear Reactors, ORNL/TM-9846.

Low-Level Radwaste Engineering Economics, EPRI-NP-3577.

Low-Level Radwaste Solidification, EPRI-NP-2900.

Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

Proceedings of the Seventh Annual Participants' Information Meeting, DOE Low-Level Waste Management Program in Las Vegas, Nevada, September 11 - September 13, 1986, CONF-8509121.

Proceedings of the Sixth Annual Participants' Information Meeting, DOE Low-Level Waste Management Program in Denver, Colorado, September 11 - September 13, 1984.

Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987.

Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986.

Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985.

Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984.

Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983.

Radwaste Incinerator Experience, EPRI-NP-3250.

Waste Treatment Handbook, ORNL/NFW-84/5.

3. REFERENCES CATEGORIZED BY TECHNOLOGY

This section lists the references cited in the annotated bibliography according to LLW volume reduction and stabilization technology. The section is divided into the following sub-sections:

3.1 General
3.2 Economics
3.3 Volume Reduction

3.3.1 Incineration
3.3.2 Shredders/Compactors
3.3.3 Evaporator/Extruders
3.3.4 Vitrification

3.4 Stabilization

3.4.1 Solidification
3.4.2 High-Integrity Containers

3.5 Mixed Waste

3.1 General

J. E. Day, B. D. Guilbeault, B. Vigreaux, "Volume Reduction Services - The Alternative to Permanent Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 341-345.

National Low-Level Waste Management Program, Documentation on Currently Operating Low-Level Radioactive Waste Treatment Systems, DOE/ID/12568, November 1987.

Oak Ridge National Laboratory, Low-Level Radioactive Waste From Commercial Nuclear Reactors, ORNL/TM-9846, Volume 2, May 1986.

Oak Ridge National Laboratory, Waste Treatment Handbook, ORNL/NFW-84/5, February 1984.

J. W. Phillips, "Qualification of Waste Forms to Meet the Requirements of 10 CFR 61," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 183-187.

L. Rutland, A. S. Dam, M. D. Naughton, "Characterization of Low-Level Radwaste Volume Reduction Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 431-437.

L. Rutland, N.C. Papaiya, M. D. Naughton, "Current Status and Future Potential for Advanced Volume Reduction Technologies," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 69-73.

3.2 Economics

Electric Power Research Institute, Low-Level Radwaste Engineering Economics, EPRI-NP-3577, July 1984.

Electric Power Research Institute, Long-Term Low-Level Radwaste Volume-Reduction Strategies, Volumes 1-5, EPRI-NP-3736, November 1984.

W. C. McArthur, B. G. Kniazewycz, "The Economic Impact of Regional Waste Disposal on Advanced Volume Reduction Technologies," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 477-480.

C. C. Miller, "Computer Economic Modeling of Volume Reduction Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 383-388.

J. W. Voss, B. D. Guilbeault, "The Mixed Economies of Volume Reduction," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 43-48.

P. C. Williams, E. G. Collins, "Operating Cost Estimate Low Level Radioactive Waste Volume Reduction and Packaging Options," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 465-476.

3.3 Volume Reduction

3.3.1 Incineration

R. F. Abrams, "Radwaste Incinerator Scrubber Materials Test Program," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 231-234.

N.V. Beamer, "Experience with Low-Level Waste Incineration at Chalk River Nuclear Laboratories," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11-March 15, 1984, Volume 2, pp. 205-212.

V. J. Barnhart, H. Gussman, "Incineration of Low-Level Radioactive Waste and Ion Exchange Resins," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 227-230.

C. R. Bowles, M. J. Bradley, R. T. Brandt, A. S. Dam, "Startup Experience and Operations of a Central Facility with an Incinerator and Supercompactor," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 275-277.

C. R. Brunner, Incineration Systems: Selection and Design, New York: Van Nostrand Reinhold Company, Inc., 1984.

R. J. Burian, R. DiSalvo, "A Demonstration Program to Evaluate Centralized LLW Incineration," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 213-218.

J. D. Dalton, H. A. Bohrer, G. R. Smolik, "Performance History of the WERF Incinerator," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Waste at San Francisco, California, May 3 - May 6, 1988, pp. T-1 through T-14.

R. DiSalvo, W. Zielenbach, "What It Took to Get an NRC License for Centralized Incineration," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 285-290.

D. R. Eggett, "Development and Testing of a Mobile Incinerator," Proceedings of the Seventh Annual Participants' Information Meeting, DOE Low-Level Waste Management Program in Las Vegas, Nevada, September 11 - September 13, 1986, CONF-8509121, pp. 254-257.

Electric Power Research Institute, Radwaste Incinerator Experience, EPRI-NP-3250, October 1983.

H. Freeman, Innovative Thermal Hazardous Waste Treatment Processes, EPA/600/2-85/049, April 1985.

D. A. Hutchins, L. C. Borduin, R. A. Koenig, J. S. Vavruska, C. L. Warner, "Performance Assessment of Refractory Samples in the Los Alamos Controlled Air Incinerator," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 469-472.

L. M. Klinger, K. M. Armstrong, Application of a Glass Furnace System to Low-Level Radioactive and Mixed Waste Disposal, MLM-3351-OP, 1986.

H. Kuribayashi, A. Yamanaka, Y. Koshiba, A. Hasega, "Volume Reduction by Oxidation," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 105-107.

Le, V. T., N. V. Beamer, L. P. Buckley, "Experience with Radioactive Waste Incineration at Chalk River Nuclear Laboratories," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988, pp. G-1 through G-11.

K. E. Lewandowski, G. W. Becker, K. E. Mersman, W. A. Roberson, "An Incineration Demonstration at Savannah River," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 395-398.

J. A. Logan, M. M. Larsen, R. Y. Maughan, "Waste Experimental Reduction Facility Description and Progress Report," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 97-103.

J. Marcaillou, B. Vigreux, "French Experience on Low Level Radwaste Incineration," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 235-243.

J. N. McFee, R. L. Gillins, "Low-Level Radioactive Waste Incineration at the Idaho National Engineering Laboratory During 1985," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 445-447.

D. L. Michlink, R. W. Marshall, V. L. Turner, K. R. Smith, E. M. VanderWall, "The Feasibility of SpentResins Incineration at Nuclear Power Plants," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 439-443.

R. L. Moscardini, R. M. Waters, J. K. Johnston, J. F. Zievers, "Comparison of High Temperature Gas Particulate Collectors for Low-Level Radwaste Incinerator Volume Reduction Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 299-303.

J. Redimsky, A. Shah (eds.), Evaluation of Emerging Technologies for the Destruction of Hazardous Wastes, EPA/600/2-85/069, June 1985.

A. Saha, A. Dietrich, G. Cefola, "Advanced Low Level Radwaste Volume Reduction and Solidification Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3 1983, Volume 1, pp. 293-297.

R. E. Sauer, "A Commercial Regional Incinerator Facility for Treatment of Low-Level Radioactive Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 283-290.

E. M. Steverson, D. P. Clark, J. N. McFee, "Addition of Liquid Waste Incineration Capability to the INEL's Low-Level Waste Incinerator," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 463-468.

E. M. Steverson, J. N. McFee, "The Incineration of Absorbed Liquid Wastes in the INEL's WERF Incinerator," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 631-638.

3.3.2 Shredders/Compactors

H. Baudisch, M. Szukala, H. Project, H. Miller, C. Sathrum, F. Karow, K. Grewe, "DAW Volume Reduction (VR) Using the Newly Developed 20 MN (2,200 tons) Superpack - A New Generation of Supercompactor Equipment," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 513-515.

M. J. Dunn, J. N. Vance, "Use of a Shredder/Compactor for Reducing Dry Active Waste Volumes in Nuclear Power Stations," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 459-463.

D. N. Enegess, "High Force Compaction: Its Capabilities and Limitations for Dry Active Waste Processing," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 79-81.

R. L. Gillins, M. M. Larsen, W. C. Aldrich, Characterization of INEL Compactible Wastes, Compactor Options Study, and Recommendations, EGG-WM-7167, March 1986.

J. D. Henderson, M. A. Boyd, "Operating Experience with a Dry Active Waste Shredder/Compactor at a Nuclear Power Plant," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 523-528.

Impell Corporation, Department of Energy Documentation of Currently Operating Low-Level Radioactive Waste Treatment Systems-Shredder/Compactor Report, DOE/ID/12635, April 1987.

H. Kuribayashi, S. Kita, T. Yagi, K. Sauda, "DAW Volume Reduction and Solidification by the Screw Compactor," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 415-418.

R. Lugar, J. W. Phillips, "Resin Volume Reduction by High Force Compaction," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 425-428.

R. W. Marshall, C. E. Tocco, "Development of a Shredder-High Pressure Compactor System for Dry Active Waste Processing," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 403-407.

R. N. McGrath, M. Volodzko, M. D. Naughton, "Operating Experience of a Mobile Waste Shredding System," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 181-186.

P. C. Williams, W. S. Phillips, "Supercompactor Force Effectiveness as Related to Dry Act Waste Volume Reduction," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 419-423.

D. A. Zigelman, F. J. Mis, "Volume Reduction of Dry Active Waste - The Mobile Service Option," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 517-522.

3.3.3 Evaporator/Extruders

B. B. McKercher, C. C. Miller, M. D. Naughton, "Operational Experience of the Palisades Station Volume Reduction System - The First Two Months," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 87-90.

T. P. Neal, C. C. Miller, M. D. Naughton, "Operational Experience of the Palisades Volume Reduction System - The First 12 Months," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 545-549.

R. Soto, R. Harkins, "Mobile Liquid VR System - A Cost Effective Alternative," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 191-195.

3.3.4 Vitrification

W. S. Horton, A. M. Ougouag, "Low-Level Radioactive Waste Vitrification Effect of Cs Partitioning," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 1, pp. 601-604.

D. E. Larson, J. L. Buelt, W. O. Heath, W. L. Partain, Assessment of Power Reactor Waste Immobilized by Vitrification, EPRI-NP-3225, August 1983.

3.4 Stabilization

3.4.1 Solidification

T. W. Andress, J. Barcalow, D. Sykes, "Design, Fabrication, Testing, and Startup of a Mobile Volume Reduction and Solidification System," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 429-436.

H. Brunner, B. Christ, "Recent Experiences with Cement Solidification Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 493-495.

J. E. Carlson, "Containment of Radioactive Wastes Using Improved Cementitious Binders," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 533-537.

J. P. Cordier, R. F. Abrams, "PEC Engineering's Waste Solidification Process," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 575-578.

Electric Power Research Institute, Low-Level Radwaste Solidification, EPRI-NP-2900, March 1983.

J. C. Homer, J. D. Greaves, "Solidification of Dry Radioactive Salts and Incinerator Ash in a Polymer Matrix," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 317-325.

M. J. Kobran, W. J. Guarini, Jr., "10 CFR 61 Waste Form Conformance Program for Asphalted Radwaste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 525-529.

R. Köster, "Cementation of Radioactive Wastes in the Federal Republic of Germany," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 487-491.

R. I. A. Malek, D. M. Roy, "Stability of Low-Level Cement-Based Waste Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 363-368.

T. B. Mullarkey, R. J. Cudd, "Verification of Volume Reduction Data from the Volume Reduction and Solidification (VRS™) System at the Palisades Nuclear Plant," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 445-449.

A. A. Rahman, F. P. Glasser, Cements in Radioactive Waste Management - Characterization Requirements of Cement Products for Acceptance and Quality Assurance Purposes, Directorate-General, Science, Research and Development, Commission of the European Communities, EUR 10803, Luxembourg, 1987.

T. L. Rosenstiel, R. G. Lange, "The Solidification of Low-Level Radioactive Organic Fluids with Envirostone Gypsum Cement," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 169-172.

A. Saha, A. Dietrich, G. Cefola, "Advanced Low Level Radwaste Volume Reduction and Solidification Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3 1983, Volume 1, pp. 293.297.

T. F. Schuler, D. L. Charlesworth, "Solidification of Radioactive Incinerator Ash," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 1, pp. 489-493.

M. Snellman, M. Valkiainen, "Long-Term Behavior of Bituminized Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 501-507.

M. L. Thompson, G. P. Miller, C. B. Kincaid, R. W. Caputi, M. E. Weech, L. F. Rodriguez, "Aztech Systems and Testing," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 233-237.

H. Zhou, P. Colombo, "Solidification of Radioactive Waste in a Cement/Lime Mixture," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 163-168.

3.4.2 High-Integrity Containers

H. S. Arora, R. Dayal, "Properties of Radioactive Wastes and Waste Containers," Proceedings of the Sixth Annual Participants' Information Meeting, DOE Low-Level Waste Management Program in Denver, Colorado, September 11 - September 13, 1984, CONF-8409115, pp. 444-457.

B. G. Kniazewycz, W. C. McArthur, "High Integrity Containers," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 1, pp. 353-358.

H. Lowenberg, "Development of a Composite Polyethylene-Fiberglass Reinforced Plastic High Integrity Container for Disposal of Low-Level Radioactive Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 569-570.

S. B. McCoy, W. M. Poplin, T. A. Jur, "A Hybrid High Integrity Container for Disposal of Low-Level Radioactive Wastes," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 571-574.

R. E. O'Brien, J. Krieger, G. Anderson, A. D'Urso, "A High Integrity Package for Tritiated Liquid Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 355-359.

R. C. Schmitt, R. L. Chapman, K. C. Sumpter, H, W. Reno, "High Integrity Containers: A Demonstrated Disposal Alternative to Solidification of Radioactive Wastes," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 537-543.

3.5 Mixed Waste

A. M. Boehmer, R. L. Gillins, M. M. Larsen, "Stabilization of Mixed Waste at the Idaho National Engineering Laboratory," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 737-746.

A. M. Boehmer, M. M. Larsen, "Solidification of Hazardous and Mixed Radioactive Waste at the Idaho National Engineering Laboratory," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 1, pp. 635-642.

T. M. Gilliam, "Immobilization of Mixed Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 729-731.

C. R. Kempf, D. R. MacKenzie, "Treatment of Radioactive Mixed Wastes in Commercial Low-Level Wastes," Proceedings of the Seventh Annual Participants' Information Meeting, DOE Low-Level Waste Management Program in Las Vegas, Nevada, September 11 - September 13, 1986, CONF-8509121, pp. 324-333.

D. R. MacKenzie, C. R. Kempf, "Treatment Methods for Radioactive Mixed Wastes for Commercial Low-Level Wastes - Technical Considerations," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 23-27.

D. D. Nishimoto, K. L. Falconer, D. J. Wiggins, "Options for Treatment, Storage, and/or Disposal of Radioactive Mixed Waste at the Idaho National Engineering Laboratory," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 101-106.

4. ANNOTATED BIBLIOGRAPHY

R. F. Abrams, "Radwaste Incinerator Scrubber Materials Test Program," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 231-234.

Extensive testing was performed on various materials of construction for wet scrubbers used on radwaste incinerators. Long term immersion tests provided the most conclusive results of the corrosion resistance of the alloys in two different concentrations of sodium chloride solutions.

T. W. Andress, J. Barcalow, D. Sykes, "Design, Fabrication, Testing, and Startup of a Mobile Volume Reduction and Solidification System," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 429-436.

The modular concept was utilized in the design and fabrication of the low-level radioactive waste Transportable Volume Reduction and Bitumen Solidification System, the TVR-II. This concept has been taken one step further with the design and construction of a mobile unit, the TVR-III. The new unit is designed to move onto a plant site, process waste, and move to the next plant site. A portion of the TVR-III's capacity is being used to fulfill a five-year contract for volume reduction and solidification services at Illinois Power Company's Clinton Power Station.

Many challenges were met and overcome in the design and fabrication of this system into a compact unit while complying with all applicable codes, standards, and design criteria. This paper discusses some of these challenges and how they were met.

H. S. Arora, R. Dayal, "Properties of Radioactive Wastes and Waste Containers," Proceedings of the Sixth Annual Participants' Information Meeting, DOE Low-Level Waste Management Program in Denver, Colorado, September 11 - September 13, 1984, CONF-8409115, pp. 444-457.

Major tasks in this NRC sponsored program include: 1 an evaluation of the acceptability of low-level solidified wastes with respect to minimizing radionuclide releases after burial, and 2) an assessment of the influence of pertinent environmental stresses on the performance of high-integrity radwaste container (HIC) materials.

The waste form performance task involves studies on small-scale laboratory specimens to predict and extrapolate : 1) leachability for extended time periods; 2) leach behavior of full-size forms; 3) performance of waste forms under realistic leaching conditions; and 4) leachability of solidified reactor wastes. The results show that leach data derived from testing of small-scale specimens can be extrapolated to estimate leachability of a full-scale specimen and that radionuclide release data derived from testing of simulants can be employed to predict the release behavior of reactor wastes. Leaching under partially saturated conditions exhibits lower releases of radionuclides than those observed under the conventional IAEA-type or ANS 16.1 leach tests.

The HIC assessment task includes the characterization of mechanical properties of Marlex CL-100, a candidate radwaste high density polyethylene material. Tensile strength and creep rupture tests have been carried out to determine the influence of specific waste constituents as well as gamma irradiation on material performance. Emphasis in ongoing tests is being placed on studying creep rupture while the specimens are in contact with a variety of chemicals including radiolytic by-products of irradiated resin wastes.

V. J. Barnhart, H. Gussmann, "Incineration of Low-Level Radioactive Waste and Ion Exchange Resins," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 227-230.

An advanced controlled air pyrolysis incinerator has been developed and placed into operation for low-level radioactive wastes and has demonstrated the capability to incinerate ion exchange resin. The resin incineration program has proven the ability of the incineration process to successfully incinerate varying mixtures of low-level dry active wastes and spent ion exchange resins while maintaining offgas contamination well below limits set by regulatory authorities.

Both commercial and nuclear installations have been operated with the most recent application being a central incinerator for low-level radioactive waste presently being licensed in the United States. The NRC license for this facility is expected mid 1984. This incinerator will process two million pounds of dry active waste and ion exchange resin per year.

H. Baudisch, M. Szukala, H. Projekt, H. Miller, C. Sathrum, F. Karow, K. Grewe, "DAW Volume Reduction (VR) Using the Newly Developed 20 MN (2,200 tons) Superpack - A New Generation of Supercompactor Equipment," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 513-515.

A high performance supercompactor using a unique patented design to reduce size and cost with improved performance will be described. Results of a waste reduction campaign in a nuclear power plant will be presented.

During a backfitting campaign from September 1982 to September 1983, the Brunsbuttel Nuclear Plant, located in West Germany, produced approximately 100 tons of pressable waste, which was all precompacted in more than 4,000 caustic soda drums of 180 lites each (47.5 US-Gallons). Some 2,365 of these drums have been transformed into 658 drums of 55 gallon content using a very novel development: the 20 MN SUPERPACK™ of Hansa-Projekt (HP), serviced by INET Corporation in the United States. SUPERPACK is a space and cost saving solution for waste management, fulfilling all safety requirements.

The SUPERPACK used in Brunsbuttel gave a volume reduction factor (VRF) of 3.6 for drums which were precompacted by a factor of about four. These results are based on experience with more than 4,000 pressed drums. The equipment cost for this low-level waste management technique was amortized in less than one year. Availability of the system was better than 95 percent during its first year of operation.

N. V. Beamer, "Experience With Low-Level Waste Incineration at Chalk River Nuclear Laboratories," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 205-212.

Construction of a full-scale Waste Treatment Center to volume reduce, stabilize, and immobilize CRNL's low-level radioactive wastes for improved storage or disposal is essentially complete. A batch-operated starved-air incinerator for solid combustible waste is one of the processes installed in this facility. Commissioning of this prototype incinerator with inactive waste began in 1980 August and concluded in 1981 December; twenty-two 1-tonne charges (i.e., "burns") were completed during that phase. Since then, it has routinely processed most of the current arisings of combustible low-level radioactive waste (LLW) at CRNL. To date, about 1,400 m^3 of LLW containing up to about 20 mCi/m^3 (740 MBq/m^3) of mixed activity have been incinerated in 113 burns. Overall performance has remained good during the nearly 3,000 h of service with LLW feed. All operational and maintenance functions have been performed without contamination or exposure problems. Particulate beta-gamma stack releases have routinely remained less than 1 uCi (37 kBq) per burn. The incinerator consistently produces a fully satisfactory inert ash product to an average volume reduction factor greater than 150:1.

A. M. Boehmer, R. L. Gillins, M. M. Larsen, "Stabilization of Mixed Waste at the Idaho National Engineering Laboratory," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 737-746.

EG&G Idaho, Inc., has initiated a program to develop safe, efficient, cost-effective treatment methods for the stabilization of some of the hazardous and mixed wastes generated at the Idaho National Engineering Laboratory. Lab-scale testing has shown that Extraction Procedure toxic wastes can be successfully stabilized by solidification, using various binders to produce nontoxic, stable waste forms for safe, long-term disposal as other landfill waste or low-level radioactive waste, depending upon the radioactivity content.

This paper presents the results of drum-scale solidification testing conducted on hazardous, low-level incinerator flyash generated at the Waste Experimental Reduction Facility. The drum-scale test program was conducted to verify that lab-scale results could be successfully adapted into a production operation.

A. M. Boehmer, M. M. Larsen, "Solidification of Hazardous and Mixed Radioactive Waste at the Idaho National Engineering Laboratory," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 1, pp. 635-642.

EG&G Idaho has initiated a program to develop treatment options for the hazardous and mixed wastes generated at the Idaho National Laboratory (INEL). This program includes development of solidification methods for some of these wastes. Testing has shown that toxic wastes can be successfully solidified using cement, cement-silicate, or ENVIROSTONE binders to produce nontoxic stable waste forms for safe, long-term disposal. This paper presents the results of the solidification development program conducted at the INEL by EG&G Idaho.

C. R. Bowles, M. J. Bradley, R. T. Brandt, A. S. Dam, "Startup Experience and Operations of a Central Facility with an Incinerator and Supercompactor," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 275-277.

The Babcock and Wilcox Company has constructed and is starting up a commercial facility with both an incinerator and a supercompactor for reducing the volume of low-level radioactive wastes. This paper describes the activities completed to date associated with constructing, licensing, and testing at the facility and the planned activities leading up to commercial operations. In addition, the impacts that B&W's commitment to processing institutional/industrial waste has had on designing the facility, selecting the volume reduction technology, and licensing the facility operations is highlighted.

C. R. Brunner, Incineration Systems: Selection and Design, New York: Van Nostrand Reinhold Company, Inc., 1984.

Incineration is increasingly looked to as a favorable means of waste disposal, especially when compared to alternative methods. As presented in this book, the field of incineration encompasses the destruction or processing of solid, sludge, liquid, gaseous, and radioactive wastes.

The text has been written to accommodate technical and nontechnical persons alike. It is meant to provide both a broad view of the subject as well as detailed system design techniques of primary interest to the specialist. References appear periodically to direct the reader to relevant publications and other sources of technical information.

The emphasis throughout is on detailed systems design. Before design can begin, however, it is obvious that the applicable statutory requirements must be understood. Two chapters are therefore allotted to the regulations that govern the incineration of hazardous and nonhazardous wastes. Six chapters then address analytical methods for systems design, from waste characterization to the prediction of air emissions. The various types of incinerator systems currently in use are discussed in the following eight chapters, which include design calculations, dimensional data, and other incinerator parameters.

Other chapters include one on energy recovery that presents a method for determining the heat recovery potential of an incinerator system, along with relevant design examples, and another on air pollution control equipment, which includes descriptions of the large variety of control devices available and their capacities, dimensions, and design parameters.

The reader has sufficient information in this single text to determine equipment selection, sizing, and parameters of operation for the incinerator equipment that burns the vast variety of wastes generated by municipal, commercial, industrial, and institutional sources.

H. Brunner, B. Christ, "Recent Experiences with Cement Solidification Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 493-495.

Recent developments and experiences with cement solidification systems have been concerned with modified in-drum mixers (DEWA and MOWA) for solidification of evaporator concentrates, sludges, dry filter residues, and stationary or mobile continuous mixing systems. Plants and processes are described including throughputs, dose rates, radiation exposure of the staff and product qualities obtained. The data are based on more than 2,800 drums, mainly produced in the years 1983 and 1984.

R. J. Burian, R. DiSalvo, "A Demonstration Program to Evaluate Centralized LLW Incineration," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 213-218.

Dramatic increases in low-level waste burial charges in the last five years have spurred interest in achieving higher volume reduction than currently achieved by compaction. Battelle has completed a planning study to demonstrate the technical and economic feasibility of central site incineration for dry active waste to service several generators within a geographical area. We initiated licensing by the USNRC and Ohio EPA and developed plans, procedures, and estimated costs for licensing, construction, operation, and decommissioning of a central site incinerator. In addition, acceptance criteria were established for incoming waste. Response from the NRC and Ohio EPA indicated that no major obstacles existed toward obtaining licenses. The economic study indicated that a commercial incineration operation lasting 20 years or more was economically advantageous over direct burial of compacted waste, assuming that burial costs continue to escalate at their current rates. However, a 5-year demonstration period was not economically advantageous because of the short period to recover the fixed capital investment.

J. E. Carlson, "Containment of Radioactive Wastes Using Improved Cementitious Binders," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 533-537.

Continuing research to improve the solidification of radioactive waste using Portland cement has produced waste forms with markedly lower leach rates for Cesium-137, as well as for other nuclides tested, such as Strontium-85. This has been accomplished primarily by utilizing mineral materials replacing part of the cement, to combine in-situ with lime formed as a by-product during hydration reactions. It has now been demonstrated that these pozzolanic reactions within the pores of the matrixes will even prevent the rapid leaching of concentrated nitrate solutions that have been solidified with these same cement admixtures.

J. P. Cordier, R. F. Abrams, "PEC Engineering's Waste Solidification Process," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 575-578.

The new concept for waste embedding plant should accept either solid wastes from incinerator or dryer and liquid waste in case of volume reduction plant failure of even maintenance.

The first step in volume reduction is to feed as much wastes as possible per container, getting a final quality product in accordance with the regulations.

To reach the necessary regulations requirements, an extensive formulation research program is needed to define the behavior of each waste as additives.

The high filling grade may be obtained by equipment development such as mixing equipment (anti-vortex control head - continuous mixer) and dewatering equipment.

J. D. Dalton, H. A. Bohrer, G. R. Smolik, "Performance History of the WERF Incinerator," Proceedings on the International Conference on Incineration of Hazardous, Radioactive, and Mixed Waste at San Francisco, California, May 3 - May 6, 1988, pp. T-1 through T-14.

As society's environmental conscience grows, diverse political, economical, and social contentions cloud the issue of proper waste management. However, experience at the Waste Experimental Reduction Facility (WERF) at the Idaho National Engineering Laboratory (INEL) demonstrates clearly that incineration is an effective component in responsible, long-term waste management. Using a simple but safe design, the WERF incinerator has successfully reduced the volume of low-level beta/gamma waste. As of the end of March 1988, this incinerator, a 180-kg/hr (440-lb/hr) controlled-air unit with a completely dry off-gas treatment system, has accumulated approximately 4,500 hours of operation, processing over 4,250 M^3 (150,000 ft^3) of waste, and achieving volume reduction ratios of approximately 300:1. This paper discusses some of the achievements and problems experienced during operation of the WERF incinerator.

J. E. Day, B. D. Guilbeault, B. Vigreaux, "Volume Reduction Services - The Alternative to Permanent Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 341-345.

Interest in radwaste volume reduction/solidification services has increased dramatically in the past two years. This increase is due in part to the increasing complexity of selecting a permanent low-level radwaste solidification service as a short- and long-term alternative to a permanent system. Issues examined in comparing services to permanent systems include capital versus operating funds, time required for start-up, space requirements, licensing, technology obsolesence, and regulatory changes. A portion of this paper focuses on one specific aspect of the evaluation of alternatives--the acceptability of the product. To illustrate the evaluation of product acceptability, a bituminized waste form produced by a volume reduction system is examined for leach resistance.

R. DiSalvo, W. Zielenbach, "What It Took to Get an NRC License for Centralized Incineration," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 285-290.

In 1982, Battelle joined five other commercial generators of low level radioactive waste in conducting a study of the technical and economic feasibility and the licensability of a central facility for incinerating LLW. The project generated a license application to the USNRC and supporting documentation related to the safety and environmental impacts of the facility. After thorough review, the NRC has issued a Finding of No Significant Impact and the associated license authorization, which is the first of its kind for an incineration facility.

M. J. Dunn, J. N. Vance, "Use of a Shredder/Compactor for Reducing Dry Active Waste Volumes in Nuclear Power Stations," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 459-463.

A shredder/compactor system has been designed to provide for volume reduction of dry radioactive waste. The design has been tested and a volume reduction factor of 2 demonstrated when comparing compacted shred waste to compacted nonshred waste. The testing program demonstrated the ability of the shredder to process typical waste materials. A cost-benefit evaluation was performed to demonstrate the economic benefits and payback considerations for the system.

D. R. Eggett, "Development and Testing of a Mobile Incinerator," Proceedings of the Seventh Annual Participants' Information Meeting, DOE Low-Level Waste Management Program in Las Vegas, Nevada, September 11 - September 13, 1986, CONF-8509121, pp. 254-257.

The development and testing of a mobile incinerator for processing of combustible dry active waste (DAW) and contaminated oil generated at Nuclear Power Plants is presented. Topics of discussion include initial thoughts on incineration as applied to nuclear waste; DOE's, Aerojet's and CECo's role in the Project; design engineering concepts; site engineering support; licensability; generation of test data; required reports of the NRC and Illinois and California EPA's; present project schedule for incinerating DAW at Dresden and other CECo Stations; and lessons learned from the project.

Electric Power Research Institute, Long-Term Low-Level Radwaste Volume-Reduction Strategies, Volumes 1-5, EPRI-NP-3736, November 1984.

This report provides the basis for a utility to investigate the benefits of purchasing volume reduction equipment. The work includes the establishment of a volume reduction data base, the creation of the volume reduction cost analysis computer program VRTECH, and a generic analysis designed to identify the major factors influencing the economics of the various equipment options. The results are presented in five volumes. Volume 1 serves as an executive summary. The second volume describes the VRTECH code and presents the results of the generic economic analysis. The work shows that radwaste generation rates and future burial price increases are the key factors in assessing the economic value of volume reduction. Volume 3 describes several volume reduction equipment options in great detail. General arrangement drawings for generic installation are included and serve as the basis for cost estimates for the installed equipment. Volume 4 establishes pricing levels at new shallow land burial grounds. These last two volumes form the volume reduction data bases. Volume 5 is limited to a presentation of the computer results for the VRTECH economic analysis.

Electric Power Research Institute, Radwaste Incinerator Experience, EPRI-NP-3250, October 1983.

This report is a detailed survey of the current status of operating low-level radioactive waste (LLW) incinerators, and compares the technology to the design requirements for use at U.S. nuclear power plants. Data is presented on incinerator design and performance for operating facilities and development prototypes in Europe, Japan, Canada, and the U.S. The systems are described by subsystem categories: feed preparation, combustion chamber, offgas treatment, and ash handling. The history of operations and maintenance (O&M) is included for these operating facilities.

The incinerator types which will most likely be utilized at U.S. nuclear power plants are discussed to assess their licensability under U.S. regulations in light of the operational performance achieved on world-wide basis.

Electric Power Research Institute, Low-Level Radwaste Engineering Economics, EPRI-NP-3577, July 1984.

This topical report on engineering economics for low-level radwaste systems details the methodologies used for economic analyses of radwaste treatment systems and provides examples of radwaste economic evaluations. All of the parameters and cost items used in an evaluation are defined. Examples of the present-value-of- revenue-requirements methods, levelized-revenue-requirements method, and the equivalent-capital-investment method are provided. Also, the calculation to determine the maximum justifiable capital expenditure for a radwaste system is illustrated. The report also provides examples of economic evaluations for many current radwaste treatment options. These options include evaporation versus demineralization, dewatering resins versus solidification of resins, and several volume reduction systems.

Electric Power Research Institute, Low-Level Radwaste Solidification, EPRI-NP-2900, March 1983.

Low-Level Radwaste Solidification Topical Report characterizes radwaste solidification processes and systems currently in use and under development. The report identifies the types of waste, solidification agents, and general criteria which affect radwaste solidification systems and processes. The chemistry and physics of the radwaste solidification processes are discussed along with a summary of several studies. The various radwaste solidification processes and corresponding commercial radwaste solidification systems are described. Radwaste shipping and burial containers, including high integrity containers, along with container handling and storage systems are briefly discussed and many of the commercially available containers are described. Other topics discussed include dry active waste (DAW) production, DAW processing techniques, and some of the commercial compaction equipment is described. Radwaste packaging efficiencies for several commercial processes are also provided.

D. N. Enegess, "High Force Compaction: Its Capabilities and Limitations for Dry Active Waste Processing," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 79-81.

A study was performed of the operating experience of high force compactors (HFCs), particularly the volume reductions achieved. These operating data were then employed in an economic analysis to determine the conditions under which HRC's are cost-justified in the U.S. The results indicate that this technology is best applied in the U.S. in the same way that has been justified in other countries, for central processing facilities or in a mobile configuration, for the servicing of multiple plants.

H. Freeman, Innovative Thermal Hazardous Waste Treatment Processes, EPA/600/2-85/049, April 1985.

This report contains discussions of 21 thermal processes identified by the U.S. Environmental Protection Agency (U.S. EPA) as innovative processes for treating or destroying hazardous organic wastes. The subject processes were identified through two national solicitations for innovative processes and several extensive literature surveys.

Information about the subject processes was provided voluntarily by the process developers. The criteria used for selection of a process for the report included the innovativeness of the process when compared with conventional existing processes and the potential contribution the process could make to the evolving field of hazardous waste management technology.

T. M. Gilliam, "Immobilization of Mixed Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 729-731.

A fundamental relationship between ANS 16.1 and EP-Tox leach results has been developed and experimental data presented verifying the relationship for solidified waste products. The relationship can be used as a powerful tool for quality assurance during disposal operations; to guide formulation development efforts; and to expand existing data bases to a wider variety of mixed wastes.

R. L. Gillins, M. M. Larsen, W. C. Aldrich, Characterization of INEL Compactible Wastes, Compactor Options Study, and Recommendations, EGG-WM-7167, March 1986.

This report provides the results of a detailed characterization and evaluation of low-level radioactive waste (LLW) generated at the Idaho National Engineering Laboratory (INEL) and an evaluation of compactors available commercially. The results of these evaluations formed the basis for a study of compactor options suitable for compacting INEL-generated LLW. Seven compactor options were evaluated. A decision analysis performed on the results of the compactor option study and cost analysis showed that a 200-ton box compactor and a 5000-ton box super compactor were the best options for an INEL compaction facility. This report also includes an evaluation of locations for an INEL compaction facility. [The results of this report are summarized in R. L. Gillins, M. M. Larsen, "Characterization of INEL Compactible Low-Level Wastes and Evaluation of Compactor Options," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 623-629.]

J. D. Henderson, M. A. Boyd, "Operating Experience with a Dry Active Waste Shredder/Compactor at a Nuclear Power Plant," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 523-528.

Dry Active Waste (DAW) produced at nuclear power plants generally accounts for a large portion of the total low-level radioactive waste shipped for disposal at shallow land burial sites. Dry active waste generally consists of paper, cloth, scrap wood, light metals, sheet plastics, and other miscellaneous items. Most nuclear plants package the compactible waste with either a drum or box compactor. Noncompactible waste is packaged in either metal or wooden boxes. The shredder/compactor system was developed to shred normally bulky noncompactible waste and thus make it capable of being compacted into a low specific activity (LSA) box with other compactible waste. The result is the elimination of void spaces reduced springback tendency, and an increase in the density of the waste which can be compacted into a box.

Carolina Power & Light Company installed a shredder/compactor system developed by Impell Corporation at the Brunswick Steam Electric Plant in October 1984. This paper describes the shredder/compactor system, the performance of the system using a simulated EPRI waste mixture, the system performance using a simulated Brunswick plant DAW mixture, system operating experience, a discussion on overall plant DAW waste minimization and reaches the conclusion that the shredder/compactor system is a cost effective and efficient technique for processing and achieving dry active waste volume reduction for typical BWR plant waste.

J. C. Homer, J. D. Greaves, "Solidification of Dry Radioactive Salts and Incinerator Ash in a Polymer Matrix," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 317-325.

With the current emphasis in radioactive waste disposal being placed on volume reduction, waste forms have evolved to the point where conventional solidification agents, process equipment and procedures are no longer suitable for these radwaste operations. Incineration of dry active waste and the processing of waste solutions to virtual dryness require a water independent solidification agent and process equipment designed to transfer, store and encapsulate several thousand cubic feet of radioactive powder annually. With volume reduction, the activity of the powdered waste product has increased by nearly two orders of magnitude making airborne contamination a significant factor that must be addressed in the design of the equipment and process. Solidification agents have changed from powders that were easy to handle and readily flushed from equipment with water to viscous, water insoluable fluids that stick to equipment surfaces and plug interface nozzles. Removal is accomplished with solvents that, in themselves, introduce another waste form that must be dealt with.

In approaching the problems introduced by volume reduced waste forms, engineers have developed a process and a family of equipment carefully engineered to address these problems head on. A brief description of the process equipment, the powder coating process and test solidification work are presented here. Emphasis has been placed on the problems intrinsic to handling these new waste forms and specific process and equipment solutions.

W. S. Horton, A. M. Ougouag, "Low-Level Radioactive Waste Vitrification: Effect of Cs Partitioning," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 1, pp. 601-604.

The traditional Low-Level Radioactive Waste (LLW) immobilization options are cementation or bituminization. Either of these options could be followed by shallow land burial (SLB) or above ground disposal. These rather simple LLW procedures appeared to be readily available, to meet regulatory requirements, and to satisfy cost constraints. The authorization of State Compacts, the forced closure of half of the six SLG disposal facilities of the nation, and the escalation of transportation/disposal fees diminish the viability of these options. The synergistic combination of these factors led to a reassessment of traditional methods and to an investigation of other techniques. This paper analyzes the traditional LLW immobilization options, reviews the impact of the LLW stream composition on Low-Level Waste Vitrification (LLW), then proposes and briefly discusses several techniques to control the volatile radionuclides in a Process Improved LLW system (PILLWV).

D. A. Hutchins, L. C. Borduin, R. A. Koenig, J. S. Vavruska, C. L. Warner, "Performance Assessment of Refractory Samples in the Los Alamos Controlled Air Incinerator," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 469-472.

A refractory evaluation project was initiated in 1979 to study the performance of six selected materials within the Los Alamos Controlled Air Incinerator (CAI). Determining refractory resistance to thermal shock, chemical attach, and plutonium uptake was of particular interest. The experimental refractories were subjected to a variety of waste materials, including transuranic (TRU) contaminated wastes, highly chlorinated compounds, and alkaline metal salts of perchlorate, nitrate and oxylate, over the six-year period of this study. Results of this study to date indicate that the use of high alumina, and possibly specialty plastic refractories, is advisable for the lining of incinerators used for the thermal destruction of universe chemical compounds.

Impell Corporation, Department of Energy Documentation of Currently Operating Low-Level Radioactive Waste Treatment Systems - Shredder/Compactor Report, DOE/ID/12635, April 1987.

This report documents a volume reduction waste treatment system for dry active waste, a shredder/compactor, and includes specifics on system selection, system descriptions, and detailed system performance data from three operational nuclear power plants. Data gathered from the plants have shown the ability to increase the density (thereby reducing the volume) of dry active waste to approximately 50 pounds per cubic foot when using shredder/compactors and approximately 80 to 100 pounds per cubic foot for shredder/high pressure compactors depending on reactor type and plant-specific waste characteristics.

An economic evaluation of various alternative volume reduction systems for dry active waste is also presented. The report presents a method of calculating the associated costs and paybacks achieved using various volume reduction alternatives. A 10 year cost (operating expenses and capital outlay for equipment) for a shredder/high pressure compactor is 1.85 million dollars for a boiling water reactor (BWR) as compared to approximately 3 million for a conventional drum compactor. The resulting payback for the shredder/compactor is as low as 1.7 years. The report provides generators of low-level waste additional information to understand the nuances of shredder/compactor systems to select a system which best suits their individual needs.

C. R. Kempf, D. R MacKenzie, "Treatment of Radioactive Mixed Wastes in Commercial Low-Level Wastes," Proceedings of the Seventh Annual Participants' Information Meeting, DOE Low-Level Waste Management Program in Las Vegas, Nevada, September 11 - September 13, 1986, CONF-8509121, pp. 324-333.

Management options for three generic categories of radioactive mixed waste in commercial low-level wastes have been identified and evaluated. These wastes were characterized as part of a BNL study in which a large number of generators were surveyed for information on potentially hazardous low-level wastes. The general management targets adopted for mixed wastes are immobilization, destruction, and reclamation. It is possible that these targets may not be practical for some wastes, and for these, goals of stabilization or reduction of hazard are addressed. Solidification, absorption, incineration, acid digestion, segregation, and substitution have been considered for organic liquid wastes. Containment, segregation, and decontamination and re-use have been considered for lead metal wastes which have themselves been contaminated and are not used for purposes of waste disposal shielding, packaging, or containment. For chromium-containing wastes, solidification, incineration, containment, substitution, chemical reduction, and biological removal have been considered. For each of these wastes, the management option evaluation has necessarily included assessment/estimation of the effect of the treatment on both the radiological and potential chemical hazards present.

L. M. Klingler, K. M. Armstrong, Application of a Glass Furnace System to Low-Level Radioactive and Mixed Waste Disposal, MLM-3351-OP, 1986.

In 1981 a study was begun to determine the feasibility of using an electrically heated glass furnace for the treatment of low-level radioactive wastes generated at commercial nuclear power facilities. Experiments were designed to determine, 1) whether the technology offered solutions to industry waste disposal problems, and if so, 2) whether it could meet what were thought to be critical requirements for radioactive thermal waste processing. These requirements include: high quality combustion of organic constituents, capture and immobilization of radioactivity, integrity of final waste form, and cost effectiveness. To address these questions a variety of wastes typical of the types generated by nuclear power facilities, including not only standard trash but also wastes of high aqueous and/or inorganic content, were spiked with predominant waste radioisotopes predominant in plant wastes and processed in the glass furnace. The results of this study indicate that the unit is capable of fully meeting the addressed needs of the nuclear industry for power plant waste processing.

The quality of combustion observed during the initial studies on the glass furnace was such that a more demanding application was suggested--that of hazardous waste processing. To fully evaluate the furnace's capabilities in this area a study was initiated in December, 1984 which simulated a "trial burn" of the type required for an EPA Part B permit for thermal processing of RCRA hazardous wastes. Solvents and sludges, some of which contained high percentages of water, were spiked with a "cocktail" of organics determined to be "difficult to incinerate" by the EPA. A complete sampling program following EPA protocol demonstrated destruction and removal efficiencies exceeding RCRA standards.

B. G. Kniazewycz, W. C. McArthur, "High Integrity Containers," <u>Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986</u>, Volume 1, pp. 353-358.

The concept of a "high integrity" container (HIC) has been approved by the Department of Health and Environmental Quality of the State of South Carolina and the Nuclear Regulatory Commission. The objective of the HIC is to provide an additional environmental barrier for waste disposed at low-level radioactive waste disposal facilities.

The problem of clean-up, handling, transportation and disposal of hazardous, toxic, and radioactive substances is complex and poses many challenges. Radioactive and other hazardous wastes are packaged in various kinds of containers, ranging from 55-gallon (210-liter) drums to large disposable liners having volumes of 50 to 300 cubic feet. The problems with traditional methods of waste disposal are seen every day in the form of container leakage, environmental contamination, and litigation.

Based on a development program with DOE, KLM Technologies (KLM) has advanced the concept of the HIC. The initial HIC concept considered the use of engineered fiberglass to developed a waste package which is explicitly engineered for the waste contained within the package, as well as the conditions experienced by the outside of the packaging. The engineered reinforced fiberglass construction guarantees the long life and integrity of the unit as well as the public safety. An engineered fiberglass container that has design qualities that meet or exceed recent design criteria has been designed, fabricated, and successfully tested. Available in 55-gallon to 300 cubic feet designs, HICs can be applied to spill clean-up, radioactive waste transport and disposal, chemical transport, hazardous industrial waste transport and disposal, as well as on-site storage of hazardous and/or toxic materials. This is a technically superior and economically justifiable container to handle low-level radioactive waste and possible Type A or Type B TRU waste from defense, DOE, and commercial waste activities, as well as toxic substance originating from chemical non-nuclear wastes.

M. J. Kobran, W. J. Guarini, Jr., "10 CFR 61 Waste Form Conformance Program for Asphalted Radwaste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 525-529.

With the enactment of Title 10, Code of Federal Regulations, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste" came the imposition of new requirements on licensees who dispose of radioactive waste via shallow land burial. Specifically, 10 CFR 61 both imposed a waste classification system requiring segregation of waste according to hazard and established waste performance characteristics required to enhance stability of the burial site. In order to provide licensees with guidance regarding implementation of applicable requirements of 10 CFR 61, the NRC Low Level Waste Licensing Branch issued two Technical Positions.

To demonstrate compliance of asphalted radwaste produced with oxidized asphalt with 10 CFR 61 criteria of the NRC's Technical Position, five utilities combined resources. The five utilities sponsoring the program were Public Service Electric and Gas Company, Niagara Mohawk Power Company, Detroit Edison Company, the New Hampshire Yankee, and Consumers Power Company.

R. Köster, "Cementation of Radioactive Wastes in the Federal Republic of Germany," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 487-491.

The cementation of solid and liquid raw wastes as well as of waste concentrates to produce solid products has been an established technique for many years. Cementation will also be the method for the fixation of cladding hulls, dissolver residues, evaporator low-level and intermediate level waste concentrates and solid wastes arising from the planned 350 MTHM/year reprocessing plant. The cementation techniques used are discussed briefly. They include indrum mixers, rotating containers with pebbles or mixing installations and continuously operating cementation mixers. The influence of organic compounds in the waste solutions on the hardening process is discussed. Basic data on product properties like mechanical stability, chemical stability (corrosion, leaching), and radiation stability are presented on the basis of laboratory and full-scale unit investigations. Main objective of the work is to establish source term formulations as input functions for safety analysis for the radionuclide mobilization via gas phase after mechanical or thermal impacts. In order to evaluate source terms for the mobilization of relevant radionuclides via liquid phase as a function of time due to leaching and corrosion, detailed experimental and theoretical investigations of processes occurring when cemented waste forms are inc contact with salt brines were carried out. Recent developments concerning improvements of existing cementation methods and the increasing significance of waste container application along with a newly developed standardized container system are presented. The conclusion can be drawn that the present FRG cementation technology is adequate for the wastes from nuclear power reactor operation and the solid and liquid LL and IL wastes from the reprocessing plant. There is a demand to improve waste products due to economic and safety considerations especially for wastes of higher alpha-activity like dissolver residues or burnable materials. Consequently, the current ROD is concentrated on optimizing grout formulations and conditioning processes.

H. Kuribayashi, A. Yamanaka, Y. Koshiba, A. Hasegawa, "Volume Reduction by Oxidation," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 105-107.

The treatment of various combustible and organic wastes generated at nuclear power stations and reprocessing plants has been actively investigated. Three new technologies studied produce dramatic volume reductions and complete conversion of wastes into inorganic substances for durable storage and disposal. Those technologies are: 1) incineration, 2) wet oxidation, and 3) photo-oxidation. Incineration is an excellent volume reducer for combustible wastes, and wet oxidation, using hydrogen peroxide, is also a good way for reducing spent ion-exchange resins without any offgas problems Photo-oxidation is a new technology to purify polluted water for recycled use in the stations without the release of contaminated water to the environment. Polluted water may include NH_4^+, detergents, chelating agents and other organic decontamination agents. These VR technologies are all based on "Oxidation" from which the title of this paper comes.

H. Kuribayashi, S. Kita, T. Yagi, K. Sauda, "DAW Volume Reduction and Solidification by the Screw Compactor," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 415-418.

High amounts of dry active waste (DAW) are generated at nuclear power stations. Treatment requires many manhours and expensive equipment, which, as a result, economically burdens their waste management. To solve these problems, a new technology called the Screw Compactor was developed. The Screw Compactor, which consists of one axial screw housed in a shall, melts DAW by compression and friction heat; thermo-plastics such as polyethylene which is contained in DAW, are utilized as a binder, mixed with other materials, then extruded from the Screw Compactor. Results obtained from an actual size mobile type demonstration prove that the Screw Compactor can volume-reduce a wide range of DAW and ion-exchange resins, both economically and efficiently, to yield products that meet 10 CFR Part 61.

D. E. Larson, J. L. Buelt, W. O. Heath, W. L. Partain, Assessment of Power Reactor Waste Immobilized by Vitrification, EPRI-NP-3225, August 1983.

A study was performed to determine the technical and economic viability of applying vitrification to volume reduction and immobilization of nuclear power plant radioactive waste. Vitrification technology has been extensively developed in the United States and abroad for immobilization of high-level radioactive waste. A conceptual design of a facility to vitrify light water reactor radioactive waste (except noncompactible/noncombustible wastes) was developed. Technical, economic, and safety evaluations were performed for waste vitrification. Technical and economic comparisons were made with available technologies for radwaste volume reduction and immobilization. It was concluded that vitrification is a viable and competitively attractive approach; however, some additional process verification should be conducted prior to plant application.

V. T. Le, N. V. Beamer, L. P. Buckley, "Experience with Radioactive Waste Incineration at Chalk River Nuclear Laboratories," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - September May 6 1988, pp. G-1 through G-11.

Chalk River Nuclear Laboratories is a nuclear research center operated by Atomic Energy of Canada Limited. A full-scale waste treatment center has been constructed to process low- and intermediate-level radioactive wastes generated on-site. A batch-loaded, two-stage, starved-air incinerator for solid combustible waste is one of the processes installed in this facility. The incinerator has been operating since 1982. It has consistently reduced combustible wastes to an inert ash product, with an average volume reduction factor of about 150:1. The incinerator ash is stored in 200 L drums awaiting solidification in bitumen. The incinerator and a 50-ton hydraulic baler have provided treatment for a combined volume of about 1,300 m^3/a of solid low-level radioactive waste. This paper presents a review of the performance of the incinerator during its six years of operation. In addition to presenting operational experience, an assessment of the starved-air incineration technique will also be discussed.

K. E., Lewandowski, G. W. Becker, K. E. Mersman, W. A. Roberson, "An Incineration Demonstration at Savannah River," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 395-398.

A full-scale incineration process for Savannah River Plant (SRP) low-level beta-gamma combustible waste was demonstrated at the Savannah River Laboratory (SRL) using nonradioactive wastes. From October 1981 through September 1982, 15,700 kilograms of solid waste and 5.7 m^3 of solvent were incinerated. Emissions of offgas components (NO_x, SO_2, CO, and particulates) were well below South Carolina state standards. Volume reductions of 20:1 for solid waste and 7:1 for Purex solvent/lime slurry were achieved. Presently, the process is being upgraded by SRP to accept radioactive wastes. During a two-year SRP demonstration, the facility will be used to incinerate slightly radioactive (less than 900 uCi/meter^3) solvent and suspect level (less than 1 mR/hr at 0.0254 meter) solid wastes. The next phase will include upgrading the facility for nonradioactive hazardous wastes such as 1,1,1-trichloroethane.

J. A., Logan, M. M. Larsen, R. Y. Maughan, "Waste Experimental Reduction Facility - Description and Progress Report," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 97-103.

This paper traces the establishment of and describes the current characteristics of the Waste Experimental Reduction Facility, now processing low-level beta/gamma contaminated waste at the Idaho National Engineering Laboratory. It outlines principal findings and facility and procedural changes that occurred during the facility startup period (September 1982 to July 1983) while sizing (cutting) and melting uncontaminated metal in preparation for processing contaminated metal, which commenced in July 1983. It also describes processing experiences thus far with contaminated metal.

H. Lowenberg, "Development of a Composite Polyethylene-Fiberglass Reinforced Plastic High Integrity Container for Disposal of Low-Level Radioactive Waste, Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 569-570.

Bondico, Inc. has received numerous industry requests for a high integrity container (HIC) for the disposal of low-level radioactive wastes (LLW) that has excellent chemical resistance as well as structural stability. As a result, Bondico has initiated a design and development program to utilize its unique technology used for making hazardous waste containers, to provide a HIC of composite construction with an inner layer of polyethylene (PE) and an outer casing of fiberglass reinforced plastic (FRP) that has improved volumetric efficiency and integrity. Two sizes of HIC are planned initially for containing 7 ft^3 and 10 ft^3 of waste. Future development of larger size units to about 200 ft^3 capacity is planned. Each HIC has a full opened lid which is sealed remotely after filling by means of a high integrity polyethylene weld. To date handmade prototype units have been fabricated, loaded, sealed, and tested to the most demanding NRC and state requirements. In many cases the HIC prototypes have exceeded key requirements by about 100 percent. A comprehensive materials testing program to cover physical strength properties, creep characteristics, performance under thermal cycle conditions, performance after gamma and ultraviolet radiation, resistance to biodegradation, and resistance to interior and exterior chemical exposures is in progress. Concurrently, production methods and equipment are being finalized. Production units will be produced and subjected to full-scale testing conditions. Based upon this development program, a topical report will be submitted to NRC for review and approval later this year.

R. Lugar, J. W. Phillips, "Resin Volume Reduction by High Force Compaction," <u>Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986</u>, Volume 3, pp. 425-428.

The packaging, transportation, and disposal of contaminated spent ion exchange resin constitutes one of the most expensive items on the utility radwaste manager's budget. The waste volume limits and surcharges imposed by the Low-Level Radioactive Waste Policy Act Amendments of 1985 have created strong incentives for the application of high force compaction to reduce the volume of ion exchange resin shipped for disposal. Lab and full-scale test results demonstrated that the volume reduction achieved by compaction is a function of compressive force, resin type, moisture and crud content, and the container/packaging method. Simulated waste resin and actual plant-generated resin was tested using compressive forces between 600 and 6,680 psi. Volume reduction factors, as compared to conventional dewatering, of 2:1 to 6:1 were measured using high force compaction.

The relative simplicity of compaction technology as compared to other resin volume reduction technologies, and the availability of high force compaction equipment set the stage for a very cost effective and easily implemented volume reduction system.

D. R. MacKenzie, C. R. Kempf, "Treatment Methods for Radioactive Mixed Wastes for Commercial Low-Level Wastes - Technical Considerations," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 23-27.

Treatment options for the management of three generic categories of radioactive mixed waste in commercial low-level wastes (LLW) have been identified and evaluated. These wastes were characterized as part of a study in which LLW generators were surveyed for information on potential chemical hazards in their waste. The general treatment options available for mixed wastes are destruction, immobilization, and reclamation. Solidification, absorption, incineration, acid digestion, wet-air oxidation, distillation, liquid-liquid solvent extraction, and specific chemical destruction techniques have been considered for organic liquid wastes. Containment, segregation, decontamination, and solidification or containment of residues, have been considered for lead metal wastes which have themselves been contaminated and are not used for purposes of waste disposal shielding, packaging, or containment. For chromium-containing wastes, solidification, incineration, wet-air oxidation, acid digestion, and containment have been considered. For each of these wastes, the management option evaluation has included an assessment of testing appropriate to determine the effect of the option on both the radiological and potential chemical hazards present.

R. I. A. Malek, D. M. Roy, "Stability of Low-Level Cement-Based Waste Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 363-368.

A low temperature hydrated ceramic waste form has been designed for solidification and stabilization of low-level radioactive waste. The suggested waste forms were based mainly on cementitious materials. A solution composed of 2.5M $NaNO_3$, 0.8 $MaNO_2$, and 1.2M NaOH was used as a waste solution. This represents both the high alkalinity and high nitrate/nitrite contents of many LLW solutions. The high alkalinity of the waste solution made it possible to blend some by-product materials (e.g., ground granulated blast-furnace slag and flyashes) with minimum amounts of cement to obtain a lightweight, low density waste form of economic value and excellent processibility. The chemical environment created by mixing this LLW solution with cementitious materials will affect the stability and long-term performance of the waste form. In addition, the information gained from studying such an environment will certainly help attaining the best performance. For such purposes, the Eh and pH of the pore fluids expressed from hydrating waste forms were measured. The measured values were located on various Eh-pH diagrams to find the stability/instability regions for compounds of major concern. Furthermore, the dimensional and thermal stabilities of the hardened waste forms were determined by measuring expansive stresses, and length changes as a function of time and heat cycle. The effects produced by such findings on long-term durability of the waste forms are discussed.

J. Marcaillou, B. Vigreux, "French Experience on Low Level Radwaste Incineration," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 235-243.

The experience acquired with two models of fixed hearth incinerators processing solid waste, essentially low beta-gamma solid radwaste and contaminated solvents, in the Research Centers of the Commissariat a l'Energie Atomique, in Cadrache and Grenoble, is presented by the authors. It represents a number of years of active operation.

The Cadrache incinerator operates with a dry and wet system for offgas treatment. A synthesis of data obtained in active operation as well as comments on some difficulties encountered in the gas purification system are presented.

The Grenoble incinerator is equipped with a dry process for offgas purification; the design has been refined and standardized by SGN and installed in several countries. Results from these applications are also given.

R. W. Marshall, C. E. Tocco, "Development of a Shredder-High Pressure Compactor System for Dry Active Waste Processing," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 403-407.

Currently, there are a wide variety of systems available to reduce the volume and to package dry active waste (DAW). These systems include conventional drum compactors, large box compactors, various types of supercompactors, an initial design of a shredder mated with a box compactor, and a system design of a shredder mated with a high pressure compactor (1,270 psig ram face pressure).

Early in 1985 a horizontal high pressure compactor was tested to determine the effect of increasingly higher compaction forces on the density of shredded DAW. A simulated waste mixture was used for this testing that duplicated, as closely as possible, the EPRI 1981 BWR plant average waste composition. The tests revealed that a shredder-high pressure compactor combination could achieve DAW densities approximately 70 percent higher than a shredder-box compactor combination and approximately 150 percent higher than a box compactor without a shredder.

Based on this testing, an integrated shredder-high pressure compactor system design was developed. After an economic evaluation of the alternative DAW processing systems available, the Tennessee Valley Authority selected the shredder/high pressure compactor system as the most cost effective DAW volume reduction system for installation at their Watts Bar Nuclear Plan. This paper addresses the details of the developmental testing, provide a technical description of the system, and look at the economics of the system as it compares with other DAW volume reduction and packaging systems.

W. C. McArthur, B. G. Kniazewycz, "The Economic Impact of Regional Waste Disposal on Advanced Volume Reduction Technologies," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 477-480.

Waste volume reduction has received increased emphasis over the past decade as annual operating costs have risen from $250,000/year to $3,500,000 for 1983. Emphasis has been given to developing and designing into new nuclear power plants process and DAW volume reduction technologies such as fluidized-bed dryers, incinerators, and evaporative-solidification systems. The basis for these systems was originally the correct perception that a crisis would be reached with the, then available, shallow land disposal sites which would increase costs substantially and possibly jeopardize power plant operations. With the passage of the Low-Level Waste Policy Act of 1980 and increased emphasis on interim on-site storage of low-level waste, the "economics of volume reduction" are susceptible to increased uncertainties.

This paper reviews some previous volume reduction economic analyses and evaluates the revised economics based upon the development of regional waste disposal sites, improved waste generation and processing practices, and the increased use of interim on-site storage. Several case studies are presented.

S. B. McCoy, W. M. Poplin, T. A. Jur, "A Hybrid High Integrity Container for Disposal of Low-Level Radioactive Wastes," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 571-574.

High Integrity Containers (HICs) are used to bury low-level radioactive waste in shallow land burial facilities. HICs must be designed to meet a variety of shipping, handling, and burial requirements and must contain the waste without loss of integrity for at least 300 years. This paper reviews the design requirements and describes a new "hybrid" HIC made of a stainless steel outer shell and an inner liner of polyethylene. The hybrid HIC utilizes to advantage the structural properties of the stainless steel and the corrosion resistance of the polyethylene.

J. N. McFee, R. L. Gillins, "Low-Level Radioactive Waste Incineration at the Idaho National Engineering Laboratory During 1985," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 445-447.

The low-level radioactive waste incinerator at the Idaho National Engineering Laboratory (INEL) has been processing contaminated waste since September 1984 and is now accepting combustible waste from all INEL waste generators. Waste generators at the INEL sending their wastes to the incinerator for processing must comply with waste acceptance limits and supply appropriate packaging. The incinerator operations during the past year have produced very high waste volume reduction factors (100/1 to 250/1), low radioactive emission rates, and low operator dose rates. Changes in the off-gas system operation have been made to extend the life of the bags in the baghouse.

R. N. McGrath, M. Volodzko, M. D. Naughton, "Operating Experience of a Mobile Waste Shredding System," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 181-186.

The disposal of low-level radioactive waste (LLW) in the United States has become a significant problem challenging the commercial nuclear power industry. Over the past several years, there have been major changes in various aspects of LLW generation, shipment, and disposal. These changes have been characterized by legislative uncertainty, more stringent regulations, and increasing restrictions on shipments imposed by disposal sites and regulatory requirements. These effects have strongly impacted the current nationwide disposal system for LLW, and the industry is face with higher shipping and disposal costs, on-site storage and soon, in some cases, no availability LLW disposal sites.

The industry is responding to this problem by scrutinizing and improving the way in which LLW is managed on-site. Conventional and advanced volume reduction (VR) radwaste treatment systems are receiving more attention with both short- and long-term solutions being considered.

B. B., McKercher, C. C. Miller, M. D. Naughton, "Operational Experience of the Palisades Station Volume Reduction System - The First Two Months," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 87-90.

The startup and operational experience of an extruder-evaporator volume reduction and solidification system are discussed. A description of the system and the retrofit installation of the system is included. The operating parameters for processing wastes and the results of waste processing are presented.

D. L. Michlink, R. W. Marshall, V. L. Turner, K. R. Smith, E. M. VanderWall, "The Feasibility of Spent Resins Incineration at Nuclear Power Plants," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 439-443.

Over the past several years, the Tennessee Valley Authority has evaluated volume reduction (VR) systems to define, develop, and demonstrate the ability to incinerate spent ion exchange resins. In 1979 a detailed physical, chemical, and radiological analysis was performed on actual samples of resins collected from nuclear power plants. This analysis indicated that for resin incineration to be acceptable, the gases produced must be sufficiently removed in an offgas cleanup system. Subsequently, tests in prototype equipment demonstrated the ability to feed and incinerate resins while effectively removing the gases produced during the combustion processes. The demonstration effort conducted by Aerojet and monitored by TVA has shown that after the physical and chemical phenomena associated with resin incineration are realized, mechanical equipment can be combined to incinerate spent resins and process the combustion by-products in a manner consistent with utility, NRC, and other federal and state requirements. This can be accomplished while providing reasonable volume reduction factors and attractive waste disposal cost savings.

C. C. Miller, "Computer Economic Modeling of Volume Reduction Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 383-388.

An interactive computer program for the economic analysis of volume reduction and solidification systems is discussed. The interactive nature of the program allows parameters to be varied with an immediate feedback of the results. The rapid turnaround time of the program allows many processing and financial options to be examined in a short period of time. The program output includes the number of burial containers, the first year disposal costs, the total levelized system cost, and the equivalent capital investment of the system.

R. L. Moscardini, R. M. Waters, J. R. Johnston, J. F. Zievers, "Comparison of High Temperature Gas Particulate Collectors for Low-Level Radwaste Incinerator Volume Reduction Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 299-303.

Reduced burial site availability along with increasing costs for packaging, transporting, and burying low-level radioactive wastes (LLRW) have resulted in the need for development of systems to reduce the volume of these wastes at the point of generation. Incineration offers the greatest degree of volume reduction (VR). In some systems, VRs of over 200:1 have been attained.

Incineration system offgases must be treated to prevent the release of particulates, noxious gases, and radioactive elements to the environment. Fabric filters, venturi scrubbers, cyclone separators, and ceramic metal filter candles have been used for particulate removal. Dry high temperature particulate collectors have the advantage of not creating additional liquid wastes. This paper presents a graphical comparison of different methods for handling particles from high temperature incineration system offgases. Eight methods of offgas handling are compared. A much larger group may be present, but some judicious selection of different, but related systems was done for this paper based on experience with the Combustion Engineering Waste Incineration System (CE/WIS) Prototype. The eight types are: Inertial Devices, Electrostatic Precipitators (ESP), Standard Fabric Bags, Woven Ceramic Bags, Granular Beds, Sintered Metal Tubes, Felted Ceramic Bags and Ceramic Filter Candles. For high temperature LLRW particulate collection in incinerator offgas systems, ceramic filter candles are the best overall choice.

T. B. Mullarkey, R. J. Cudd, "Verification of Volume Reduction Data from the Volume Reduction and Solidification (VRS™) System at the Palisades Nuclear Plant," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 445-449.

This paper discusses a specific waste at a specific plant. The reference was included because there is relatively little operational experience with bitumen systems. At the Palisades Nuclear Power Plant, low-level radwaste was solidified with urea formaldehyde until 1978. Chemical difficulties and regulatory restrictions prompted Consumers Power Company (CPCO) to replace the UF system with a Volume Reduction and Solidification (VRS™) system. The VRS system uses an extruder to simultaneously evaporate water from the waste while encapsulating the waste solids in a thermoplastic binder, asphalt. Installation of the VRS system at Palisades was completed in 1982. Functional testing and startup on simulated waste streams have now been completed. Results demonstrate a solidified product which meets all acceptance criteria while reducing the volumes of borate, bead resin and powdered resin wastes by factors of 5 to 11 over previous practice. A substantial drop in annual waste shipments, processing manhours, and man-rem exposure is projected for Palisades when radioactive material processing commences in 1983.

National Low-Level Waste Management Program, Documentation on Currently Operating Low-Level Radioactive Waste Treatment Systems, DOE/ID/12568, November 1987.

Six reports from companies marketing or using low-level radioactive waste treatment systems are compiled in this document. The technologies represented in this compendium include a shredder/compactor system, a stabilization/solidification system using bitumen, an overview of low-level waste treatment systems in operation in northern Europe, an activated aluminum can melting system in operation at the University of Missouri, an ion-exchange resin and filter media drying system, and a pressurized demineralizer system. Most of the emphasis in this report is placed on volume reduction at nuclear reactors. Information on costs, volume reduction factors, and operational experience is presented for each of the systems described. The information in this report is also available from the National Low-Level Waste Management Program in the form of individual reports on each technology.

T. P. Neal, C. C. Miller, M. D. Naughton, "Operational Experience of the Palisades Volume Reduction System - The First 12 Months," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 545-549.

The operating experience of the first extruder-evaporator volume reduction and solidification system in the United States is discussed. The performance of the system during its first year of operation is presented. The labor and maintenance requirements for the system during the first year are also discussed.

D. D. Nishimoto, K. L. Falconer, D. J. Wiggins, "Options for Treatment, Storage, and/or Disposal of Radioactive Mixed Waste at the Idaho National Engineering Laboratory," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 101-106.

A study is being performed at the Department of Energy's Idaho National Engineering Laboratory (INEL) to determine the most feasible options for the management of INEL radioactive mixed waste and to develop a program plan for implementing the selected options.

This paper will discuss the type and volume of radioactive mixed waste generated at the INEL; selection criteria used to determine the most viable option (i.e., technical, economic, and regulatory constraints); and available options for treatment, storage, and/or disposal. Currently, there are no suitable INEL facilities for the treatment, storage, and/or disposal of radioactive mixed waste.

Oak Ridge National Laboratory, <u>Low-Level Radioactive Waste From Commercial Nuclear Reactors</u>, ORNL/TM-9846, Volume 2, February 1986.

The overall task of this program was to provide an assessment of currently available technology for treating commercial low-level radioactive waste (LLRW), to initiate development of a methodology for choosing one technology for a given application, and to identify research needed to improve current treatment techniques and decision methodology. The resulting report is issued in four volumes.

Volume 2 discusses the definition, forms, and sources of LLRW; regulatory constraints affecting treatment, storage, transportation, and disposal; current technologies used for treatment, packaging, storage, transportation, and disposal; and the development of a matrix relating treatment technology to the LLRW stream as an aid for choosing methods for treating the waste. Detailed discussions are presented for most LLRW treatment methods, such as aqueous processes (e.g., filtration, ion exchange); dewatering (e.g., evaporation, centrifugation); sorting/segregation; mechanical treatment (e.g., shredding, baling, compaction); thermal processes (e.g., incineration, vitrification); solidification (e.g., cement, asphalt); and biological treatment.

Oak Ridge National Laboratory, <u>Waste Treatment Handbook</u>, ORNL/NFW-84/5, February 1984.

Each generator of low-level radioactive waste must consider three sequential questions: 1) Can the waste in its as-generated form be packaged and shipped to a disposal facility? 2) Will the packaged waste be acceptable for disposal? 3) If so, is it cost-effective to dispose of the waste in its as-generated form? These questions are aimed at determining if the waste form, physical and chemical characteristics, and radionuclide content collectively are suitable for shipment and disposal in a cost-effective manner. If not, the waste management procedures will involve processing operations in addition to collection, segregation, packaging, shipment, and disposal.

This handbook addresses methods of treating and conditioning low-level radioactive waste for shipment and disposal. A framework is provided for selection of cost-effective waste processing options for generic categories of low-level radioactive waste. The handbook is intended as a decision-making guide that identifies types of information required to evaluate options, methods of evaluation, and limitations associated with selection of the processing options.

R. E O'Brien, J. Krieger, G. Anderson, A. D'Urso, "A High Integrity Package for Tritiated Liquid Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 355-359.

A high integrity container for the shallow land burial of concentrated tritiated liquid waste has been designed. Under worst case conditions the container will not rupture from radiolytically generated gas pressures, will not leak, will withstand corrosion from internal and external forces and will be structurally stable for more than 250 years.

J.W. Phillips, "Qualification of Waste Forms to Meet the Requirements of 10 CFR 61," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 183-187.

The purpose of this paper is to provide guidance to waste generators in the development and management of a program to qualify solidified low-level radioactive wastes to the suitability requirements of 10 CFR 61. Starting with a review of the implementing regulations and the NRC Branch Technical Position (BTP) the paper discusses various options available in testing methods and procedures. The approach outlined in this paper starts with small scale laboratory testing to select solidification parameters for testing. Suggestions are given on the number and size of samples to use in the various tests. These suggestions are based not only on the technical requirements of the BTP, but also the practical experience of having completed a successful program and the economic considerations needed to run a cost-effective program. This paper also discusses how to implement a step by step scale up program when the actual process equipment cannot be used to produce the samples tested. Finally, an overview is provided of the resources, from the standpoint of time (schedule), manpower and contractor supplemented testing, necessary to conduct a complete, comprehensive and successful program.

A. A. Rahman, F.P. Glasser, Cements in Radioactive Waste Management - Characterization Requirements of Cement Products for Acceptance and Quality Assurance Purposes, Directorate-General, Science, Research and Development, Commission of the European Communities, EUR 10803, Luxembourg, 1987.

Cementitious materials are used as immobilizing matrices for low- (LLW) and medium-level wastes (MLW) and are also components of the construction material in secondary barriers and repositories. This report critically assesses the quality assurance aspects of the immobilization and disposal of MLW and LLW cemented wastes.

The report collates the existing knowledge of the use and potential of cementitious materials in radioactive waste immobilization and highlights the physico-chemical parameters which need to be investigated. Subject areas reviewed include an assessment of immobilization objectives and cement as a durable material, waste stream and matrix characterization, quality assurance concepts, nature of cement-based systems, chemistry and modeling of cement hydration, role and effect of blending agents, radwaste-cement interaction, assessment of durability, degradative and radiolytic processes in cements and the behavior of cement-based matrices and their near-field interactions with the environment and repository conditions.

Areas requiring additional research are identified and include: the existing variability and the need for characterization of the waste stream; investigation of the interactions between a) wasteform and cements, b) wastes and blending agents, c) cements and blending agents, and d) components of the waste forms and matrix materials with components of the repository environment; and durability of the cements in the repository. The experience of cementitious systems in the construction industry offers some parallels to establish the limits of acceptance, but the special needs for long-term durability and immobilizing capacity for radionuclides by the cementitious matrices make the direct transfer of construction industry experience insufficient.

J. Redimsky, A. Shah (eds.), Evaluation of Emerging Technologies for the Destruction of Hazardous Wastes, EPA/600/2-85/069, June 1985.

The objective of this report is to provide detailed information regarding four innovative alternative technologies demonstration projects for treating and destroying hazardous wastes. Under a cooperative agreement between the U.S. EPA and the State of California, the Department of Health Services (DHS) carried out a pilot scale test program on the following promising technologies.

1. High Temperature Fluid-Wall - Thagara Research
2. Evaluation of Emission Tests from SunOhio Mobile PCB Treatment Process - Air Resources Board, State of California
3. Wet Air Oxidation - Zimpro
4. Evaluation of Emission Tests from Wet Air Oxidation, Zimpro Process - Air Resources Board, State of California

Discussions of the above processes include process descriptions, experimental procedures, test methods, results, and discussions, conclusions, and recommendations.

This report was submitted in partial fulfillment of Cooperative Agreement No. R-808908 under sponsorship of the U.S. EPA and the State of California, DHS.

T. L. Rosenstiel, R. G. Lange, "The Solidification of Low-Level Radioactive Organic Fluids With Envirostone Gypsum Cement," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 169-172.

The primary method for the management of low-level radioactive waste (LLW) has been and continues to be the isolation of the waste in a solid mass. Of the four typical LLW streams, organic fluids pose the most significant waste isolation problem. The organic fluids comprised of lubrication oils, hydraulic fluids, sludges, scintillation fluids, etc., results from the operation and maintenance of nuclear power generating stations, research activities, tooling operations, and diagnostic analyses.

A system has been developed which has been patented as the ENVIROSTONE Gypsum system for the solidification of all types of low-level radioactive wastes to facilitate handling and transportation to regulated LLW disposal sites. For the solidification or organic fluids, ENVIROSTONE Gypsum Cement is used in conjunction with ENVIROSTONE Emulsifier, selected for its ability to emulsify a broad range of organic fluids in aqueous solutions. In the solidification process it is theorized that as the crystalline matrix of the gypsum forms, the micelles of the emulsifier behave as a chemical bridge which draws the organic fluid into the crystalline structure via the hydration water.

Initial testing of physical properties of solidified waste forms, including leachability, per the requirements and the procedures specified for 10 CFR Part 61 as outlined in the Branch Technical Position Report from the United States Nuclear Regulatory Commission were in progress as of the writing of this paper. Upon completion of this testing a Topical Report will be submitted to the USNRC for review and approval.

The presentation reviews field experience in the use of ENVIROSTONE Gypsum Cement for the solidification of low-level radioactive organic fluids from nuclear power generating stations and makes an economic comparison between ENVIROSTONE Gypsum Cement and portland cement systems.

L. Rutland, A. S. Dam, M. D. Naughton, "Characterization of Low-Level Radwaste Volume Reduction Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 431-437.

The Electric Power Research Institute is sponsoring a study to develop a long-range assessment of low-level radwaste (LLW) volume reduction (VR) options for nuclear power plants for scenarios accounting for evolving regulations, transportation requirements, and disposal facility conditions. Characterization of advanced volume reduction systems is being done in sufficient detail to permit utilities to evaluate representative processing alternatives. Equipment of the following general types were considered: compactor, incinerator, fluid bed dryer and incinerator, evaporator crystallizer, and evaporator extruder. Information was first developed to represent LLW generated for compactible trash and for liquid and slurry type radwaste streams from LWRs. Performance of the reference VR systems for the waste streams was estimated, and capital and operating costs were estimated for representative facilities that incorporate the reference advanced VR technologies.

L. Rutland, N. C. Papaiya, M. D. Naughton, "Current Status and Future Potential for Advanced Volume Reduction Technologies," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 69-73.

With escalating costs for disposal of low-level radioactive waste (LLW) from nuclear power plants, and the possibility of unavailability of disposal space, some nuclear power utilities responded by committing to implementing advanced volume reduction (VR) systems. This paper presents recent experience to implement advanced volume reduction technologies; their performance and typical operating and capital costs. This experience in the light of current economic conditions may enable us to predict the direction that future advanced VR technology commitments is taking.

A. Saha, A. Dietrich, G. Cefola, "Advanced Low-Level Radwaste Volume Reduction and Solidification Systems," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 293-297.

Disposal of radioactive waste produced by the many operating nuclear power plants represents an increasingly significant problem to the nuclear industry. Currently being offered to utilities is the Radwaste Volume Reduction/Solidification System and the Controlled Air Incineration System, which reduces the volume of both liquid and solid waste.

The Radwaste Volume Reduction/Solidification System employs a vacuum cooled crystallization process to effect volume reduction, coupled with high speed, high shear mixing of the waste with cement to achieve solidification. The final mixture is a homogenous, high strength matrix containing no residual water. The end product, automatically packaged in waste disposal containers, is consistent with current and currently anticipated regulatory requirements for the shipment and disposal of radioactive wastes.

Incineration is becoming increasingly popular among nuclear utilities. To assist utilities and defense waste generators with upgraded incinerator design, the Department of Energy funded a program at Los Alamos National Laboratory (LANL) and developed the "Controlled Air Incineration" concept. The Los Alamos concept was adopted and a radwaste incineration system for the uranium contaminated wastes was implemented. The design was upgraded for application to commercial nuclear power plant wastes with fission products. This paper describes the upgraded radwaste systems.

R. E. Sauer, "A Commercial Regional Incinerator Facility for Treatment of Low-Level Radioactive Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 283-290.

In 1981 studies began on the feasibility of constructing and operating a regional radioactive waste incinerator facility. Two sites in North Carolina were studied for location of the facility. In 1984 a permit application for a radioactive material license to the North Carolina Department of Human Resources was submitted. The facility will accept wastes from power reactors, medical and research institutions, and other industrial users, and will incinerate dry solid waste, pathological waste, scintillation fluids, and turbine oils. The incinerator will be a dual chamber controlled air design, rated at 600 lbs/hr, with a venturi scrubber, packed column, HEPA, and charcoal filters for pollution control. The stack will have a continuous monitor.

R. C. Schmitt, R. L. Chapman, K. C. Sumpter, H. W. Reno, "High Integrity Containers: A Demonstrated Disposal Alternative to Solidification of Radioactive Wastes," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 537-543.

The EPICOR and Waste Research and Disposition Program at the Idaho National Engineering Laboratory developed, tested and is using a High Integrity Container (HIC) for commercial disposal of EPICOR-II prefilter liners from the cleanup of Unit 2 of the Three Mile Island Nuclear Power Station. The HIC permits disposal of EPICOR-II liners as Class "C" low-level radioactive wastes without prior solidification of resins therein. Design rationale for and testing of the HIC are discussed, and costs of using the container for disposal of EPICOR-II liners are compared with costs of solidification. It is concluded that the HIC is a cost competitive alternative to solidification for disposal of unusual types and quantities of low-level radioactive waste.

T. F. Schuler, D. L. Charlesworth, "Solidification of Radioactive Incinerator Ash," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 1, pp. 489-493.

The Ashcrete process will solidify ash generated by the Beta Gamma Incinerator (BGI) at the Savannah River Plant (SRP). The system remotely handles, adds material to, and tumbledrums of ash to produce ashcrete, a stabilized wasteform. Full-scale testing of the ashcrete unit began at Savannah River Laboratory (SRL) in January 1984, using nonradioactive ash. Tests determined product homogeneity, temperature distribution, compressive strength, and final product formulation. Product formulation that yielded good mix homogeneity and final product compressive strength were developed. Drum pressurization and temperature rise (resulting from the cement's heat of hydration) were also studied to verify safe storage and handling characteristics. In addition to these tests, an expert system was developed to assist process troubleshooting.

M. Snellman, M. Valkiainen, "Long-Term Behavior of Bituminized Waste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 501-507.

The long-term properties of bituminized ion exchange resins were studied in a repository environment with access of water equilibrated with concrete. In these circumstances, the most important properties are related to the interactions of bituminized waste with the surrounding barriers. The most important phenomena are water uptake due to rehydration of the resins and subsequent swelling of the product.

R. Soto, R. Harkins, "Mobile Liquid VR System - A Cost Effective Alternative," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 191-195.

The need for cost effective alternatives to treat large volumes of liquid radwaste has never been more evident. State-of-the-art technologies have been developed to offer a mobile liquid volume reduction system that satisfies nuclear industry requirements, with respect to liquid radwaste handling.

This system optimizes proven technology by employing a crystallizer unit to concentrate the waste liquids to 50 weight percent solids, thereby reducing the volume to be solidified by factors of 40, while using only 20 percent of the energy required by conventional evaporative systems. In addition, the system employs a field proven cement solidification process which has been accepted in a Topical Report by the US NRC and which offers the highest waste to container volume ratios for stable waste forms in the industry. This volume reduction-solidification system is able to reduce over 7,000 gallons of liquid waste per day to less than 30 cubic feet of 10 CFR 61 certified stable solidified waste for ultimate disposal or on-site storage. This document describes the system, its applicability, economics, volume reduction, scope of responsibility and experience. Major benefits include higher VR factors, assurance of continual regulatory compliance, and no capital investment.

E. M. Steverson, D. P. Clark, J. N. McFee, "Addition of Liquid Waste Incineration Capability to the INEL's Low-Level Waste Incinerator," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 463-468.

A liquid waste system has recently been installed in the Waste Experimental Reduction Facility (WERF) incinerator at the Idaho National Engineering Laboratory (INEL). In this paper, aspects of the incineration system such as the components, operations, capabilities, capital cost, EPA permit requirements, and future plans are discussed. The principal objective of the liquid incineration system is to provide the capability to process hazardous, radioactively contaminated, non-halogenated liquid wastes. The system consists primarily of a waste feed system, instrumentation and controls, and a liquid burner, which were procured at a capital cost of $115,000.

E. M. Steverson, J. N. McFee, "The Incineration of Absorbed Liquid Wastes in the INEL's WERF Incinerator," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 1 - March 5, 1987, Volume 3, pp. 631-638.

The concept of burning absorbed flammable liquids in boxes in the WERF incinerator was evaluated as a waste treatment method. The safety and feasibility of this procedure were evaluated in a series of tests. In the testing, the effect on incinerator operations of burning various quantities of absorbed flammable liquids was measured and compared to normal operations conducted on low-level radioactive wastes (LLW). The test results indicated that the proposed procedure is safe and practical for use on a wide variety of solvents with quantities as high as one liter per box. No adverse or unacceptable operating conditions resulted from burning any of the solvents tested. Incineration of the solvents in this fashion was no different than burning LLW during normal incineration.

M. L. Thompson, G. P. Miller, C. B. Kincaid, R. W. Caputi, M. E. Weech, L. F. Rodriguez, "Aztech Systems and Testing," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 233-237.

An advanced technology radwaste system, known as the AZTECH volume reduction and solidification system, has been developed. This system will be used for the treatment of low-level waste streams typically encountered in BWR and PWR plants. This paper discusses the systems and approach used for development of the AZTECH process, as well as waste from qualification testing performed by GE to satisfy the 10 CFR 61 licensing requirements. The AZTECH process development equipment included bench scale, pilot plant, and full-scale demonstration systems. The qualification testing program follows the specific 10 CFR 61 requirements guidance, including test standards, provided in the NRC Branch Technical Position (BTP) on waste form. The basic premise of this unique testing plant for AZTECH qualification (NRC approval) was to prepare samples for analysis using actual (representative) processing in a pilot plant and a demonstration plant for full-scale (55-gallon drum) correlation. Samples were analyzed by an independent laboratory and the results were provided to the NRC in a Licensing Topical Report (LTR). Simulated waste forms of sodium sulfate, boric acid, powdered resin, bead resin, and a typical decontamination solution were tested. Simulated waste samples containing non-radioactive tracers (cobalt, cesium, and strontium) were used for leachability and immersion testing. A unique advantage of the approach in developing this test plan is representative and full-scale correlated testing which will allow future testing of simulated customer waste streams using the AZTECH pilot plant.

J.W. Voss, B.D. Guibeault. "The Mixed Economies of Volume Reduction," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11-March 15, 1984, Volume 2, pp. 43-48.

Comparison of available volume reduction systems must be performed with care to ensure that total systems are compared against all performance requirements and all significant additional performance attributes. It is too easy to focus only upon partial systems as individual performance attributes, missing or discounting information which is critical to defensible decision making. Ths paper focuses on defining total systems, performance requirements and attributes, and relevant performance data on individual volume reduction systems.

P. C. Williams, E. G. Collins, "Operating Cost Estimate Low-Level Radioactive Waste Volume Reduction and Packaging Options," Proceedings of the Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 1983, Volume 1, pp. 465-476.

Many nuclear power plant operators are presently or in the near future will be considering changes and improvements in their low-level radwaste management programs. These changes are being dictated by more stringent waste form technical requirements, escalating transportation and burial costs and waste disposal uncertainties which threaten continued operation of the plants themselves. Measures will take the form of programs to minimize waste generation in the first place and facilities to reduce the volume of liquid and solid wastes generated, package the resultant waste forms in compliance with regulations for storage, transportation, and burial and store wastes for several years, if necessary. This paper reviews the operating economics for several volume reduction (VR) and packaging alternatives commonly being considered for three generic power plant streams: 1) Dry Active Waste, 2) Resins and Sludges, and 3) Liquid Wastes.

The ultimate selection of programs and equipment systems for radwaste management is dependent on site specific considerations. This not only includes technical considerations such as the number of reactors, and liquid waste treatment systems employed, but also matters such as the utility's financial position and desired return on investment. Geographic location impacts thinking on transportation concerns and future waste disposal prospects. On top of these factors, there are a host of technologies being made available for VR, solidification and packaging. Those charged with making the choice must consider widely varying VR technologies and potential application of one of several different solidification agents.

The projected operating cost data examine the differences in compaction and incineration for DAW. Two commonly achieved densities for compaction are presented, while a third case approaching the theoretical density of the cloth and paper materials shows the interesting possibilities of improved compaction. Incineration at two benchmarks for the chlorinated compact component of typical DAW illustrates the impact waste stream make-up has on economics.

P. C. Williams, W. S. Phillips, "Supercompactor Force Effectiveness as Related to Dry Active Waste Volume Reduction," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986, Volume 3, pp. 419-423.

The first permanently installed supercompactor in the U.S. is now in operation in Parks Township, Pennsylvania. Tests with various DAW (dry active waste) material have been conducted, recording press force versus drum height as one means of estimating volume reduction capability of this machine at various compaction forces. The results of these tests, as well as other factors, are presented herein.

D. A. Zigelman, F. J. Mis, "Volume Reduction of Dry Active Waste - The Mobile Service Option," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 24 - March 28, 1985, Volume 2, pp. 517-522.

Dry activated waste (DAW) produced at nuclear power plants accounts for the largest fraction of the radio-active waste volume generated and shipped for burial. Since burial of this waste is charged on a dollar per plant's burial costs. This paper addresses the mobile high force compaction service option as an economic alternate to capital expenditures for purchase of column reduction equipment.

H. Zhou, P. Colombo, "Solidification of Radioactive Waste in a Cement/Lime Mixture," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984, Volume 2, pp. 163-168.

The suitability of a cement/lime mixture for use as a solidification agent for different types of wastes was investigated. This work includes studies directed towards determining the waste/binder compositional field over which successful solidification occurs with various wastes and the measurement of some of the waste form properties relevant to evaluating the potential for the release of radionuclides to the environment. In this study, four types of low-level radioactive wastes were simulated for incorporation into a cement/lime mixture. These were boric acid waste, sodium sulfate waste, ion exchange resins and incinerator ash.

APPENDIX C

INFORMATION ON SELECTED INSTALLED OR OPERATING INCINERATORS

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CONTENTS

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FIGURES

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1. INTRODUCTION

This appendix discusses in greater detail some of the operating incinerators highlighted in Chapter 7 of this Manual. Most incinerators described in this appendix are intended to incinerate low level radioactive waste (LLW). Major differences in applying incinerator technology to LLW involve shielding requirements, air filtration requirements, methods of ash disposal and radiological safety considerations during maintenance operations.

This appendix reviews controlled-air incinerators in Section 2, rotary-kiln incinerators in Section 3, and fluidized-bed incinerators in Section 4.

2. CONTROLLED-AIR INCINERATORS

2.1 Los Alamos National Laboratory

The Los Alamos National Laboratory at Los Alamos, New Mexico, operates a controlled air incinerator (CAI) for volume reduction (VR) of radioactive and hazardous chemical wastes. The CAI was developed in the mid-1970s as a demonstration unit for incinerating transuranic (TRU) solid wastes and has since been modified to treat hazardous chemical wastes (mixed wastes).

A dual-chamber controlled air unit, with extensive modifications for containment of TRU isotopes, is at the center of the Los Alamos facility. Natural gas is burned as a supplementary fuel when the heating value of the wastes is low. Solid wastes are fed to the incinerator by a ram feeder through a completely enclosed train with scanning monitor to detect TRU content high enough to pose a problem in ash handling. A liquid feed system mixes liquid waste from drums with fuel oil, then the mixture is sprayed into the main combustion chamber as a fine mist. The flue gas cleaning system is a wet system capable of treating acid gases. It consists of a spray quench tower, a venturi scrubber, an acid gas absorber, a condenser, a mist eliminator, a flue gas reheater, high efficiency particulate air (HEPA) filters, and an activated carbon adsorber.[C-1]

The wastes treated in the CAI consist of liquid organic chemicals, contaminated sludges, and low-level waste (LLW) generated from lab operations. The solid wastes are typically paper, rags, plastics, and rubber, which are prepackaged in cardboard boxes.[C-2]

There are no major reported maintenance problems at the CAI. The activated carbon adsorption bed is highly successful at removing organics from the flue gas. Capacity for solids is about 100 lb/hr,[C-3] and the operating temperature is 1,600°F in the primary chamber and 2,000°F in the secondary chamber (Reference C-1).

The Los Alamos CAI was the first LLW incinerator in the U.S. to burn PCBs, receiving its Toxic Substance Control Act (TSCA) permit in May of 1984. It has interim status under the Resource Conservation and Recovery Act (RCRA), having completed trial burns. A RCRA Part B permit is expected later in 1989 (Reference C-3).

2.2 Chalk River Nuclear Laboratory

The Chalk River Nuclear Laboratory (CRNL) at Chalk River, Ontario, operates a low- and intermediate-level radioactive waste treatment center that includes an incinerator for solid combustible waste as shown in Figure C-1. The incinerator has been operating since 1982.

CRNL uses a batch-loaded, two-stage, starved-air incinerator, one of the simplest among advanced incineration techniques. The system consists of a vertical stainless-steel primary chamber, a horizontal refractory-lined secondary combustion chamber (SCC), and a dry flue gas cleaning system. Waste is loaded into the primary chamber where it is pyrolyzed (starved air) into combustible gases that are completely incinerated in the SCC. The flue gas system is comprised of a heat exchanger to cool the gases, a baghouse, and a HEPA filter.

A wide variety of LLW is incinerated in the CRNL starved-air incinerator. Approximately 2,200 lb of solid waste are processed in a 24-hour burn cycle (batch operation). However, material is segregated to prevent those wastes that contain radioiodine and PVC from entering the incinerator, since the flue gas treatment system lacks an acid gas scrubber.[C-4]

The CRNL incinerator consistently produces an inert ash product with an average volume reduction factor of 150:1. The primary chamber operates at 930°F, while the SCC is limited to 1,610°F to reduce the rate of corrosion of heat exchanger tubes. These temperatures are insufficient to treat hazardous waste, and as such, hazardous wastes are not included in the waste stream. Radioactive oils and solvents are successfully burned. Heat exchanger tubes are cleaned or replaced

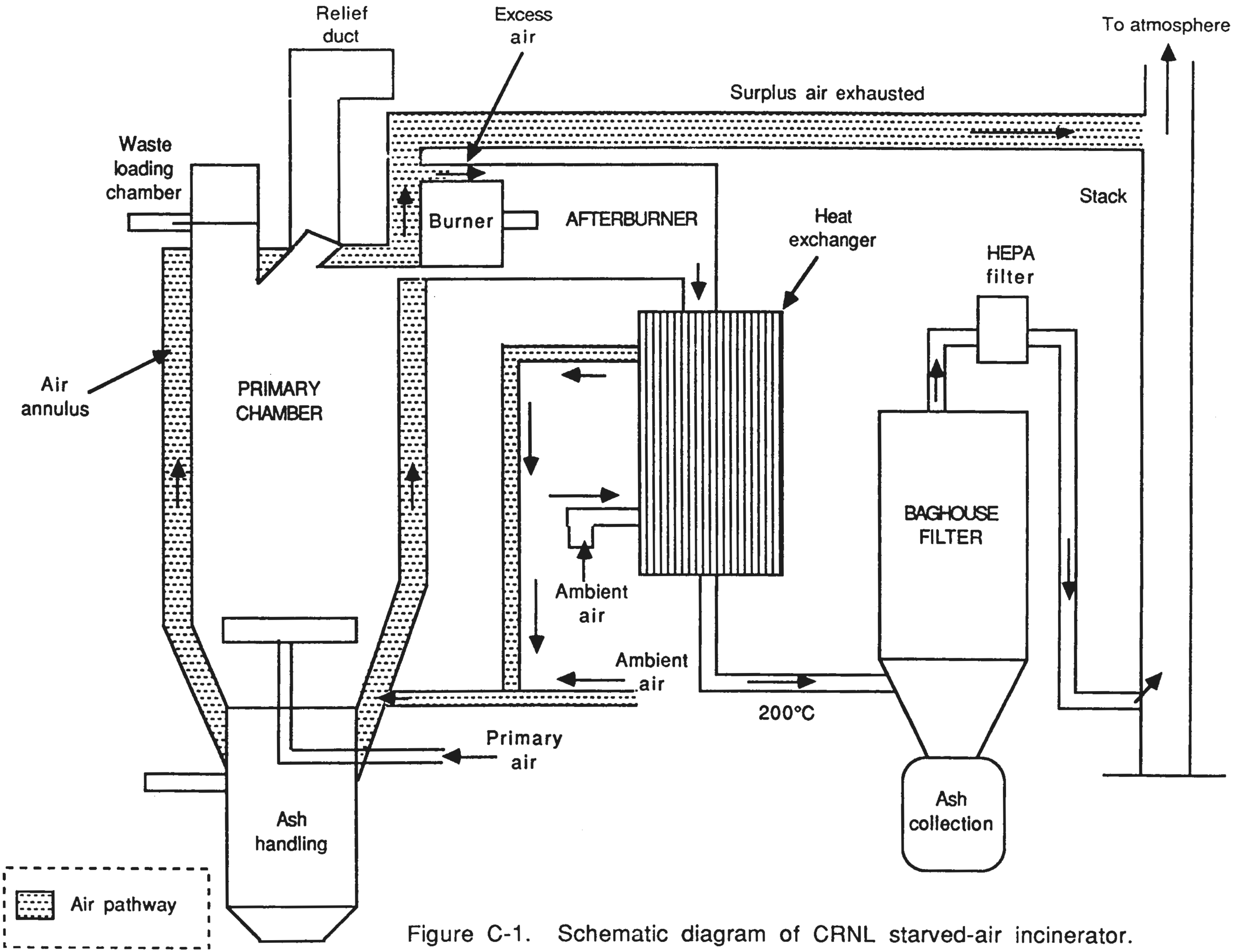

Figure C-1. Schematic diagram of CRNL starved-air incinerator.

periodically because of fouling and corrosion. The incinerator's batch operating mode has some disadvantages, such as the cost and risk of numerous labor-intensive waste loading cycles and the effects of continual heating and cooling on the SCC lining (Reference C-4).

2.3 Idaho National Engineering Laboratory

The Waste Experimental Reduction Facility (WERF) is a fully operational LLW reduction facility at the Idaho National Engineering Laboratory (INEL) near Idaho Falls, Idaho. It began processing radioactive waste in September 1984, includes incineration as one of its reduction technologies, and has been burning all combustible INEL waste since October 1985.

The WERF incinerator is a dual-chamber, controlled-air incinerator originally designed for solid waste but with the added capability to process liquid waste. Solid wastes are loaded into the primary chamber through an airlock chute while liquid waste is pumped to a vortex burner mounted on the primary chamber wall. The flue gas is cooled by air dilution and a heat exchanger, then passes through a baghouse and HEPA filters. A diagram of the complete system is shown in Figure C-2.

Waste is sent to WERF in cardboard boxes lined with polyethylene bags. Only those boxes with contact radiation levels less than 20 mrem/hr are accepted for processing to protect against exposure from ash handling.[C-5] The waste stream from INEL operations can be highly variable, ranging from 100 percent wood to 100 percent plastic, but materials containing halogens (such as PVC) are kept out of WERF since its flue gas treatment system lacks an acid gas removal.

The WERF is successfully achieving a VR factor of nearly 300:1 while processing about 400 lb/hr of LLW. Analysis of material deterioration in the off-gas system has shown only negligible cracking and material loss from oxidation, while the incinerator refractory, subjected to 2,100°F temperatures, remains in excellent condition. Operational problems encountered have included premature failure of baghouse bags and clinkers obstructing the ash removal system.[C-6]

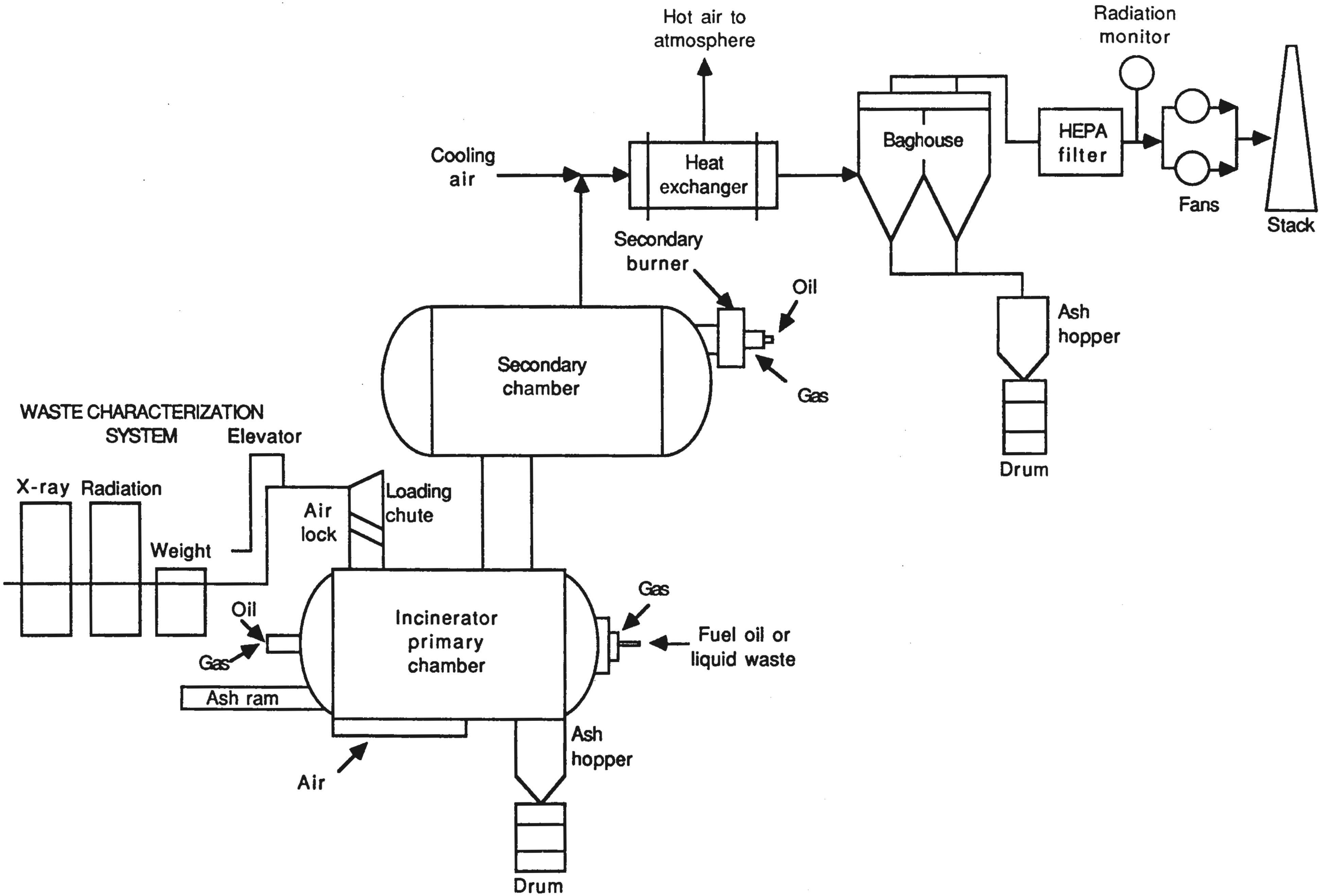

Figure C-2. Schematic diagram of the waste experimental reduction facility (WERF).

The WERF has completed RCRA trial burns for its liquid waste system but is still awaiting a Part B permit to incinerate hazardous organic liquids (Reference C-6).

2.4 Bruce Nuclear Power Plant

The Radioactive Waste Operations Site (RWOS) at the Bruce Nuclear Power Development near Bruce, Ontario, processes solid LLW generated at Ontario Hydro's pressurized water reactor (PWR) nuclear stations and its Research and Central Maintenance Facilities. Waste is incinerated in a batch-mode, controlled-air incinerator, which has undergone modifications to increase its capacity.

The RWOS system consists of a primary combustion chamber where gases are partially oxidized, followed by an SCC where incineration is completed. A heat exchanger for cooling the flue gases and a baghouse to filter particulates comprise the off-gas treatment system. A new on-line loader permits LLW to be fed into the primary chamber at operating temperature, thus increasing the amount of waste incinerated compared to a strict batch operation.

The annual volume of incinerable waste at RWOS is expected to average 145,000 ft^3 in the next few years. The composition of the waste is primarily 40 percent paper and 39 percent plastic. The remainder of the waste is composed of the following: cotton (9 percent), rubber (5 percent), wood (4 percent), and noncombustibles (3 percent).[C-7]

Annual VR achieved with the RWOS incinerator has averaged 75:1. Operating temperatures range from 570°F to 930°F for on-line loading of wastes and are over 1,750°F in the afterburner. Elimination of heat-up and cool-down times has improved incinerator capacity by 25 percent. Problems encountered during tests of the on-line loading modifications include slagging (caused by low temperature ash melting) in the primary chamber and high amounts of uncombusted carbon caused by turbulence from the loading operation.

2.5 Juelich Nuclear Research Center

The Juelich incinerator at the Juelich Nuclear Research Center is the central state collection site for radioactive waste of the Federal State of North Rhine-Westphalia in the Federal Republic of Germany. The facility began radioactive operation in 1976.

The incinerator transfers waste through zones of increasing temperature causing the waste to initially undergo drying and volatilization followed by complete oxidation. Precise amounts of air and recirculated flue gas are injected at the appropriate stage. The off-gas stream is first cooled by a radiation heat exchanger (which is not subject to plugging like common tube heat exchangers), a tube heat exchanger, a cyclone for dust removal, a HEPA filter for removal of aerosols, and finally a scrubber for acid gas removal.

The waste incinerated in the Juelich facility originates from a variety of sources, such as nuclear power stations, medical and nuclear research and development, and hospitals. The waste includes paper, rubber, plastics, and ion exchange resins. Waste is delivered in drums and transferred to the incinerator with no prior sorting. Capacity of the Juelich incinerator is 110 lb/hr.[C-8]

The Juelich facility has operated for over 10 years with very little maintenance. It has consistently processed a diverse waste stream and can operate unattended for long periods because of its self-regulation features. The VR factor has averaged 40:1 but can be as high as 100:1 for some materials.[C-9]

2.6 CEN-Cadarache Incinerator

The Nuclear Research Center (CEN) at Cadarache, France, operates a starved-air incinerator to reduce the volume of its LLW and to store and transform these wastes into a chemically stable form. The first incinerator was built in 1966 and operated until 1975 when a replacement unit went into service.

The incinerator is preceded by a shredding operation that prepares the waste for the combustion chamber. The furnace is of a vertical design, divided into two chambers. The lower chamber operates with starved air, while the upper chamber has excess air injected into it to create high turbulence, which assists combustion. The flue gas is cooled by dilution and filtered by two HEPA filters, then diluted again and finally scrubbed of acid gases in the neutralizer scrubber unit.

LLW considered for incineration is composed of PVC (35 percent); polyethylene (20 percent); latex gloves (20 percent); wet cellulose, primarily cotton (20 percent); and other materials (5 percent). Waste is shipped to the facility in drums and loaded into the shredding unit through an airlock. Incinerator capacity ranges between 40 and 55 lb/hr.[C-10]

A VR factor of 80 was obtained on average in a study of the operation. Levels of radioactivity in the neutralizer/scrubber water were lower than the limits on discharge into the chemical effluents sewer system. The variety of wastes treated has presented problems in maintaining a steady rate of heat release in the furnace chambers. This has led to rapid clogging of filters and associated cleaning and replacement (Reference C-10).

2.7 Scientific Ecology Group

Scientific Ecology Group, Inc. (SEG) of Oak Ridge, Tennessee is constucting a combined partial pyrolysis and controlled-air incinerator as a commercial processing facility for DAW and other incinerable wastes generated throughout the nation. The incinerator is manufactured by Faurholdt Engineering of Denmark and contains two chambers where partial and complete combustion occur. The large secondary chamber will have sufficient temperature and gas residence time to destroy hazardous wastes, including PCBs. The incinerator will have a thermal capacity of 12 million Btus/hour. Considering typical DAW, this means the incinerator will have a throughput of approximately 1,600 pounds per hour. The incinerator is expected to operate on a continuous mode, 24-hour per day basis. Off-gases pass from the secondary chamber into a waste heat boiler where they are cooled to 400°F. They then enter a baghouse followed by a dual set of HEPA filters, gas quenchers, liquid scrubbers and, finally, are reheated prior to sampling and release to the atmosphere.

The SEG incinerator has received all of the regulatory approvals necessary to incinerate LLW: a radioactive materials license, NESHAPS approval, Air Pollution Control Permit, and specific approval from the City of Oak Ridge. After approximately one year of operational experience, SEG expects to apply for a RCRA and TSCA permit to allow incineration of mixed wastes.

Ash will be treated using a vitrification system from Penberthy Electromelt, Seattle, Washington. The vitrification system will add 25 percent, by volume, of glass formers to the ash. The resulting vitrified ash product will have an overall volume reduction factor of 3. This dramatic reduction in volume over untreated ash is due to eliminating voids within and between particles of ash. The vitrified ash is expected to be produced as 225 pound blocks of glass that fit in a standard 55-gallon drum, without the need for additional shielding in most cases. SEG's vitrified ash product is expected to be managed as a Class A LLW. In addition to a favorable volume reduction factor, vitrified ash has anticipated added benefits. It is likely not only to qualify as a stabilized waste under the NRC's BTP (reference 1-4) but also to pass EPA's toxicity test under RCRA.

Operating efficiencies are expected to be similar to the facility operated by Studvik Energiteknik (Appendix C, Section 2.9).[C-11]

2.8 Women's College Hospital

A new incinerator was installed at Women's College Hospital in Toronto, Ontario, to replace an antiquated and undersized incinerator and in anticipation of the possible closure of a landfill where the remainder of the hospital's waste was disposed. A controlled air incinerator was installed in 1986 and has since been disposing of biomedical waste.[C-12]

The hospital's incinerator is a two-chamber design; the primary chamber operates in a semipyrolytic mode (starved air). Complete carbon oxidation and destruction of organisms occurs in the second, higher temperature chamber. Off-gases are then treated before discharge to the atmosphere.

Wastes incinerated in the hospital include infectious waste, small quantities of hazardous waste, chemotherapeutic wastes, and general refuse. It does not process LLW. The incinerator is processing 2,900 lb/day of biomedical and other hospital wastes. Its capacity is 370 lb/hr.

The Women's College Hospital incinerator is operating satisfactorily after the primary chamber pressure was corrected from positive to slightly negative. Analysis of ash samples has detected no microorganisms nor fixed carbon. Some problems were encountered such as slagging of glass on the grate and unstable temperatures in the primary chamber, but these were corrected by adjustments in operating procedures.

While the new incinerator was undergoing construction approval, the Ministry of Environment was revising its guidelines on biomedical waste incineration. Through close cooperation, the hospital met the intent of the new guidelines by including newly required features in the incinerator design.

2.9 Studsvik Energiteknik AB Radwaste Incinerator

A low level radwaste incinerator was constructed in 1976 at the Swedish state-owned nuclear and energy research facility in Studsvik, which is 17 miles south of Stockholm.[C-13] Since its construction, the facility has been used for the centralized treatment of LLW from

Sweden's eight operating nuclear power plants. Smaller amounts of waste from hospitals, universities, and industry are also incinerated at the facility.

Radwaste to be incinerated is collected in plastic bags or cardboard boxes at the point of generation. The waste is then shipped by truck to Studsvik. After the bags are received, they are registered, weighed, surveyed for radiation, and incinerated. The resulting ash is discharged into drums, analyzed by spectrometry, and, if required, encapsulated in concrete and stored for disposal.

The primary chamber of the incinerator is a vertical unit that is fed in batches of 270 lb every 30 minutes. The primary chamber operates slightly above theoretical air at 1,560°F. The gases then enter the SCC for final destruction and are then cooled with ambient air mixing to 1,100°F. Further cooling to 400°F is accomplished by a gas-to-air heat exchanger. The air used for secondary cooling is exhausted to the atmosphere. The gases are then filtered in two fabric filters. The ash is collected in drums where the radionuclide content is determined.

Since mid-1976, the unit has been operating on a regular basis. The fabric filters were installed in 1979. In 1987 the unit treated over 500 tons of LLW. An average VR factor has been 50 with a weight reduction of 6. A system similar to that at Studsvik is going to be installed at Oak Ridge, Tennessee, by Scientific Ecology Group.

Studsvik has been operating air monitoring stations for over 38 years at the facility. The incinerator was operated 3 years without a fabric filter and 6 years with such a filter. Studsvik has shown that the incinerator has produced no adverse effects on the environment. Recent measurements of Cobalt-60 has shown levels 100 million times lower than reference values used at nuclear power stations.[C-14] The recent Chernobyl accident in April 1986 eliminated any chance of repeating future measurements at the facility.

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2.10 Swedish State Power Board Pilot Plant

The Swedish State Power Board has developed a pilot plant for pyrolysis of TBP/kerosene and spent resins. It has operated since 1980, with radioactive operations commencing in 1983.

The pyrolysis system consists of a pyrolysis reactor that is filled with a bed of Al_2O_3 balls kept in slow motion by a helical agitator. Pyrolyzed particles fall to the bottom of the reactor while the gases proceed to the afterburner where combustion is completed. Off-gases are cooled in an air cooler and washed of acid gases in a scrubber. Entrained droplets in the air stream are removed by a demister. The off-gases are finally reheated to enhance filtration through a HEPA filter.

Pyrolysis of powder resins and subsequent solidification of the residues was the reason for developing the pilot plant. The resin is pretreated in a batch dryer then injected into the pyrolysis reactor by a ram feeder. Plant capacity is 70 lb/hr of spent resin.

The overall VR factor is 4 with a normal cementation process and 5 if the residue is evaporated to leave a dry salt. This is attained with operating temperatures of 660°F in the pyrolysis reactor and 2,200°F in the afterburner. The low temperature of the reactor and the use of metallic filter candles produces high decontamination factors for radioactive elements, such as 10^5 for C_s and 2.3×10^3 for CO.[C-15]

2.11 Atomic Energy Commission of France Prototype Incinerator

To reduce the volume of waste produced at its manufacturing and research operations, the French Atomic Energy Commission (CEA) is carrying out a project to incinerate radioactive waste in a pyrolysis incinerator.[C-16] Full operation is scheduled to start in 1992.

The prototype incinerator includes a pyrolysis furnace that operates with an inert atmosphere, a calcination furnace with ambient air, and an afterburner for combustion of pyrolysis gases. The off-gas treatment system consists of gas cooling, prefiltration, a HEPA filter, and final chemical cleaning of acid gases before discharge.

Solid waste processed at the CEA incinerator is generated from the operating and maintenance procedures at nuclear facilities. Its composition is approximately 50 percent plastic material, 35 percent gloves made of latex or neoprene, and 15 percent cellulose. This refuse is packed in PVC plastic bags and boxes to send to the incinerator and is shredded before it is fed to the pyrolysis reactor. The capacity of the incinerator is 11 lb/hr.

The prototype facility at Marcoule Center is being tested to collect information that will be indispensable to the design of a fully operational plant.

3. ROTARY KILN INCINERATORS

3.1 Idaho National Engineering Laboratory

The Process Experimental Pilot Plant (PREPP) was constructed to incinerate TRU waste retrieved from the Idaho National Engineering Laboratory (INEL) storage area.[C-17] The facility, located near Idaho Falls, Idaho, is currently undergoing startup tests.

The PREPP consists of a rotary kiln incinerator with a vertical SCC, a wet off-gas treatment system, a bottom ash processing and solidification unit, and a shredder feed system. Residence time for solids in the kiln is 30 to 90 minutes depending on its rotational speed. Combustion gases and ash pass through the kiln into the secondary combustion chamber, where the noncombustible solids drop into the discharge conveyor and are sent to the solidification unit. The flue gases are cooled in a wet quench tower, scrubbed in a venturi scrubber, then pass through two stages of entrainment removal before being filtered by four parallel HEPA filters.[C-18] The TRU waste that the PREPP is to incinerate contains more chlorinated material than was estimated for its design. This change will prompt additional neutralization in the off-gas scrubbing units creating a greater quantity of spent scrubber solution for disposal (Reference C-18). Again, the generation of acid gas scrubbing solutions will lower the system's overall VR factor.

The PREPP incinerator is currently undergoing test burns. Several needed modifications have been identified, including triple seals on the rotary kiln, better cooling of the solids conveyor, and water softening to reduce scale deposits. No VR factors were estimated.

The goal of the startup tests is to have the PREPP comply with RCRA requirements before full-scale operation begins. Mandated changes due to RCRA include installing an on-line CO monitor and redesigning the ventilation system to route organic vapors to the kiln.

4. FLUIDIZED-BED INCINERATORS

4.1 Oconee Nuclear Station

The Oconee Radwaste Facility processes liquid and solid LLW generated at the Oconee Nuclear Station located in Georgia. This facility consists primarily of a fluidized-bed incinerator/dryer system.

Volume reduction of LLW at Oconee is accomplished by a fluidized-bed dryer and a fluidized-bed incinerator. Liquid waste is concentrated in the dryer and carried out the top of the vessel with fine material (less than 100 microns in diameter). Ash from the incinerator exits with the exhaust gases and, together with the dryer exhaust, enters the flue gas treatment train. A gas/solids separator removes 80 percent of the solids greater than 10 microns to an isolation hopper, while the gases pass through a scrubber/preconcentrator and secondary scrubber. Following an air reheater, the gas stream passes through a HEPA filter, a charcoal filter, and another HEPA filter.

The Oconee VR system processes dry active waste (DAW), oil, resins, and evaporator concentrates. DAW is fed to the incinerator at a rate of 60 lb/hr, oil at a rate of 5 to 6 gal/hr, and resin slurry at a rate of 19 gal/hr.[C-19] The incinerator operates at a bed temperature of 1,450°F and the dryer at 950°F. Particulate emissions represent only 0.01 percent of the total solids processed by the facility. No VR reduction factors were given. The most serious operating problem has been bed agglomeration in the incinerator during resin incineration (Reference C-19).

5. REFERENCES

C-1. J. S. Vavruska, L. C. Borduin, D. A. Hutchins, R. A. Koenig, C. L. Warner, "The Los Alamos Controlled Air Incinerator for Hazardous, Chemical, and Mixed Radioactive Wastes," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986.

C-2. D. A. Hutchins, L. C. Borduin, R. A. Koenig, J. S. Vavruska, C. L. Brown, "Performance Assessment of Refractory Samples in the Los Alamos Controlled Air Incinerator," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2 - March 6, 1986.

C-3. L. C. Borduin, private communication, Los Alamos National Laboratory, June 14 - June 17, 1988.

C-4. V. T. Le, N. V. Beamer, L. P. Buckley, "Experience with Radioactive Waste Incineration at Chalk River Nuclear Laboratory," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

C-5. H. A. Bohrer and J. D. Dalton, "Low-Level Waste Incineration Experience at the Idaho National ENgineering Laboratory," Proceedings of the Eighth Annual DOE Low-level Waste Management Forum, 1984.

C-6. J. D. Dalton, H. A. Bohrer, G. R. Smolik, "Performance History of the WERF Incinerator," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

C-7. K. R. Brown, D. A. Kocela, R. B. Pietrzak, "Controlled Air Incineration Conversion to Allow On-line Additions," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

C-8. W. Wurster, G. Zapf, M. Laser, "Latest Developments in the Juelich Incineration System Design and Similarities in the Treatment of Hospital Wastes," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.

C-9. V. J. Barnhart and H. Gussmann, "Incineration of Low-Level Radioactive Wastes and Ion Exchange Resins," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1988.

C-10. J. Marcaillou and B. Vigreux, "French Experience on Low-Level Radwaste Incineration," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 11 - March 15, 1984.

C-11. B. Arrowsmith, Scientific Ecology Group, Inc., Personal communication, December 21, 1988.

C-12. A. Prasad and P. Miller, "Thermal Incineration of Solid Infectious and Pathological Wastes," Proceedings of the International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes at San Francisco, California, May 3 - May 6, 1988.