

**DOE/LLW-240**

**COMMERCIALLY  
AVAILABLE LOW-LEVEL  
RADIOACTIVE AND MIXED  
WASTE TREATMENT  
TECHNOLOGIES**

*National Low-Level Waste  
Management Program*

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**COMMERCIALLY AVAILABLE  
LOW-LEVEL RADIOACTIVE  
AND MIXED WASTE  
TREATMENT TECHNOLOGIES**

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## **Abstract**

This report provides a discussion of low-level radioactive waste (LLW) and mixed waste (MLLW) streams that are commercially-generated in the United States. Treatment technologies that are currently available to commercial LLW and MLLW generators are also discussed. Discussions include what LLW and MLLW streams exist in the commercial sector, the current commercially available treatments for those wastes, technical information regarding those specific waste treatments, and vendors that are currently available to provide a service to treat waste. Vendors listed have the capability of treating waste at their facility, bring a mobile unit into the field for on-site treatment, or provide a unique product for treatment of commercially-generated LLW or MLLW.

## Executive Summary

There are several commercially-generated low-level radioactive waste and mixed waste streams. These waste streams may be generated at nuclear power plants, hospitals, research facilities, laboratories, biomedical facilities, radiopharmaceutical companies, government research facilities, or universities. These commercially-generated waste streams may need processing and treatment prior to disposal or storage. There are dozens of vendors that provide LLW or MLLW treatment for these commercially-generated waste streams.

The U.S. Nuclear Regulatory Commission (NRC) outlined 36 low-level radioactive waste streams generated at commercial facilities in the United States in NUREG-0782. The list of waste streams can actually be reduced to nine different waste streams. Although there are many waste streams generated at different sizes of facilities, industrial trash from a large facility is treated the same way as industrial trash from a smaller facility. Pressurized water reactor (PWR) concentrated liquids are treated the same way as concentrated liquids from boiling water reactors (BWRs). These are examples of the redundancy in the NRC table of waste streams when dealing with how each waste stream is treated.

Individually, these nine waste streams require different means of treatment. The nine categories of LLW and MLLW include:

- X ion-exchange resins
- X concentrated liquids
- X cartridge filters
- X compactible trash
- X non-compactible trash
- X liquid scintillation vials
- X liquid waste
- X biological waste
- X mixed waste.

Many commercially available treatment technologies to treat LLW and MLLW are discussed in detail in this report. The general categories for these technologies include:

- X Sizing
- X Compaction
- X Filtration
- X Decontamination
- X Evaporation
- X Separation
- X Incineration
- X Vitrification
- X Immobilization/Stabilization
- X Metal Recovery
- X Physical/Chemical Treatments.

Thirty-nine vendors have been identified as being capable of treating commercially-generated low-level radioactive or mixed waste. These companies were reviewed as to whether they actually provide a waste treatment at their own facility, and/or provide a mobile unit to treat waste on-site, and/or provide a unique product to the industry to treat low-level radioactive or mixed waste.

Table 1 shows a list of commercial vendors with their associated technology for treating LLW and MLLW.

**Low-level Radioactive and Mixed Waste Treatment Vendors** (Page 1 of 2)

Company	sol/liq	mobil	LLW	MLL	Sizing	Compaction	Super-Comp	Filtration	Decon	Evaporator	Separator	Incinerate	Vitrification	Immobilization/Stabilization	Metal Recovery	Phys/Chem Treatment	LSV
Yes/No																	
ADCO Services, Inc.	S	N	X		X	X											
ALARON Corporation	S	N	X		X		X		X								
Allied Technology Group, Inc.	S	N	X		X	X	X										
Applied Health Physics, Inc	S	Y	X			X			X								
Applied Radiological Control	S	Y	X						X								
B&W Nuclear Env. Services, Inc.	S	N	X				X										
Bartlett Nuclear, Inc.	S	Y	X		X				X								
Chem-Nuclear Systems, Inc.	S/L	Y	X			X		X	X		X				X		
Corpex Technologies	S	Y	X						X								
Diversified Scientific Services, Inc.	L	N		X								X					X
Diversified Technologies Services	S	Y	X								X				X		
EET Corporation	S	N	X										X				
Eichrom Industries, Inc.	L	Y	X								X						
Envirocare	S	N	X	X	X										X		
Environmental Alternative's Inc.	S	Y	X						X								
Fluid Tech. Inc.	S/L	Y	X		X				X						X		
Framatome Technologies, Inc.	S/L	Y	X		X				X	X	X						
Frank W. Hake Associates	S	N	X			X			X								
Gencorp Aerojet	S	N	X			X			X								

III.A

**Table 1.** Commercial vendors and their associated LLW or MLLW treatment applications.

<b>Low-level Radioactive and Mixed Waste Treatment Vendors</b>		(Page 2 of 2)															
<b>Company</b>	<b>sol/liq</b>	<b>mobil</b>	<b>LLW</b>	<b>MLL</b>	<b>Sizing</b>	<b>Compaction</b>	<b>Super-Comp</b>	<b>Filtration</b>	<b>Decon</b>	<b>Evaporator</b>	<b>Separator</b>	<b>Incinerate</b>	<b>Vitrification</b>	<b>Immobilization/Stabilization</b>	<b>Metal Recovery</b>	<b>Phys/Chem Treatment</b>	<b>LSV</b>
	Yes/No																
General Atomics	S/L	N	X	X	X												X
GTS Duratek	S/L	N	X										X				X
Imbibitive Technologies	L	Y	X											X			
INET Corporation	S	Y	X				X										
Interstate Nuclear Services	S	Y	X						X								
Manufacturing Sciences Corporation	S	N	X													X	
M4 Environmental	S	N	X	X												X	X
Nuclear Fuel Services	S	Y	X	X	X	X		X	X					X	X	X	X
Nuclear Metals, Inc.	S	Y	X			X			X						X		
Nuclear Sources and Services, Inc.	S/L	N	X	X		X		X	X		X			X	X	X	X
NUKEM Nuclear Technologies	S	Y	X			X		X		X	X			X			
Perma-Fix of Florida	S/L	Y	X	X					X					X		X	X
Scientific Ecology Group, Inc.	S/L	Y	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Sevenson Environmental Services,	S	Y	X											X			
Southwest Research Institute	S	N	X	X										X			
Thermo NUtech	S	Y	X								X						
Thomas Gray and Associates, Inc.	S	Y	X				X										
US Ecology	S	Y	X		X		X		X								
VECTRA	S/Y	Y	X			X								X			
Waste Reduction by Waste Reduction, Inc.	S/L	Y	X														X

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## 1. Introduction

This report discusses the low-level radioactive and mixed waste streams that are commercially-generated and the technologies available to treat them. These waste streams may be generated by nuclear power plants, universities, hospitals, government research facilities, radiopharmaceutical companies, biomedical firms, or industrial plants (to name a few) as discussed in Section 2. Section 3 of this document discusses the commercially-available waste treatment technologies for these streams. Section 4 of this document includes eleven different categories of waste treatment technologies. These categories include the following:

- X Sizing
- X Volume Reduction
- X Filtration
- X Decontamination
- X Evaporation
- X Separation
- X Incineration
- X Vitrification
- X Immobilization/Stabilization
- X Metal Recovery
- X Physical/Chemical Treatment.

Within each category are discussions about various commercially-available technologies. These discussions include descriptions of input and output streams, advantages and disadvantages of using the particular technology, technology status, and commercial vendors available that provide a service with that technology.

Information is provided in the following format:

- X common name
- X input stream
- X output stream
- X advantages
- X disadvantages
- X technology status
- X commercial vendors available.

Much of the information regarding the waste treatment technologies discussed in this report was taken directly from document EGG-WMO-10244, entitled *Mixed and Low-Level Waste Treatment Technologies*, September 1992.<sup>6</sup> The information in EGG-WMO-10244 primarily deals with treatment technologies in dealing with U.S. Department of Energy produced waste streams. EGG-WMO-10244 was reviewed and the information was updated for its applicability and relevance to the commercial sector.

There are many companies that provide treatment for commercially-generated low-level radioactive waste and mixed waste. A nearly comprehensive list of vendors was generated through a thorough search in catalogs, references, the Internet, the Thomas Register, and personal contacts. Many vendors from this vast compilation were excluded from this study because of their lack of involvement with radioactive materials. Other companies provided services to only DOE and other Federal agencies; others were excluded because they did not currently provide technologies to treat LLW or MLLW. Although there may be more vendors providing services for treating LLW and MLLW that are not listed here, this report will discuss the capabilities provided by thirty-nine vendors that were identified and treat commercially-generated waste. These vendor's capabilities range from the sizing and cutting of radioactive materials to more sophisticated techniques such as incineration and vitrification. Detailed discussions of vendor capabilities are discussed in Section 5 of this report.

## **2. Commercial Low-Level Radioactive and Mixed Waste Streams**

The following section describes sources and characteristics of typical low-level radioactive waste (LLW) streams. In general, there are three major sources of low-level radioactive wastes:

- Nuclear power plants
- Industries, institutions, and medical facilities
- Government research and defense activities.

The primary sources of commercial low-level radioactive waste streams are operations of nuclear power plants and their supporting fuel cycle facilities.<sup>5</sup> Industrial manufacturers of radioactive materials and commercial research and testing institutions are the second major LLW source. Low-level radioactive waste from government research, defense programs, and weapon production are primarily the responsibility of the Department of Energy (DOE) and are handled, treated, and disposed of at DOE-owned facilities. These DOE waste streams are not subject to Nuclear Regulatory Commission (NRC) or Agreement State license authority and are not discussed in this report. Commercial low-level radioactive waste streams exhibit highly variable physical, chemical, and radiological characteristics.

### **2.1 Nuclear Power Plants**

Low-level radioactive waste generated from power plants 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.

#### **2.1.1 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 as will be discussed in this report.

Typical BWR liquid wastes include sodium sulfate solutions resulting from recycling demineralizer filters on ion-exchange processors. 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.

Decontamination solutions are another liquid waste type common to both PWR and BWR reactors. 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 and small amounts of chelating agents.

### **2.1.2 Wet Solid Wastes**

Radioactive wet solid wastes consist of solid wastes containing greater than 5% 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 a high integrity container. The following section describes the characteristics and sources of these three types of wet solid wastes.

#### **2.1.2.1 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.

#### **2.1.2.2 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.

#### **2.1.2.3 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.

### **2.1.3 Dry Active Solid Wastes**

Dry active solid wastes (DAWs) are industrially produced wastes containing traces of radioactivity. Table 1-1 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. 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.

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<sup>3</sup>, and non-compactible DAWs have an average density of 22 lb/ft<sup>3</sup>. With the introduction of supercompactor systems, DAWs that were previously considered non-compactible can now be compacted.

**Table 2-1.** List of Typical Dry Active Solid Wastes (DAWs)

- Anticontaminant clothing
- Cloth (rags, mops, gloves)
- Conduit
- Contaminated dirt
- Contaminated tools and equipment
  - Hand tools
  - Eddy current equipment
  - Vessel inspection equipment
  - Ladders
  - Lighting fixtures
  - Spent fuel racks
  - Scaffolding
  - Laboratory equipment
- Filters
  - Filter cartridges
  - HEPA filters
  - Respiratory cartridges
- Glass
- High density concrete block
- Miscellaneous metal
  - Aerosol cans
  - Buckets
  - Crushed 55 gallon drums
  - Fittings
  - Pipes and Valves
- Miscellaneous wood
- Plastic
  - Bags, gloves, shoe covers
  - Sample bottles
- Rubber
- Sweeping Compounds
- Irradiated metal alloys
  - Flux wires
  - Flow channels
  - Fuel channels
  - In-core instrumentation
  - Poison channels
  - Shim rods

### **2.1.3.1 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. 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.

### **2.1.3.2 Non-compactible Wastes**

Non-compactible 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 non-compactible 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 non-compactible wastes are mostly wood items such as wood crates, ladders, and scaffoldings. Most non-compactible 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.

### **2.1.4 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 LLW 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, but the amount of oil must be carefully controlled. Waste oils can also be solidified with polyester binder agents, 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).

## **2.2 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
- 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.

### **2.2.1 Liquid Radioactive Wastes**

Institutional liquid radioactive wastes are typically produced in small chemically unique batches precluding processing or treatment with typical ion-exchange and filtration systems. Since institutional liquid radioactive 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.

### **2.2.2 Dry Active Solid Wastes**

Dry active solid wastes generated by institutional users also reflect the diverse nature of the generator. Laboratory glassware and used syringes represent occupational as well as radiological hazards in institutional waste.

### **2.2.3 Liquid Organic Wastes**

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 wastes, 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 radioactive waste volume.

### **2.2.4 Biological Wastes**

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 treated.

### **2.2.5 Sealed Sources**

Sealed sources are primarily used in industry in quality or process control applications or measuring instrumentation. According to the Branch Technical Position (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 have more stringent provisions than the BTP. Specific confirmation should be made with the regulator of the disposal site prior to stabilizing sealed sources.

## **2.3 Mixed Wastes**

Mixed wastes are low-level wastes that are also subject to the requirements of the RCRA. These wastes either exhibit a hazardous characteristic (ignitability, corrosivity, reactivity, or toxicity) or are specifically listed by the Environmental Protection Agency (EPA) or a state. Liquid scintillation wastes are now often incinerated as a fuel additive under RCRA. Generation of small volumes of mixed wastes still occur throughout industry, medicine, and research.

### 3. Waste Treatment for Commercially-Generated Waste Streams

This section of the report is intended to be a guide for LLW generators to assist them in determining which waste treatment may be appropriate for their particular waste stream. LLW streams are generated by all of the following categories of generators: academic, government, industrial, medical, and the utilities. The academic category includes university hospitals and university medical and nonmedical research facilities. The government includes state and federal agency's waste. Industrial waste includes waste produced by commercial entities such as research and development companies, manufacturers, non-destructive testing, mining, fuel fabrication facilities, and radiopharmaceutical manufacturers. Medical generators include hospitals and clinics, research laboratories, and medical offices. The utility category includes commercial nuclear power plants. See Table 2-1 for typical waste streams generated by generators in each of the above named categories. (State-by-State Assessment for 1993, Sept. 1994.)<sup>1</sup>

**Table 3-1. Typical Commercial Waste Streams by Generator Categories**

#### Academic

compacted trash or solids  
 institutional laboratory or biological waste  
 absorbed liquids  
 animal carcasses

#### Medical

compacted trash or solids  
 institutional laboratory or biological  
 waste  
 absorbed liquids  
 sealed sources

#### Government

compacted trash or solids  
 contaminated plant hardware  
 absorbed liquids

#### Utilities

spent ion-exchange resins  
 evaporator bottoms and concentrated  
 waste  
 filter sludge  
 dry compactible waste  
 irradiated components  
 contaminated plant hardware

#### Industrial

depleted uranium  
 compacted trash or solids  
 contaminated plant hardware  
 absorbed liquids  
 sealed sources

Low-level waste streams were outlined by the NRC in 1983.<sup>2</sup> For purposes of waste treatment, the list was reduced to exclude redundancy as institutional trash would be treated the same way as industrial trash. Also, waste is not prejudice on whether it comes from a large or small facility. An outline of the various waste streams for treatment is as follows: ion-exchange resins, concentrated liquids, cartridge filters, compactible waste, non-compactible waste, liquid scintillation vials, liquid waste, biological waste and mixed waste.

### **3.1 Ion-Exchange Resins**

Ion-exchange resins can be treated by incineration, vitrification, the Quantum-Catalytic Extraction Process or by applying supercritical water oxidation technology. Each of these technologies is readily available in the commercial sector. The technologies will be discussed in more depth later in this report.

### **3.2 Concentrated Liquids**

Concentrated liquids, including liquids resulting from the compression of ion-exchange resins, and filtered sludge can be treated in a variety of ways. Most commonly, concentrated liquid and filter sludges go through one of the following processes: a filtration process, evaporation process, separation process, including reverse osmosis, ion-exchange, carbon absorption, precipitation, centrifugation, drying, dewatering, distillation, or steam stripping. Some physical/chemical treatments may also be applied such as neutralization, especially for sludges, slurries, and liquids in the utility waste streams. Once absorbed, the waste can be stabilized and immobilized. Each waste stream is unique and each specific waste stream needs to be evaluated prior to each treatment.

### **3.3 Cartridge Filters**

Cartridge filters from power plants can be crushed, shredded and/or compacted prior to disposal.

### **3.4 Compactible Trash**

Compactible trash includes most DAW, contaminated clothing, plastic, sheet metal, and other compressible items. Depending upon the volume reduction required, this waste can be compacted, supercompacted, cut, shredded, sorted, incinerated, vitrified, immobilized, stabilized, or a physical or chemical treatment can be applied. Metals can be treated through a metal melt recovery process.

### **3.5 Non-Compactible Trash**

Non-compactible waste includes pumps, valves, larger reactor components, tools, etc. These wastes cannot be easily compacted. It may be best for these wastes to be decontaminated through

mechanical or chemical processes. These processes are discussed further in the report.

### **3.6 Liquid Scintillation Vials**

Liquid scintillation vials (LSV) are usually a low-level radioactive mixed waste. There are only three facilities in the United States that handle LSV waste. All facilities crush and compact the vials. One facility has a contract with a municipal industrial boiler that incinerates the glass to ash and eliminates any waste product, except for a little ash.

### **3.7 Liquid Waste**

Liquid waste from laboratories and other facilities, other than utilities is usually sorbed into some type of absorption media (paper towel, diaper, etc.). Most of this waste is stored for decay and disposed in a public municipal landfill or into the sewer system. Other waste is dried, compacted, and compressed in drums, then disposed. Waste that is not sorbed can be processed through filtration (electrodialysis, ultrafiltration, or granular bed). Liquid waste can go through evaporators. The chemistry of the liquid will determine what type of evaporator should be employed. Separation (reverse osmosis, ion-exchange resins, and others) is another liquid waste treatment that can be applied to a liquid waste stream, depending, again, upon the chemistry.

### **3.8 Biological Waste**

There are relatively few options available for generators possessing contaminated animal carcasses. Treatment technologies applicable to biowaste are the following:<sup>3</sup>

#### **Oxidizing Treatment Technologies:**

- Incineration
- Vitrification
- Acid Digestion
- Molten Salt
- Alkaline Hydrolysis

#### **Sterilization:**

- Heat Sterilization
- Sterilization Agents
- Irradiator

#### **Desiccation:**

- Freeze Drying
- Autoclaving
- Drum Drying

#### **Physical Treatment Technologies:**

- Compaction
- Shredding

#### **Solidification Treatment Technologies:**

- Cement Solidification
- Bitumen Solidification
- Polymer Solidification

Oxidizing treatment technologies such as incineration, vitrification, or an alkaline hydrolysis

treatment will treat biological waste and reduce it to a disposable waste form. Desiccation along with solidification may provide a waste form suitable for disposal. Physical treatment technologies such as compaction and shredding reduce volumes of biological material and prepare it for further treatment or storage. Sterilization is used to eliminate microorganisms from a particular medium of interest and does not reduce the radiological hazard.

In the commercial sector, only two of those technologies listed is available commercially through vendors. Scientific Ecology Group, Inc. in Oak Ridge, Tennessee, accepts animal carcasses for incineration. Waste Reduction by Waste Reduction (WR<sup>2</sup>) is a company developed by Dr. Gordon Kaye. Dr. Kaye employs an alkaline hydrolysis process to dissolve animal carcasses contaminated with radioactive material. Effluent from the process has been shown to meet regulatory criteria to be disposed in the public sewer system. Other processes listed are practiced by the generators producing contaminated animal waste, but the processes are not readily available for the commercial market.

### **3.9 Mixed Waste**

Low-level radioactive mixed waste can be treated commercially at several facilities. There are companies that can crush liquid scintillation vials and send them off for incineration. Envirocare has a mixed waste treatment facility. General Atomics in California uses supercritical water oxidation technology to destroy organic mixed wastes by removing the hazardous component and reducing the volume of low-level radioactive waste. Nuclear Fuel Services can immobilize mixed waste by adding a proprietary product to the waste matrix. Nuclear Sources and Services, Inc., south of Houston, Texas, accepts liquid scintillation vials for treatment and crushes vials. Nuclear Sources and Services, Inc. also stores mixed waste on-site for customers at their facility. Southwest Research Institute provides chemical decontamination to clean metals and concrete contaminated with mixed waste. Also, Scientific Ecology Group, Inc. employs several technologies for treating mixed waste including incineration, steam reforming, and the Quantum-Catalytic Extraction Process. All of these technologies are discussed in more depth throughout this report.

## 4. Commercially Available Treatment Technologies

Commercial treatment technologies of LLW and MLLW range from the very simple to extremely complex. For purposes of this report, treatment technologies were divided into eleven broad categories. The categories are as follows:

- X Sizing
- X Compaction
- X Filtration
- X Decontamination
- X Evaporation
- X Separation
- X Incineration
- X Vitrification
- X Immobilization/Stabilization
- X Metal Recovery
- X Physical/Chemical Treatments.

The first treatment technology category is sizing. Sizing is usually one of the first approaches to treating LLW. There is often a need to reduce the size of the waste by cutting, shredding or fracturing before proceeding to using another technology. Often wastes are shredded before compaction or incineration.

### 4.1 Sizing

This section contains various sizing techniques that can be used to prepare the materials for various volume reduction technologies, as a pretreatment for decontamination, treatment, or incineration systems, or as a stand alone size reduction process. These operations are typically used to process large metal or plastic items. For many of the methods, cutting can be carried out either in the dry state or under water.<sup>6</sup>

Sizing is very versatile and can be performed at various stages of a process. Typically, there are two main types of applications: at the source (reducing transportation costs) and/or within a treatment process. These technologies, in general, have hundreds of suppliers and are considered to be a proven technology. It should be noted, however, that not all suppliers have sized low-level radioactive waste. Suppliers exist for both size reduction services and various sizing equipment. Only those companies that have experience in the low-level radioactive or mixed waste arena are listed in this section.

Specific types of sizing processes and their applicability to particular waste types are discussed as follows:

<u>Section</u>	<u>Technology</u>
4.1.1	Arc Saw Cutting
4.1.2	Plasma Arc Cutting
4.1.3	Oxygen Burning
4.1.4	Hacksaws and Guillotine Saws
4.1.5	Shredding
4.1.6	Cryogenic Fracturing
4.1.7	Abrasive Cutter
4.1.8	Thermite Reaction Lance
4.1.9	Laser Cutting
4.1.10	Water Jet Cutting
4.1.11	Abrasive Jet Cutting
4.1.12	Cryogenic Cutting
4.1.13	Shears
4.1.14	Pipe/Wire Cutters

#### **4.1.1 Arc Saw Cutting**

A circular, toothless saw blade is used to cut metals by establishing a high current electric arc between the blade and the material being cut. No physical contact occurs between the blade and the work piece. The polarity of the current is chosen so that the major material removal occurs to the work piece, although, the blade is gradually consumed. Rotation of the blade is essential to aid in cooling of the blade and maintenance of its structural integrity. However the rotational speed (300 to 1800 rpm) is not a critical parameter. The depth of the cut is limited by the blade diameter.

#### **Input Streams**

The input stream is typically conductive metals up to 36 in. (0.9 m) thick.

#### **Output Streams**

The output stream is typically the sized input stream, and small, highly oxidized pellet cuttings of the material that has been cut.

#### **Advantages**

Some advantages of arc saw cutting are (1) arc saw cutting is a "noncontact" cutting process and requires less force to hold the work piece in place than other mechanical cutting processes, (2) the

cutting process operates at a much higher energy level, resulting in faster cutting speeds than other process such as oxygen burning, (3) the ability to sever any electrically conductive material makes it especially attractive for cutting nonferrous metals that could not be cut by the oxygen burning process, (4) the process can be started up instantly without requiring preheat system, (5) it can operate under water or in air, and (6) the rotating blade lasts longer than the tungsten electrode use in plasma arc cutting.

### **Disadvantages**

Some disadvantages of arc saw cutting are (1) increased hazards such as electrical shock, fire, intense light, fumes and gases, and noise that may not be present with mechanical processes, (2) increased difficulty for close tolerance work, (3) equipment tends to be more expensive than oxygen burning equipment, (4) the process requires a large amount of electric power, (5) the process alters the structure of the metal in the cut zone and introduces internal tensile stresses from the rapid expansion, upsetting, and contraction of the metal at the cut surface, and (6) the depth of cut is limited by the blade diameter that gets smaller with increased use.

### **Technology Status**

Proven: Arc saw cutting has been used to cut irradiated pipe and metal.

#### **4.1.2 Plasma Arc Cutting**

The plasma arc cutting process severs metal by using a constricted, direct current arc to melt a localized area of a work piece, removing the molten material with a high-velocity jet of ionized gas (plasma) issuing from the constricting orifice. Plasma arcs operate typically at temperatures of 18,000 to 25,000EF (9,983 to 13,871EC).

Plasma cuts in plates up to approximately 3 in. (8 cm) thick may have a surface smoothness similar to that produced by oxyfuel gas cutting. On thicker plates, low travel speeds produce a rougher surface and discoloration. On thick stainless steel, 5 to 7 in. (13 to 18 cm), the plasma arc process has little advantage over oxyfuel gas powder cutting. The cut widths (kerf) of plasma arc cuts are 1.5 to 2 times the width of oxyfuel gas cuts in plates up to 2 in. (5 cm) thick. This width increases as the thickness of the material to be cut increases.

The plasma cutting process is currently used with either a handheld torch or a mechanically-mounted torch. Several types and sizes of each are available, depending on the thickness of metal to be cut. The equipment includes (1) torch positioning equipment, (2) a torch traveling system, (3) air, starting gas, and plasma gas supplies, (4) a constant-current or drooping volt-ampere characteristic, relatively high-voltage direct-current power supply, and (5) associated automatic controls. Plasma arc equipment normally includes controls to (1) start and stop the equipment, (2) sequence the entire operation, including varying the gas flow and power level if necessary, (3) shutdown the torch in the event of gas failure since the torch may be damaged by internal arcing

without an adequate supply of gas, and (4) control coolant for high-current torches.

### **Input Streams**

This process was initially used for cutting aluminum but can cut carbon steel, or any other conductive nonferrous metal, including those resistant to acetylene cutting. The maximum cut depth for many materials is 7 in. (18 cm). The process has been used to cut stainless steel up to 5 in. (13 cm) thick or aluminum alloy up to 6 in. (15 cm) thick.

### **Output Streams**

The output will consist of smaller pieces of the input material, small amounts of the cuttings, and small amounts of oxidized and/or devolatilized metals.

### **Advantages**

Some advantages of plasma arc cutting are (1) the amount of force required to hold the work piece in place and move the torch (or vice versa) is much lower with the "noncontact" plasma arc cutting process than other mechanical cutting processes, (2) the cutting process operates at a much higher energy level, resulting in faster cutting speeds than oxygen burning, (3) the ability to sever any electrically conductive material makes it especially attractive for cutting nonferrous metals that could not be cut by the oxygen burning process, (4) the process can be started up instantly without requiring preheat system and can operate under water or in air, and (5) the process can be a hand-held operation or automated.

### **Disadvantages**

Some of the disadvantages of plasma arc cutting are (1) increased hazards such as electrical shock, fire, intense light, fumes and gases, and noise that may not be present with mechanical processes, (2) increased difficulty for close tolerance work, (3) equipment tends to be more expensive than oxygen burning equipment, (4) the process requires a large amount of electric power, (5) the process alters the structure of the metal in the cut zone and introduces internal tensile stresses from the rapid expansion, upsetting, and contraction of the metal at the cut surface, (6) the depth of cut is limited by the blade diameter that gets smaller with increased use, and (7) the tip and electrode wear during cutting that deteriorates cutting performance.

### **Technology Status**

Proven: Plasma arc cutting has been extensively used on full-scale nonradioactive hardware and confirmed its effectiveness in segmenting bulky metallic waste materials. It has also been proven

to be successful in decommissioning reactor vessels and segmenting irradiated piping.

### **4.1.3 Oxygen Burning**

Oxygen burning, also known as oxyfuel cutting, is a process where the metal is severed or removed by the chemical reaction of oxygen with the metal at elevated temperatures, leaving a clean cut surface. Oxygen burning consists of circulating a mixture of a fuel gas and oxygen at the orifice of an ignited torch. The cutting tip of the torch is at the main oxygen jet orifice. This orifice is surrounded by a ring of preheater jets. The oxygen jet rapidly oxidizes most of the metal in a narrow section to make the cut. Metal oxides and molten metal are expelled from the cut by the kinetic energy of the oxygen stream. In the case of oxidation resistant metals, the reaction is aided by adding chemical fluxes or metal powders to the cutting oxygen stream.

Oxygen burning can be used to cut plates up to 7 ft (2 m) thick. As material thickness increases, oxygen flow rates must usually be increased. Cutting tips with larger cutting oxygen ports are required to handle the higher flow rates. Consequently, the width of the cut (kerf) also increases as the material thickness being cut increases. Varying the cutting speed from those recommended for best quality cuts usually results in irregularities in the kerf.

Two basic types of oxygen burning equipment are available: manual and machine. The manual equipment is used primarily for maintenance, scrap cutting, cutting risers off castings, and other operations that do not require a high degree of accuracy or a high quality cut surface. Machine cutting equipment is used for accurate, high quality work, and for large volume cutting, such as in steel fabricating shops.

The basic equipment needed for manual oxygen burning are (1) one or more cutting torches suitable for the preheat fuel gas to be used and the range of material thicknesses to be cut, (2) cutting tips to cut a range of material thicknesses, (3) oxygen and fuel gas hoses, (4) oxygen and fuel gas pressure regulators, (5) sources of oxygen and fuel gases to be used, and (6) flame strikers, eye protection, flame and heat resistant gloves and clothing, and safety devices.

Machine cutting equipment often includes (1) a machine to move one or more torches in the required cutting pattern, (2) torch mounting and adjusting arrangements on the machine, (3) a cutting table to support the work, (4) means for loading and unloading the cutting table, and (5) automatic preheat ignition devices for multiple torch machines.

### **Input Streams**

This process can only be used on metals that undergo rapid exothermic oxidation; namely, ferrous metals and wrought iron products [up to 7 ft (2 m) thick]. This process cannot be used on stainless steel, cast iron, aluminum, and nonferrous metals without increasing the cutting temperature above the melting point of the refractory oxides.

## **Output Streams**

The output will consist of smaller pieces of the input material.

## **Advantages**

Some advantages of oxygen burning are (1) steels can generally be cut faster than by mechanical chip removal processes, (2) section shapes and thicknesses that are difficult to produce by mechanical means can be severed economically, (3) equipment costs are low compared to machine tools, (4) equipment is portable and can be used in the field, (5) cutting direction can be changed rapidly on a small radius during operation, (6) large plates can be cut rapidly in place by moving the torch rather than the plate, and (7) the process can be a hand held operation or automated.

## **Disadvantages**

Some disadvantages of oxygen burning are (1) dimensional tolerances are significantly poorer than machine tool capabilities, (2) the process is essentially limited commercially to cutting steels and cast iron, although other readily oxidized metals, such as titanium, can be cut, (3) the preheat flames and expelled red hot slag present fire and burn hazards to personnel, (4) fuel combustion and oxidation of the metal require proper fume control and adequate ventilation, (5) special process modifications are needed for high alloy steels and cast iron, and (6) hardenable steels may require preheat, postheat or both to control their metallurgical structures and mechanical properties adjacent to the cut edges. Oxygen burning is not recommended for extensive remote cutting.

## **Technology Status**

Proven: Oxygen burning has been used in the nuclear industry.

### **4.1.4 Hacksaws and Guillotine Saws**

Hacksaws and guillotine saws are common industrial tools used for cutting all metals. The cutting process results from the reciprocating action of a hardened steel saw blade against the metal being cut. Portable power hacksaws are clamped with a chain to a pipe in a position such that the blade contacts the underside of the pipe. This allows the weight of the motor to advance the blade into the work piece about the chain mount pivot point. An operator may increase the feed pressure manually by applying downward force on the motor body or by suspending weights from the body. As a general rule a 8 in. (20 cm) diameter Schedule 40 pipe can be cut in 6 to 10 minutes with a power hacksaw. In general, blade lubrication is not necessary.

A portable guillotine saw also clamps by chain to a pipe but the saw and motor are mounted above the cut allowing the weight of the unit to advance the saw into the work piece. Cutting

speed is approximately 1 minute for each inch of pipe diameter based on Schedule 40 pipe. In general, blade lubrication is not necessary.

### **Input Streams**

Inputs consist of metals, piping [up to 14 in. (36 cm) diameter for power hacksaws and up to 18 in. (46 cm) diameter for guillotine saws], wood products, and plastics.

### **Output Streams**

Outputs consist of segmented metals, pipes, wood products, and plastics and secondary waste streams from cutting fluids if used.

### **Advantages**

Some of the advantages of hacksaws and guillotine saws are (1) reduced fire hazards, (2) simpler radioactive contamination control because no fumes or gases occur, (3) available in portable or stationary modes, (4) requires minimum operator assistance after positioning thus reducing operator exposures when cutting in high radiation zones, (5) motors powered by air or electricity, (6) automatic feed, measure, and cut off of a series of pieces (production-type machines), (7) easy to change from one job to another, (8) inexpensive alloy and high steel blades have long lives, (9) accepts a wide variety of materials, and (10) low operating costs.

### **Disadvantages**

Some of the disadvantages of hacksaws and guillotine saws are (1) the process is slow because the stroke of a hack saw is intermittent, (2) the rate a hack saw penetrates the material depends on the feeding force, and (3) cutting fluids, if used, will produce a secondary waste stream.

### **Technology Status**

Proven: Hacksaws and guillotine saws have been used in the nuclear industry.

#### **4.1.5 Shredding**

Shredding is normally used for processing dry solids before incineration, compaction or other treatment of the solids. Low-speed shredders simultaneously open the waste containers and size the wastes for processing. Shredder operation consists of two counter rotating shafts with cutter wheels attached. The cutter wheels intermesh and tear apart the waste as it is drawn through. The waste material is trapped between the wheels and cut to the size of the clearance between the wheels. A "comb" is used on the noncutting side of the shafts to prevent waste from falling through. The discharged material is dropped into a container that can be processed by

incineration or compaction.

A typical shredder contains a number of intermeshing, counter rotating shafts driven by a variable-speed motor. Features such as a motor controller, which reverses the direction of the motor and shaft if jamming occurs, along with various design of cutting teeth, are readily available. The waste is usually fed to the shredder by a conveyor.

### **Input Streams**

Shredders can be used on all types of dry solids - paper, cloth, plastics, wood, and even some light metal.

### **Output Streams**

The output materials consist of pieces of the input material that have been shredded to a smaller, more uniform size distribution.

### **Advantages**

Some advantages of shredding include (1) reliability, (2) low power requirements, (3) unshreddable items left on top of cutters are easily removed when shredder is turned off, and (4) does not pulverize the waste, which would create large amounts of dust.

The advantages of shredding before compaction include (1) springback after compaction is reduced, (2) traditionally "non-compactable" waste such as wood can be compacted, (3) the required compaction pressure may be reduced because material deformation is not necessary for compaction, and (4) mixing of the waste during shredding prevents the generation of "hot spots" during compaction.

### **Disadvantages**

Some of the disadvantages of shredding include (1) fugitive dust emissions (2) cleaning of internal hopper area and shredding teeth could affect overall processing time and, (3) high maintenance.

### **Technology Status**

Proven: The shredding process is well proven in nonnuclear industries and has been used in the nuclear industry in more recent years.

#### **4.1.6 Cryogenic Fracturing**

In cryogenic fracturing, solid materials are cooled in a liquid nitrogen bath to reduce their temperature to below their nil-ductility temperature. The nitrogen bath temperature is -320°F

(-196EC ). At this temperature, the materials are more brittle and easily broken having lost their ability to absorb energy via plastic deformation. Articles are removed from the liquid nitrogen and placed in a hydraulic press to crush the frozen materials. Adequate force applied to a material below nil-ductility temperature causes the material to brittle fracture into shards. A recycle system allows large pieces to recycle back through the cryogenic fracturing process.

The time required to freeze a sealed container can be reduced by puncturing the container. The typical time required to cool a nonpunctured drum can be reduced from approximately 17 hours to 45 minutes. Typical hydraulic press forces during cryogenic fracturing can range from 60 to 900 tons.

Cryogenic fracturing equipment consists of storage tanks for the liquid nitrogen, liquid nitrogen baths, a hydraulic press, and equipment to move the parts from the liquid nitrogen baths to the press.

### **Input Streams**

Input streams can include cloth, paper, plastic, wood, carbon steel concrete, asphalt, paper, lifting cables, electrical cables and other materials that become brittle when cooled to -320EF (-196EC).

### **Output Streams**

Same wastes as influent except the size is reduced to smaller particles.

### **Advantages**

Some advantages of cryogenic fracturing include (1) the colder temperatures decrease the average energy of the molecules, (2) cryogenic temperatures freeze bioactivity and significantly reduce chemical reaction rates and volatility, (3) cryogenic fracturing produces small amounts of secondary wastes, (4) the process is suited for fully remote-automated design, and (5) less energy is required due to the embrittlement of the material to be sized.

### **Disadvantages**

Some of the disadvantages of cryogenic fracturing include (1) large liquid nitrogen requirements, (2) when cryogenic fracturing soil, concrete, and asphalt, these materials build up under the hydraulic press preventing the crusher from traveling the full stroke, (3) the cooled materials must be processed quickly before the materials can warm up, and (4) some carryout of radioactive materials can occur due to entrainment in the rapidly vaporizing nitrogen gas.

### **Technology Status**

Emerging: Initially, the cryogenic fracturing process was developed to render inert and destroy

chemical weapons. Cryogenic fracturing technology has been tested at NRT in San Diego, California, for treatment of Idaho National Engineering Laboratory (INEL) waste using 55 gallon steel drums and 2 x 2 x 8 ft (0.6 x 0.6 x 2 m) plywood boxes filled with various articles.

#### **4.1.7 Abrasive Cutter**

An electrically, hydraulically or pneumatically powered wheel with an abrasive surface of resin-bonded particles of aluminum oxide or silicon carbide cuts through the work piece by grinding the metal away. This produces a clear cut (kerf). Cutting ranges for stationary abrasive wheels are approximately 1 in.<sup>2</sup> (6.5 cm<sup>2</sup>) of cut area every 7 seconds. Reported wear rates for wheels average 1 in.<sup>2</sup> of surface area consumed for each square inch of cut area. Water lubricants can be used to improve wear resistance by 50%.

#### **Input Streams**

Inputs consist of metals, piping or stock less than 8 in. diameter, chord, high-density alloys, nonferrous alloys, and nonmetallic materials such as composites, plastics, natural stone, glass, and refractory products.

#### **Output Streams**

The output stream will consist of the sized input materials, cuttings, and secondary waste streams from cutting fluids if used.

#### **Advantages**

Some advantages of abrasive cutters are (1) low cost, (2) usefulness on a wide variety of materials, and (3) equipment can be portable or stationary.

#### **Disadvantages**

Some disadvantages of abrasive cutters are (1) contamination control is difficult, since the particles are removed in small pieces, (2) water lubricants used to decrease wear on the grinding surface generate secondary wastes, (3) the cutting process creates a noise level of 140 to 160 dB, requiring hearing protection for operators, and (4) the cutting process generates sparks, making it unsafe to operate near combustibles.

Stationary applications require the materials to be cut to be brought to an established workstation. The disadvantages of portable hand-held abrasive cutters include (1) they are relatively slow, (2) require constant operator attention, (3) the reaction force of the work piece against the operator for long periods of time is tiring, and (4) the applicability of manual cutting is generally limited to pipe and components of less than 2 in. (5 cm) diameter.

## **Technology Status**

Proven: Abrasive cutting has been used in the nuclear industry.

### **4.1.8 Thermite Reaction Lance**

A thermite reaction lance is an iron pipe packed with steel, aluminum and magnesium wires with a flow of oxygen gas through it, which cuts by a thermite reaction at its tip that causes the metal to melt. The thermite reaction lance is capable of cutting any metal. The maximum depth of the cut is limited only by the ability to keep the cut (kerf) clear of the molten metal. The rate for metal cutting has been reported as generating approximately 1 in. (2.5 cm) diameter hole at the rate of 12 in. (30 cm) depth per minute, provided the molten metal is free to flow away from the kerf.

The lance is currently only used in the manual (hand-held) mode. A typical lance cutting system consists of a lance holder, the lance, and oxygen supply, gas regulator and an oxygen hose. Each lance will burn for approximately 6 minutes and consume about 60 ft<sup>3</sup> (6 m<sup>3</sup>) of oxygen.

#### **Input Streams**

Input streams are all metals at practically any thicknesses.

#### **Output Streams**

Output streams are molten metals, and smaller pieces of the original metal.

#### **Advantages**

The advantages of a thermite reaction lance include (1) usefulness in air or underwater, (2) relatively low cost, and (3) can cut all type of metals at any thickness.

#### **Disadvantages**

The disadvantages of a thermite reaction lance include (1) the operator must wear fireproof protective clothing and faceshield, which is difficult to use underwater, (2) the flames and expelled red hot slag present fire and burn hazards to personnel, and (3) hardenable steels may require preheat, postheat or both to control their metallurgical structures and mechanical properties adjacent to the cut edges.

## **Technology Status**

Proven: The thermite reaction lance has been used in the nuclear industry.

### **4.1.9 Laser Cutting**

Laser beam cutting is a thermal cutting process that severs material by locally melting or vaporizing the material using a laser beam. The process is used with or without assist gas to aid the removal of molten and vaporized material. Depending on the material, a jet of reactive gas such as oxygen can be applied coaxially with the beam, improving process speed and cut edge.

Laser cutting equipment consists of a laser, a beam delivery system, supply of assist gases (helium, nitrogen, and carbon dioxide), and the ability to maneuver the work piece or the cutting beam. For optimum cut quality, the optics should be held motionless, to avoid any vibration or misalignment in the beam delivery system. Fiber optic systems have been developed that allow greater flexibility in directing the cutting beam.

The CO<sub>2</sub> laser is the most powerful and reliable type of laser in general use. The CO<sub>2</sub> laser is a gas-discharge device that operates by sending an electric current through a gas. A high-power CO<sub>2</sub> laser can cut up to 1 in. (2.5 cm) thick carbon steel. However, good quality cuts on steel are typically made on metal thinner than 0.375 in. (0.9 cm) because of the limited depth of focus of the laser beam. Typical cutting speed for 0.375 in. (0.9 cm) carbon steel is 50 in./min (1.3 m/min) with a power consumption of 1500 W. However, these rates assume the cut quality is of importance. For simple sizing operations, "raw" processing capabilities will need to be investigated to determine the processing rate.

Laser cutting results are highly reproducible, and laser systems have achieved operating uptimes greater than 95%. Relative movement between the beam and work piece can be easily programmed. Lasers also have the flexibility for power and time sharing so that cost effectiveness of full-time beam operation can be maximized.

#### **Input Streams**

The laser can cut an extremely wide range of materials (metals, ceramics, inorganics, organics, and composites) without regard to their hardness or electrical conductivity. Inorganic materials, as a class, have low vapor pressures and poor thermal conductivities making them good candidates for laser cutting. Unfortunately, many common varieties have high melting points and poor thermal shock resistance that tends to make them harder to process than metals. Organic materials generally decompose by laser light, which enables cutting to be done at higher speeds or with lower power lasers.

#### **Output Streams**

Output streams consist of smaller pieces of input material.

## **Advantages**

Laser cutting has the advantages of (1) high cutting speeds, (2) narrow cut (kerf) widths, (3) high-quality edges, (4) low-heat input, (5) minimal work distortion, (6) easily automated, (7) cut geometry can be changed without the major rework required with mechanical tools, (8) no tool wear, (9) finishing operations are not usually required, (10) minimal job setup time, (11) no mechanical contact between the cutting device and the work piece, (12) can cut aluminum without leaving any dross, (13) eliminates secondary wastes, and (14) noise, vibration, and fume levels involved are quite low compared to most conventional processes.

## **Disadvantages**

The disadvantages of laser cutting include (1) high initial costs, (2) exposure to high voltage power supplies, (3) exposure to direct or reflected light, and (4) exposure to fumes from materials being cut.

Fixed beam laser cutting has the disadvantages of (1) complicated systems are required to move large work pieces, (2) the minimum floor area required is four times the maximum sheet size, and (3) automatic sheet feeding and part removal are difficult, as is accurate contouring with widely varying loads.

Moving optical systems have the disadvantages of (1) beam divergence due to the variance of diameters, focal point, and spot size as a function of both distance from their source, and the location where the laser beam intercepts the lens, (2) beam must be allowed to travel across the entire work piece without a change in alignment, (3) vibration and deflection are more difficult to suppress, and (4) harder to seal the beam path against dirt on the optical elements since many moving beam systems share enclosures with gears, motors, and other sources of contaminants, shortening the life of the optics.

## **Technology Status**

Available: Among the laser material processing applications, cutting is the most common process, and is experiencing an excellent growth rate worldwide.

### **4.1.10 Water Jet Cutting**

A wide variety of materials, both nonmetals and metals, can be cut using a high-velocity water jet. The jet is formed by forcing water through a 0.004 to 0.024 in. (0.1 to 0.6 mm) diameter orifice in a tungsten carbide or synthetic sapphire nozzle, under high pressure (30,000 to 60,000 psig) to obtain jet velocities ranging from 1700 to 3000 ft/sec (518 to 914 m/sec). The nozzle is typically 0.010 to 1.0 in. (0.3 mm to 25 mm) from the work piece, with distances under 0.25 in. (6 mm) being preferred. At these speeds and pressures, the water erodes many materials rapidly, acting like a saw blade. Metals and other hard materials are cut by adding an abrasive in powder form to

the water stream.

Resulting work piece tolerances depend on the equipment, work piece material and thickness, but can be as close as  $\pm 0.004$  in. (0.1 mm) on dimensions and  $\pm 0.002$  in. (0.05 mm) on positioning. In simple water jet cutting, the cut (kerf) width is usually 0.005 in. (0.13 mm) or wider. In abrasive water jet cutting, it is usually 0.032 in. (0.8 mm) or larger. Kerf tapering may be reduced by adding long chain polymers, such as polyethylene oxide, to the water or by reducing cutting speed.

The water stream, with a flow rate of 0.1 to 5 gpm, is usually manipulated by a robot or gantry system, but small work pieces may be guided past a stationary water jet by hand. The key pieces of equipment for a water jet or an abrasive water jet system are (1) the special high pressure pump or intensifier used to provide the stream of water, (2) the plumbing and tank or catcher unit to handle the water, (3) the gantry, robotic, or other delivery system to transverse and guide the water jet, and (4) the nozzle assemble unit which forms the jet. In the case of abrasive water jets, an abrasive delivery system includes a hopper, a metering valve, and a mixing unit, which mixes the abrasive particles into the water stream.

### **Input Streams**

Water jet cutting can be used on a wide range of materials (metals, concrete, leather, cardboard, plastics, and composites). An abrasive jet is particularly good for cutting laminates of different materials including sandwiches of metals and nonmetals.

### **Output Streams**

Output streams from this process include (1) smaller sized pieces of the material being cut, and (2) contaminated water and abrasive materials.

### **Advantages**

The advantages of water jet cutting include (1) a wide application range, (2) no predrilling is required to start cutting, (3) cutting may be omnidirectional, (4) minimal or no deburring is required, (5) the process is easily adapted to robot control, (6) minimal tool wear out, other than the orifice, nozzle and wear on the robot mechanism, (7) minimal lateral forces are generated simplifying fixturing, and (8) the part being cut does not heat up.

### **Disadvantages**

The disadvantages of the water jet cutting include (1) low cutting speeds, (2) initial capital costs are high because of the pumps and pressure chamber required to propel and direct the water jet, (3) nozzles must be replaced every two to four hours in abrasive water jet systems, (4) a collection device must be provided to collect the exhaust liquid from the cutting stream, (5) the

material to be cut must be softer than the abrasive used, (6) thin ductile metals tend to suffer bending stress from the abrasive jet and show exit burrs, (7) ceramics show decrease in as-fired strength, (8) the abrasive grit wears the carbide nozzles to an out-of-round conditions, and the jet loses its symmetry, causing cut quality to deteriorate, and (9) secondary wastes are created by this process that must be disposed of properly.

## **Technology Status**

Available: Industries that use water jet cutting include automotive, aerospace and defense, building supply, circuit board manufacturing, steel fabrication, foundries, food processing, glass manufacture, mining, oil and gas well equipment, packaging, paper, rubber, shipyards, and steel service centers. Equipment is available in a range from individual components to finished machine tools. More complex systems such as 5-axis robotic system, tend to be custom-built. No information was obtainable to indicate that this technology had been used in a nuclear environment.

### **4.1.11 Abrasive Jet Cutting**

Similar to water jet cutting, high pressure gas or liquid jets containing abrasive materials are used to cut through many materials, ranging from foam rubber to the hardest steels. Air, nitrogen, or carbon dioxide are ordinarily used as carrier gases, and water or light oil as carrier liquids. The abrasive materials most often used are aluminum oxide, silicon carbide, dolomite, sodium bicarbonate, and small glass beads. The technique functions by entraining the abrasive material in the carrier stream, focusing the carrier/abrasive stream through a tungsten carbide or synthetic sapphire nozzle, then impinging that stream onto the work piece. The abrasive action of the high speed particles cause the cutting action.

The key pieces of equipment for an abrasive jet cutting system are (1) the special high pressure pump or intensifier used to provide the stream of liquid or supply of high pressure gas, (2) the plumbing and tank or catcher unit to handle the liquid, abrasive material and work piece chips, (3) the gantry, robotic, or other delivery system to transverse and guide the fluid jet, (4) the nozzle assembly unit which forms the jet, and (5) an abrasive delivery system including a hopper, a metering valve, and a mixing unit, which mixes the abrasive particles into the fluid stream.

### **Input Streams**

The input stream for this technology can consist of almost any solid material (metals, concrete, leather, cardboard, plastics, and composites). Layered (metallic-nonmetallic) material that can pose problems with thermal cutting techniques can also be cut.

### **Output Streams**

The output streams consist of the cut work pieces, small particles of the material being cut,

contaminated carrier gas or liquid and contaminated abrasive materials.

### **Advantages**

The advantages of abrasive jet cutting include (1) a wide application range, (2) the ability to cut fragile, brittle, extremely hard or heat-sensitive material, (3) no predrilling is required to start cutting, (4) cutting may be omnidirectional, (5) minimal or no deburring is required, (6) the process is easily adapted to robot control, (7) minimal tool wear out, other than the orifice, nozzle and wear on the robot mechanism, (8) minimal lateral forces are generated simplifying fixturing, and (9) the part being cut does not heat up.

### **Disadvantages**

The disadvantages of the abrasive jet cutting include (1) low cutting speeds, (2) initial capital costs are high because of the pumps or compressors, and pressure chamber required to propel and direct the water jet, (3) nozzles must be replaced every two to four hours in abrasive jet systems, (4) a collection device must be provided to collect the exhaust liquid from the cutting stream, (5) the material to be cut must be softer than the abrasive used, (6) thin ductile metals tend to suffer bending stress from the abrasive jet and show exit burrs, (7) the abrasive grit wears the carbide nozzles to an out-of-round condition, and the jet loses its symmetry, causing cut quality to deteriorate, and (8) secondary wastes are created by this process that must be disposed of properly.

### **Technology Status**

Available: This technology is used in the nuclear industry.

#### **4.1.12 Cryogenic Cutting**

Cryogenic cutting is also referred to as Zero Added Waste Cutting, Abrading, and Drilling (ZAWCAD). In an effort to reduce, minimize and eliminate the creation of waste, the INEL has developed ZAWCAD technologies that focus on cutting, abrading, drilling, and cleaning processes without generating a secondary waste stream. This technology will be used to:

- X size and reduce a broad spectrum of material types
- X remove surface contamination or coatings for many material types
- X eliminate secondary waste streams inherent in other technologies.

The ZAWCAD technology was first demonstrated in fiscal year 1993 by ejecting 60,000 psi cryogenic nitrogen through a 0.007 inch diameter orifice. The method was later enhanced by combing carbon dioxide snow with the high velocity jet to enhance cutting effectiveness. The components that make up the jet are traveling in excess of 3,000 feet per second. When these components strike a surface or object, the impact forces rip away tiny pieces of the object, which

results in a cutting or abrading process.

The ZAWCAD technology:

- X is similar to abrasive waterjet technologies in appearance and function
- X uses liquid cryogenic nitrogen instead of water
- X uses solidified carbon dioxide particles instead of abrasive powders
- X cuts materials ranging from foods to metals such as stainless steel
- X abrades material surfaces to remove contaminants or coatings such as paint.

### **Input Streams**

Cryogenic cutting sizes a broad spectrum of material types, including foods to metals such as stainless steel.

### **Output Streams**

Sized objects and gases.

### **Advantages**

The ZAWCAD is an environmentally friendly technology because it produces only secondary streams.

- X Nitrogen makes up 78% of the air we breathe.
- X Carbon dioxide is also an atmospheric gas which we produce as we breathe.
- X Atmospheric gasses are used as jet components which are filtered and returned to the atmosphere.

### **Disadvantages**

The technology is not fully refined at this time.

### **Technology Status**

Work continues to make ZAWCAD a more efficient and cost-effective technology. Industrial and university relationships have been established in the areas of control systems, nozzle design, and heat transfer processes. These Cooperative Research and Development Agreements (CRADAs), cost share agreements, and licenses are the mechanisms by which ZAWCAD is becoming available to the common market for use in solving a spectrum of cutting and cleaning problems.

#### **4.1.13 Shears**

Shears are used to cut a variety of materials, including metals (sheets, angle iron, etc.), rubber, plastics, etc. Two blades come together to cut the object(s). Shears can be manually, hydraulically, pneumatically, or electrically driven. They come in various sizes and are typically used at the waste generation source to reduce the size of items that must be transported for treatment.

#### **Input Streams**

The input stream is a thin, large object typically made of metal, plastic, or rubber.

#### **Output Streams**

The output stream is a smaller version of the input stream.

#### **Advantages**

Some advantages are the following:

- X generally inexpensive
- X the process can be started immediately
- X no secondary waste generation
- X can be deployed manually or remotely.

#### **Disadvantages**

The process may require a lot of power to cut objects. Shears require high maintenance to ensure the blades are sharp. This is also not a high precision operation.

#### **Technology Status**

Proven. Shears are routinely used during the pretreatment process of low-level radioactive wastes.

#### **4.1.14 Pipe/Wire Cutters**

Pipe cutters, wire nippers, glass hose, or tubing cutters are used to cut a variety of materials. Typically these cutters are manually operated and work using various mechanical advantages including hinges, ratchets, chains, etc. There are a variety of sizes available and can handle up to a 12 in. pipe. These various cutters are typically used at the waste generation source to reduce the size of the items that must be transported for treatment.

## **Input Streams**

The input stream is a long object such as pipe, hose, chain or wire. The object can be made from numerous materials, but typically LLW will be metals or plastics.

## **Output Streams**

The output stream is typically a smaller version of the input streams.

## **Advantages**

Some advantages are typically the following:

- X inexpensive
- X the process can be initiated immediately
- X no secondary waste generation.

## **Disadvantages**

Some disadvantages are the following:

- X high maintenance to ensure sharp tools
- X not a high-precision operation
- X deforms the object being cut.

## **Technology Status**

Proven. Pipe and wire cutters are routinely used in the pretreatment of low-level radioactive wastes.

## **4.2 Compaction**

The volume reduction technologies discussed in this section are used to reduce the total volume of waste prior to disposal. This is accomplished by applying high pressures to the waste, which reduces void space. The technologies presented, compaction and baling, are both used by the nuclear industry. Specific types of volume reduction processes and their applicability to particular waste types are discussed as follows:<sup>6</sup>

<u>Section</u>	<u>Technology</u>
4.2.1	Compaction

### **4.2.1 Compaction**

Compaction is a mechanical volume reduction process by which waste material is compressed in disposal containers. The process achieves volume reduction by removing void space. Compaction is a well-proven treatment technology.

Compactor systems consist of a press, using horizontal or vertical rams to apply pressure to the waste in a drum or box-type container. Volume reduction achieved during compaction is a function of void space in the waste, the force applied by the press, the bulk density of the material, and its springback characteristics. The volume reduction factors are generally between 3 and 10. Parameters that determine the size and power requirement of a compactor include the throughput, type of waste, size of items to be compressed, disposal container size, and desired volume reduction.

The most common system used in the nuclear industry is the 55 gallon drum compactor, which contains a power unit, a hydraulic or mechanical drive, a platen, a base plate, structural supports, a drum-positioning platform, and a control panel. Waste is loaded into the drum, and the power unit is activated to bring the platen down onto the material in the drum. The platen is then raised, the drum recharged, and the process repeated.

Compactors can be divided into two main categories: low-pressure and high-pressure units. Low-pressure systems typically have ram pressures of around 35 psig, and are used to reduce general combustible and compactible trash. High-pressure compactors (supercompactors) have ram pressures ranging from 5,200 to 11,400 psig, and are capable of volume reduction with both noncombustible and traditionally non-compactible waste. Supercompactors can achieve a 2 to 4 volume reduction factor for non-compactible waste, and a 6 to 7 factor for compactible trash.

The volume reduction achieved by a compactor can be improved by preshredding the waste, using antispringback devices, and increasing the power of the unit (supercompactor).

#### **Input Streams**

Input consists primarily of dry solid wastes, with sufficient void space to achieve a useful volume reduction factor. For low-pressure systems, the typical feedstream consists of clothing, laboratory equipment, paper, and plastics.

#### **Output Streams**

The output is a volume reduced waste, consisting of the input stream pressed into the final disposal container, usually a 55 gallon drum. The compacting process usually generates airborne particulates, that can be removed by a conventional exhaust system using HEPA filters.

## **Advantages**

Advantages of compaction include (1) compaction is a proven process used throughout the world in the nuclear industry, (2) compaction systems are simple, and tend to be reliable and trouble-free, (3) waste compaction is relatively inexpensive, and (4) the process is simple to operate.

## **Disadvantages**

Disadvantages of compaction include (1) most commercial compactor systems are not available with adequate exhaust equipment and must be modified, (2) compactors cannot reduce the hazard of the incoming waste, and are therefore not appropriate for treating waste streams with hazardous constituents, (3) compaction is not recommended for wastes containing free liquids, or with wastes containing explosives, and (4) compaction should not be used on dense or bulky items where minimum volume reduction would be achieved.

## **Technology Status**

Proven: Compaction and supercompaction has been used throughout the world in both nuclear and nonnuclear industries.

## **4.3 Filtration**

Filtration is defined as the separation of suspended, undissolved, particulate solids from a fluid mixture by passage of most of the fluid through a permeable medium that retains the solids on or within itself. The mixture to be separated is called the feed, feed slurry, free slurry, influent, or prefiltrate. The solids to be separated are sometimes termed contaminant, crud, dirt, or suspended solids. The fluid that passes through the permeable medium is called the effluent or filtrate. When separated solids accumulate in amounts that visibly cover the medium, they are called the filter cake. In order to obtain fluid flow through the filter medium, a pressure drop must be applied across the medium. The fluid will continue to flow through the filter until the flow drops excessively or until the maximum pressure drop ( $\Delta P$ ) across the medium is reached due to plugging of the filter medium. Depending upon the filter type, this maximum  $\Delta P$  varies from 15 to 100 psi. Filters selected for radwaste service should be capable of producing an effluent concentration of less than 1 ppm insolubles.<sup>6</sup>

A filter is the assemblage of equipment that provides (1) housing for the filter medium, (2) room for cake accumulation (if needed), (3) holdup space for the feed and filtrate, (4) drainage channels for the filtrate, (5) means for the supply and removal of appropriate streams, and (6) control devices and instruments.

Specific types of filtration processes and their applicability to particular waste types are discussed as follows:

<u>Section</u>	<u>Technology</u>
4.3.1	Disposable Filters
4.3.2	Reusable Filters
4.3.3	Electrodialysis
4.3.4	Ultrafiltration
4.3.5	Granular Bed Filtration

### **4.3.1 Disposable Filters**

Disposable cartridge filters contain from one to several replaceable elements that are discarded when they become contaminated or loaded to the extent that the differential pressure across the filter reaches a preset value. In the nuclear industry, multiple elements are often mounted in a single removable supporting structure and, to minimize radiation exposure, the entire assembly is discarded at changeout. Disposable elements used in nuclear power plants typically have filter media of woven fabric, wound fiber (string), or pleated paper, supported on a rigid inner core of perforated stainless steel. For this type of element, the liquid flow is from outside to inside. Also, pleated or matted paper elements are available that are externally supported by a stainless steel basket to accommodate fluid flow from the inside to the outside of the element. In this case, the solids that are removed can be contained within the supporting basket should the cake be sloughed off due to interruption of flow.

Two generic types of disposable filters currently in use at nuclear facilities are cartridge filters and bag type filters. Disposable filters are best suited for the removal of gross contamination from low-pressure, low-temperature systems. Disposable filters range in filtration capability from 10  $\mu\text{m}$  to several hundred microns. Such fine particles often produce an impermeable cake with unusually high resistance for a small thickness. Therefore, the maximum cake thickness typically is approximately 0.125 in. (0.318 cm) due to the  $\Delta P$  considerations. Consequently, cartridge filtration is used primarily to clarify low-solids containing fluids to an optically clear condition, or to a much lower level of contamination measurable by microscopic or automatic particle-counting techniques, or to a sterile stage by quantitatively removing all bacteria. Disposable filters are limited to fluids containing no more than 0.01% solids, and where cake handling is unnecessary.

#### **4.3.1.1 Cartridge Filters**

Cartridge filters usually consist of a fiber yarn wound around a perforated-metal core. Depending upon the application, the fibers commonly used are resin-impregnated wool or cellulose, cotton-viscose, polypropylene, nylon, or glass. Cartridge filters are constructed so the entire flow stream is directed through the filter. For high temperature and pressure applications, porous-metal cartridges made of 316 stainless steel, inconel, monel, or nickel are used. The advantages and

disadvantages of typical disposable cartridge filters are listed in Table 4-1 below.

**Table 4-1. Typical Disposal Cartridge Filters.**

Filter Type	Advantages	Disadvantages
<b>Wound Cartridge</b>	X Compact X Low solid waste volume X No backflush gas or liquid to treat X Good solids removal	X Remote or automatic changeout difficult because of nonuniformity and poor arrangement X Changeout frequently done on radiation level rather than pressure drop X Media migration may occur
<b>Pleated-Paper</b>	X Compact X Low solid waste volume X No backflush gas or liquid to treat X Good solids removal	X Remote or automatic changeout difficult because of nonuniformity and poor arrangement X Changeout frequently done on radiation level rather than pressure drop X Media migration may occur
<b>Pleated-Wire Screen</b>	X Can operate at elevated temperatures X Good solids removal X Little or no media migration	X Fair mechanical strength when adequately supported X Plugging may cause uneven flow and non uniform cake buildup

### Input Streams

Input streams consist of liquids or gases containing no more than 0.01% solids. Cartridge filters are not recommended for processing streams that require cake handling.

### Output Streams

Output streams consist of a liquid or gas with a particle size of 10 µm and smaller particles and the used filters themselves with their filtered particulates.

### Advantages

Some general advantages of disposable cartridge filters include (1) compact, (2) low solid waste volume, (3) require no backflush gas or liquid, (4) have good solids removal, (5) can operate at elevated temperatures, (6) little or no media migration, and (7) rapid changeout.

### Disadvantages

Some general disadvantages of disposable cartridge filters include (1) a higher operating cost than reusable filters, (2) remote or automatic changeout is difficult, and (3) cannot be used in a high solids environment.

### Technology Status

Proven: Disposable filters are a proven technology that have been used in radioactive waste treatment systems.

### **4.3.1.2 Bag-Type Filters**

Bag filters may consist of fiber-mesh bags typically made from nylon, polypropylene, rayon, nomex teflon wool-silk or wool-cotton. Nominal minimum particle size retention is 15  $\mu\text{m}$ . These filters perform exceptionally well and can be changed out in a few minutes.

#### **Input Streams**

Input streams consist of liquids or gases containing no more than 0.01% solids. Bag-type filters are not recommended for processing streams that require cake handling.

#### **Output Streams**

Output streams consist of a liquid or gas with a particle size of 15  $\mu\text{m}$  and smaller particles, and the used filters themselves with their filtered particulates.

#### **Advantages**

Bag filters have the advantages of (1) rapid changeout, (2) broad chemical stability with proper choice of synthetic fibers, (3) especially suitable for straining slurries or dispersions, (4) good roughing filter, and (5) require no backflush gas or liquid.

#### **Disadvantages**

Bag filters have the disadvantages of (1) manual changeout has limited use to treating low-activity streams at low temperature and pressure, (2) remote or automatic changeout is difficult, (3) cannot be used in a high solids environment, and (4) a higher operating cost than reusable filters.

#### **Technology Status**

Proven: Bag filters have been used in radioactive waste treatment systems.

### **4.3.2 Reusable Filters**

Reusable filters are cleaned by backflushing when they become contaminated or loaded to the extent that the differential pressure across the filter reaches a preset value. This is accomplished by a reversed-flow blast of gas followed by a liquid rinse through the filter. The filter cake is pushed from the filter as a sludge. After backflushing, the filters are reused. The reusable filters are classified as filters that do not require a precoat and filters that require a precoat. Each type of filter is discussed below.

### 4.3.2.1 Reusable Filters Without Precoat

Several types of backflushable filters do not require precoats. Among these are porous-metallic filters, porous-ceramic filters, and stacked etched-disk filters. A description of the advantages and disadvantages of these filters are discussed in Table 4-2.

**Table 4-2.** Typical Reusable Filters that do not Require a Precoat.<sup>6</sup>

Filter Type	Cleaning Method	Removal Efficiency	Advantages	Disadvantages
<b>Porous-Metallic Filters:</b> Consists of woven wire or sintered metal	Backflushed with cleaning agents	Best suited for filtration of large size particles. Can be used to remove particles in the 5 to 10 $\mu\text{m}$ range	X Fair mechanical strength X May be used at temperature up to 1000 $^{\circ}\text{F}$	X Backflushing of fine particles can be difficult X Eventual permanent plugging may force replacement X Filter life unknown or limited X Harsh cleaning agents can cause corrosion
<b>Porous-Ceramic Filter:</b>	Backflushed with cleaning agents	Will remove 98% of particles >25 $\mu\text{m}$ or 95% of particles >7 $\mu\text{m}$	X Fair mechanical strength X Resistant to attack by cleaning solutions X May be used at temperatures in the range of 1000 to 2000 $^{\circ}\text{F}$	X Eventual permanent plugging may force replacement X Filter life unknown or limited
<b>Stacked Etched-Disk Filter:</b> Vertically mounted, closed pressure vessel containing filter elements composed of stacks of chemically-etched, mechanically-compressed, stainless steel disks	Backflushed (when ) P reaches 75 psi or high turbidity observed) by a burst of air (350 psi) followed by water	Will remove 100% of 5 $\mu\text{m}$ particles	X Short backflush time with thorough cleaning (about 3 to 8% of the time required for a pressure tube filter) X Expected to last for plant life X Amenable to automatic and/or remote operation X Low solid waste volume X Compact X High mechanical strength X Precoating can be used for specific jobs such as oil or color removal	X Low crud-holding capability X Corrosion characteristics unknown X Backwash waste to treat X Low oil-holding capacity X Backflushing required more frequently than for other types of precoated filters because of lower solids-holding capacity

### Input Streams

Input streams consist of liquid, sludge, slurry, or gas containing a solids content greater than 0.01%. These filters can be used for processing streams that require cake handling.

## **Output Streams**

Output streams consist of a liquid or gas with a particle size of 25  $\mu\text{m}$  and smaller, separated particulates along with the gases and liquids used for backflushing.

## **Advantages**

Reusable filters that do not require a precoat have the advantages of (1) lower solid waste generation than reusable filters that require a precoat, (2) lower operating cost than disposable filters, and (3) can handle fluids containing a higher solids content than the disposable filters.

## **Disadvantages**

Reusable filters that do not require a precoat have the disadvantages of (1) does not remove particles below 5  $\mu\text{m}$  as well as reusable filters that use precoat materials, (2) limited ability to remove oils, and (3) filter life is limited.

## **Technology Status**

Proven: Reusable filters have been used in radioactive waste treatment systems.

### **4.3.2.2 Reusable Filters With Precoat**

During normal operation, precoat filters will remove particles down to 1  $\Phi\text{m}$  in diameter. The two basic types of reusable filters with precoat, based on the discharge from the filter, are (1) the widely used tubular-support, pressure-precoat filter which discharges slurries, and (2) the flat-bed, clamshell, and centrifugal-discharge filters that produce cake products. The advantages and disadvantages of typical reusable filters that require a precoat are discussed in Table 4-3.

Reusable filters are precoated by first circulating a 5 to 10% dilute slurry of precoat material through the support mesh or septum. The precoat material particles bridge the small dimensions of the mesh openings and build a coating on the support element. The precoat is held in place by

the water pressure. When the recirculating fluid appears clear, the precoat material has been coated on the filter element and the filter is ready for service. About 0.03lb/ft<sup>3</sup> (0.5 kg/m<sup>3</sup>) of precoat is applied to the filter surface. The filter is kept in service until the pressure drop indicates the filter medium is becoming plugged. When this occurs, the buildup material is removed, and the filter is precoated again.

Precoat materials used in waste treatment are (1) diatomaceous earth (light friable, natural siliceous material composed of diatom skeletons), (2) Solka-Floc (cellulosic fiber), (3) perlite (volcanic glass with a concentric shelly structure), (4) asbestos (fibrous mineral that is chemically resistant), and (5) powdered resins (fine powdered resin made by crushing anionic, cationic, or

**Table 4-3.** Typical Reusable Filters that Require a Precoat.<sup>6</sup>

Filter Type	Precoat	Removal Efficiency	Advantages	Disadvantages
<b>Pressure-Tube Filter:</b> consists of a bundle of as many as several hundred perforated or porous vertical tubes	Diatomaceous earth or cellulose and powdered resin		<ul style="list-style-type: none"> <li>X Amenable to automatic and/or remote operation</li> <li>X Powdered resin and/or diatomaceous earth precoat can be used</li> <li>X Relatively compact</li> </ul>	<ul style="list-style-type: none"> <li>X Precoat loss upon loss of flow or fluctuation in pressure</li> <li>X Excess or uneven cake can cause strain and possible collapse of supporting screen</li> <li>X Incomplete backflushing causes uneven precoat</li> </ul>
<b>Centrifugal-Discharge Filter:</b> consists of wire-mesh screens mounted on horizontal leaves attached to an axially mounted hollow vertical shaft	Precoated using the standard method	Will remove 98 to 99% of all particles in the 1 to 5 $\mu\text{m}$ range	<ul style="list-style-type: none"> <li>X High solids-holding capacity</li> <li>X Can handle automatically and remotely all plant wastes with same filter</li> <li>X Low maintenance requirements</li> <li>X No precoat loss caused by loss of flow, pressure, or power</li> </ul>	<ul style="list-style-type: none"> <li>X Relatively high headroom</li> <li>X Cake overloading can cause distortion</li> <li>X Generates large sludge volume</li> <li>X Some cake difficulty with Solka-Floc or resins alone</li> </ul>
<b>Flatbed:</b> consists of horizontal traveling permanent-screen (belt)	Diatomaceous earth	Will remove over 95% of particles greater than 1 $\mu\text{m}$	<ul style="list-style-type: none"> <li>X High crud-holding capacity</li> <li>X Can handle automatically and remotely all plant wastes with same filter</li> <li>X No precoat loss caused by loss of flow, pressure, or power</li> </ul>	<ul style="list-style-type: none"> <li>X Relatively large floor space and high headroom</li> <li>X Cake overloading can cause belt wear</li> <li>X Generates large sludge volume</li> <li>X Some cake difficulty with resin alone</li> <li>X May require fairly high belt maintenance</li> </ul>
<b>Clamshell</b>	Diatomaceous earth	Will remove over 95% of particles greater than 1 $\mu\text{m}$	<ul style="list-style-type: none"> <li>X High crud-holding capacity</li> <li>X Can handle automatically and remotely all types of plant waste</li> <li>X Can be fully automated based on precoat time, maximum ) P, or cake depth</li> <li>X No precoat loss caused by loss of flow, pressure, or power</li> <li>X Relatively small floor space</li> </ul>	<ul style="list-style-type: none"> <li>X Relatively high headroom, generates large sludge volume</li> <li>X Maintenance requirements unknown</li> <li>X No nuclear operation data to date</li> <li>X Will remove limited amounts of oil from liquid waste</li> </ul>

mixed ion exchange resin). Precoat filters that use powdered resin have both filtration and ion-exchange capabilities. Powdered resin requires a fine mesh as a substrate. When the filter element mesh is unsuitable for powdered resin, a coating of diatomaceous earth or Solka-Floc is applied first, and a coat of powdered resin is placed over this substance. Powdered resin can be readily processed when backwashed from the filter.

### Input Stream

Input streams consist of liquid, sludge, slurry, or gas containing a solids content greater than 0.01%. These filters can be used for processing streams that require cake handling.

### Output Streams

Output streams consist of a liquid or gas with 1  $\mu\text{m}$  and smaller particles, and separated particulates along with the gases and liquids used for backflushing.

## **Advantages**

The advantages of reusable precoat filters include (1) the filtration can be automatic or remote operation, (2) precoat filters can handle a solution with a higher solids loading than disposables, (3) powdered resin can be used as a precoat medium to give both filter and ion exchange capabilities, and (4) precoat filters can remove particles down to 1  $\mu\text{m}$ .

## **Disadvantages**

The disadvantages of reusable precoat filters include (1) precoat filters produce the largest volumes of sludge, (2) precoat filters have higher operating costs than reusable filters that do not require precoating, and (3) precoat filters require a longer downtime in order to backwash, and recoat the filter media.

## **Technology Status**

Proven: Reusable precoat filters have been used in radioactive waste treatment systems.

### **4.3.3 Electrodialysis**

Electrodialysis concentrates, separates, or removes ionic species contained in a water solution. A simplified electrodialysis cell consists of an anode and a cathode separated by an anion permeable membrane adjacent to the anode, and a cation permeable membrane adjacent to the cathode. Channels are available for water flow on either side of each membrane. The water to be treated flows through the channel between the two membranes, and electrode rinse water flows in the channels containing the electrodes. A direct current electrical charge is applied across the electrodes. The positively charged ions are drawn through the cation permeable membrane to the cathode. The negatively charged ions are drawn through the anion permeable membrane to the anode. As a result, both positive and negative ion concentrations are significantly reduced in the intermediate channel containing the treated effluent.

Electrodialysis systems are generally stacks of many compartments between two electrodes, separated by alternating cation and anion permeable membranes. The process water flows through all compartments. The electric field is induced through all compartments in the stack by the two electrodes. In the electric field, ions will migrate to the appropriate electrode until they are halted by a membrane that is permeable only to the opposite charge. This way, every other flow channel becomes ion-depleted, and the adjacent channels become ion-enriched. Both positive and negative ions are concentrated in the ion-enriched compartments.

Each pass through a cell results in 30 to 60% deionization of the input ion concentration in one portion of the input stream, and equivalent increases in the other portion. The ion-depleted stream can be up to 90% of the input stream. Passing the wastewater through several stacks in series reduces the ion concentration in the depleted stream to about 10% of the input level. The

ion-enriched stream may contain ions in concentration levels of up to 20% or more. This stream may be recoverable, recyclable, or may require further treatment prior to disposal because of concentrated amounts of the target contaminants.

The most critical components in electrodialysis are the ion-selective membranes. These are thin sheets of ion-exchange resin reinforced by a synthetic fiber backing. The membranes are kept apart by plastic mesh or other types of screens to maintain compartment thicknesses to about 1 mm. This reduces ohmic loss.

In order to reduce membrane fouling, most new electrodialysis systems use reversible electrodialysis. By reversing the polarity in the cells, ionic flow in the concentrating and depleting cells is reversed. Fouling, precipitates, and surface films tend to either redissolve or are physically dislodged. Reversible electrodialysis is possible using membranes that can operate in either anion or cation selective modes and using platinum-coated titanium electrodes.

Electrodialysis is most suitable for acidic streams containing a single principal metal ion, but can also be used for treating some streams with pH of up to 14. Elevated temperatures can reduce power consumption. The process can remove heavy metals or some organics from groundwater.

Pretreatment of the wastewater is often necessary to prevent fouling of the membranes. Pretreatment may include removing suspended solids, oxidizing materials, and ferrous or manganous ions. Because the separations are imperfect and the pretreatment is complex, complications may arise. The pH may need to be adjusted to acidify the catholyte stream.

### **Input Streams**

The input stream consists of a water stream containing undesirable inorganic or organic ions, such as heavy metal salts.

### **Output Streams**

The output streams include (1) an ion-depleted and ion-enriched water streams, (2) an ion-depleted stream that is often much larger than the ion-enriched stream, (3) gaseous hydrogen and oxygen that may evolve from the electrodes, and (4) discarded membranes from periodic replacement to maintain process efficiency.

### **Advantages**

The advantages of electrodialysis include (1) electrodialysis cells can operate at nominal pressures and temperatures, (2) the ion-enriched stream can be concentrated to salt levels of 20% or more, which is higher than available from other processes such as reverse osmosis, and (3) when the wastewater is sufficiently pretreated and the membranes are cleaned regularly, they can operate for five years.

## Disadvantages

The disadvantages of electrodialysis include (1) suspended solids or high organic levels can clog or foul the membranes, (2) oxidizing materials and ferrous or manganese ions of concentrations greater than 0.3 ppm (0.3 mg/L) can damage the membrane, (3) at alkaline pH readings, membrane life may diminish, (4) calcium concentrations above 400 ppm (400 mg/L) can cause precipitation of calcium sulfate scale, (5) during operation, off-gases including highly reactive hydrogen and oxygen streams must be monitored and handled safely, (6) the membrane performance must be closely monitored due to a decrease in efficiency and (7) the capital equipment required to remove 250 ppm (250 mg/L) salt from a 500 ppm (500 mg/L) stream is comparable to removing 2500 ppm (2500 mg/L) from a 5000 ppm (5000 mg/L) stream due to a decrease in efficiency resulting from a lower electrolyte conductivity in the purified water stream.

## Technology Status

Available: Electrodialysis is used in several industries, including salt removal from brine and demineralization of brackish waters. Newer applications are or have been developed for electrodialysis in the food and pharmaceutical industry because this relatively gentle separation does not damage or thermally decompose the products. Dilute radioactive wastewater has been treated using granular ion-exchange resins that are continuously regenerated by the electric current. New developments in membrane technology are increasing the utility of electrodialysis, but the treatment of mixed wastes still requires further development.

### 4.3.4 Ultrafiltration

The process of ultrafiltration is related to reverse osmosis in that contaminated water is forced through a membrane under pressure. However, the ultrafiltration membrane is considerably more porous than the reverse osmosis membrane. As a result, most soluble species, including inorganic salts, pass through the membrane with the water. Colloids, suspended solids, and high-molecular-weight organic molecules do not pass through the membrane with the water. The porous nature of the ultrafiltration membrane allows the process to be operated with high fluxes at relatively low pressures (25 to 200 psig). This is possible because the osmotic pressure of colloids and high-molecular-weight organics are extremely low. The degree and quantity of the separation are a result of (1) the pore size of the membrane, and (2) the molecular structure, size, shape, and flexibility of the colloids and organic molecules. Pore sizes range from 0.001 to 0.01  $\mu\text{m}$  that allow separation from solution of molecules with a molecular weight between 500 and 300,000.

Ultrafiltration can be used to selectively remove dissolved metal ions from dilute aqueous solutions. A high molecular weight chelating agent is added to the incoming waste solution to form macromolecular complexes. The solution is then processed through an ultrafiltration membrane system that collects the macromolecular complexes (retentate) on the membrane but allows uncomplexed ions such as sodium, potassium, calcium, chloride, sulfate, and nitrate to pass through as filtered water (permeate).

The basic components of an ultrafiltration unit are membrane elements, a membrane support structure, a containing vessel, feed and collection tanks, a pump, and instrumentation. A system to periodically clean the membranes will also be required and consists of a cleaning solution tank, pump, and receiving tank for the cleaning waste stream.

Membranes are assembled into modules for use in a treatment system. The modules come in several forms: (1) tubular, with inner diameters greater than 10 mm, (2) hollow fiber, with inner diameters less than 1.3 mm, (3) spiral wound, and (4) plate and frame. Each type has advantages and disadvantages in processing efficiency, equipment size, operating temperatures, chemical resistance, and water pretreatment requirements.

Some advantages and disadvantages of the different treatment systems types are listed in Table 4-4.

**Table 4-4.** Advantages and Disadvantages of Ultrafiltration Modules.<sup>6</sup>

Module Type	Advantages	Disadvantages
Tubular	<ul style="list-style-type: none"> <li>X Easiest type to clean chemically or mechanically if membranes become fouled</li> <li>X Can process high-suspended-solids feed with minimal pretreatment</li> <li>X Good hydrodynamic control</li> <li>X Individual tubes can be replaced</li> <li>X High Pressure (1500 psig) equipment available</li> </ul>	<ul style="list-style-type: none"> <li>X Relative high volume required per unit membrane area</li> <li>X Relatively expensive</li> </ul>
Spiral Wound	<ul style="list-style-type: none"> <li>X Compact</li> <li>X Excellent membrane surface/volume ratio</li> <li>X Less expensive than tubular and hollow fiber modules</li> </ul>	<ul style="list-style-type: none"> <li>X Susceptible to plugging by particulates</li> <li>X Badly fouled membranes are difficult to clean– basically limited to chemical cleaning</li> </ul>
Hollow Fiber	<ul style="list-style-type: none"> <li>X Compact</li> <li>X Good membrane surface/volume ratio</li> <li>X Economical</li> </ul>	<ul style="list-style-type: none"> <li>X Susceptible to plugging by particulates</li> <li>X Badly fouled membrane modules are hard to clean–limited to chemical and mechanical methods</li> </ul>
Plate and Frame	<ul style="list-style-type: none"> <li>X Good membrane surface/volume ratio</li> <li>X Well-developed equipment</li> </ul>	<ul style="list-style-type: none"> <li>X Susceptible to plugging at flow-stagnation points</li> <li>X Potentially difficult to clean</li> <li>X Expensive</li> </ul>

The most commonly used membrane materials are cellulose acetate, aromatic polyamides, and thin film composites. The process limitations of each material are listed below.

<u>Membrane Material</u>	<u>pH Limits</u>	<u>Temperature Limits EF (EC)</u>	<u>Other Limitations</u>
Cellulose acetate	2.5-7	32-122 (0-50)	Biologically degradable
Aromatic polyamides	4-11	32-115 (0-46)	Cannot tolerate chlorine
Thin-film composites	<1-13	32-175 (0-79)	Can tolerate moderate chlorine levels (100 ppm)

The process produces a concentrated waste stream (comprising less than 5% of the influent volume) that requires treatment or disposal. A cleaning cycle must be included and the membrane should never be allowed to dry out when in contact with the feed material. After the run cycle,

### **Output Stream**

The output streams from the process include (1) a permeate (usually water) stream containing dissolved salts and low-molecular-weight organic molecules, (2) a concentrated waste stream that approximates 5% of the influent stream volume (may be as high as 70% solids), (3) solutions from cleaning the membranes, and (4) discarded membranes from periodic replacement to maintain process efficiency.

### **Advantages**

The advantages of ultrafiltration include (1) ultrafiltration can selectively remove dissolved metal ions from dilute aqueous solutions, (2) ultrafiltration can be easily integrated with other processes, (3) filtered water can be recycled or discharged, (4) ultrafiltration has high removal efficiencies (approaching 100%), (5) separation process does not require an energy-intensive phase change such as is required for distillation or evaporation, (6) capital costs are relatively low, (7) equipment does not require a large amount of space, and (8) membranes can be selected for separation of different molecular sizes.

### **Disadvantages**

The disadvantages of ultrafiltration include (1) the membrane systems require a liquid that has a low-level of particulate contamination, (2) many membranes are susceptible to chemical attack by materials dissolved in the water being treated, (3) the retentate must be treated further, and (4) little or no removal occurs of dissolved ionized solids and dissolved ionized gases.

### **Technology Status**

Proven: Ultrafiltration has been used in radioactive waste treatment.

### **4.3.5 Granular Bed Filtration**

For relatively large volume flows, granulated media such as sand, garnet, or anthracite coal are used singly or in combination to trap suspended solids within the pore spaces of the media. The granular bed particles are contained within a basin and supported by an underdrain system that allows the filtered liquid to be drawn off while still retaining the filter media. The wastewater is either gravity-fed or pumped through the granular bed media and filtered until either the flow drops excessively or the pumping pressure becomes too high because of plugging of the granular filter media. Granular media filters are usually cleaned by backwashing with previously filtered water in an upflow manner to expand the bed, loosen the media granules, and resuspend the

entrapped filtered solids. The backwash water, which is 1 to 5% of the filtered wastewater volume (may be as much as 10% of the filtered wastewater volume), is then returned to the head of the wastewater treatment system so the filtered solids in the backwash water can be settled out of solution and the water refiltered prior to discharge.

To achieve continuous operation with granular bed filters operated in a batch mode as described above, two filters must be installed in parallel, so that one can be backwashed while the other is operating. Dual and multimedia filter arrangements allow high flow rates and efficiencies.

### **Input Stream**

Input is a high volume of liquid waste containing suspended solids.

### **Output Stream**

Output is filtered liquid waste and a slurry of the filtered particles suspended in the backwash liquid.

### **Advantages**

The advantages of granular bed filtration include (1) economical in treating wastes containing less than 100 to 200 ppm (100 to 200 mg/L) suspended solids, (2) reliable and effective for removing low-levels of solids from wastes, (3) simple, readily available equipment, (4) easy to operate and control, (5) easily integrated with other processes, (6) small space requirements, (7) available in mobile or on-site systems, and (8) well developed, widely used process.

### **Disadvantages**

The disadvantages of granular bed filtration include (1) the bed must be backflushed to prevent plugging, (2) the backwash requires further treatment, (3) effluent quality is sensitive to large flow variations, (4) it is marginally effective in treating colloidal-size particles, and (5) pilot plant studies should be conducted to determine optimum size, bed depth, flow velocity, and combination of filter material.

### **Technology Status**

Proven: Granular bed filtration has been used in radioactive waste treatment systems. The operation of a sand filter in one nuclear plant was deemed unsatisfactory because the continuous addition of polyelectrolyte to the feed stream was required for efficient performance.

## 4.4 Decontamination

Decontamination is the removal of radioactive contamination deposited at or near the surface of equipment, supplies, tools, hardware, or other solids. The process will normally not completely remove all contamination. However, it can reduce the radiological hazards and result in reclassification of the waste to a lower level. On the other hand, the process creates a secondary waste stream containing the removed contaminants.<sup>6</sup>

Decontamination techniques can be broadly classified as either mechanical or chemical techniques. In practice, the two types of processes are usually either combined or performed sequentially so that the categorical separation is somewhat arbitrary. The two categories of decontamination processes and their applicability to particular waste types are discussed as follows:

<u>Section</u>	<u>Technology</u>
4.4.1	Mechanical Decontamination
4.4.2	Chemical Decontamination

### 4.4.1 Mechanical Decontamination

Mechanical decontamination methods are based on physically dislodging the surface contamination. A variety of methods are available including wiping/scrubbing, grinding/machining, media blasting, high pressure water or steam jets, vacuum cleaning, ultrasonic cleaning, and vibratory finishing. Wiping and scrubbing are labor intensive, involving manual cleaning with cloths or pads. Abrasive media can be used with the wipes, the abrasiveness varied depending on the type of surface and deposit involved. Mechanical decontamination can be combined with chemical decontamination when various chemical agents are added to react with and loosen the deposits and/or improve the ability of the wipes to retain the loosened material. Grinding and machining are essentially mechanically assisted variations of the manual wiping/scrubbing process.

Cleaning with water can be accomplished by simply flushing a surface if the deposits are easily dislodged. If more aggressive deposit removal is required, jets of high pressure water or steam can be employed, as well as detergents or cleansers. Equipment requirements for high pressure applications include a supply of water or steam, a pump, hose, and nozzle for delivery, and handling tools, as appropriate, for positioning the nozzle.

Media blasting is based on the use of solid particles suspended in a fluid that is sprayed at high pressure to abrasively dislodge the contamination from the surface. Various media can be used depending on the abrasiveness required. These media include minerals such as sand or garnet, solid carbon dioxide, glass beads, plastic beads, ground nut shells, and wheat starch. Equipment requirements for media blasting are similar to those for water jets.

The vacuum cleaning process is suitable for removing loose or easily removed particulate contamination by drawing the particulate into a vacuum system. Equipment requirements include a source of vacuum, hoses, nozzles, brushes, and a filtration system to collect the removed particulate.

The basis of ultrasonic cleaning is the immersion of the items to be decontaminated into a liquid bath that is ultrasonically excited. The excitation causes the liquid to cavitate at the interface with the solid surface. Water is usually used in the ultrasonic bath, and chemicals can be added to assist in softening or solubilizing the contamination. The equipment required is an immersion tank and the associated system necessary to induce the desired level of ultrasonic excitation.

### **Input Streams**

Input streams for mechanical decontamination consist of surface contaminated solid materials.

### **Output Streams**

Output streams vary based on the decontamination method used. A list of typical mechanical decontamination processes with their associated output streams are listed below.

<b>Process</b>		<b>Output Streams</b>
Water cleaning	X	Solids with reduced surface contamination
	X	Contaminated water
Media blasting	X	Solids with reduced surface contamination
	X	Contaminated abrasive sludge or slurry
Vacuum cleaning	X	Solids with reduced surface contamination
	X	Contaminated particulates
Ultrasonic cleaning	X	Solids with reduced surface contamination
	X	Contaminated liquids used in the ultrasonic cleaning bath
Vibratory finishing	X	Solids with reduced surface contamination
	X	Contaminated abrasive media

## **Advantages**

The advantages of mechanical decontamination include (1) mechanical decontamination is well developed, (2) it can result in reclassification of large waste items, making them much easier and cheaper to dispose, (3) many processes create either a relatively small waste stream, or a waste stream that can be further processed such that the overall result is a smaller waste stream, (4) with some methods, the waste wash can be regenerated and reused, and (5) the various blasting techniques are well suited for use on large, complex surfaces.

## **Disadvantages**

The disadvantages of mechanical decontamination include (1) limited to surface and near-surface deposits, (2) surface contamination on internal surfaces is usually more difficult to remove than external surface contamination, (3) the secondary waste streams must be treated, (4) water flushing, steam cleaning, and media blasting can generate large volumes of waste, and can also cause significant splashing and spread of contamination if not controlled carefully, (5) the scrubbing and wiping techniques are labor intensive and are less applicable to large work pieces, and (6) vacuuming is effective for only loose contamination.

## **Technology Status**

Proven: All techniques are well developed and have been used with radioactive wastes.

### **4.4.2 Chemical Decontamination**

Chemical decontamination includes methods that use chemical agents to loosen or solubilize the surface contamination. Contact may be achieved either by immersion of the work piece in a chemical bath or by surface application of the agent as a liquid, foam, gel, or paste. Chemical agents that are most commonly used include aqueous solutions of mineral or organic acids, chelating agents, or detergents used separately or in various combinations. Chemical decontamination is often done in conjunction with some form of mechanical process such as wiping/scrubbing, grinding, or ultrasonic cleaning. In particular, flushing the surface with water after chemical application is a chemical process enhanced by the effect of a flowing liquid.

For chemical decontamination by immersion, the equipment required includes a tank, pump, and agitator. The system can be modified to include the appropriate electrochemical equipment to assist the process by enhancing appropriate oxidation/reduction reactions. For surface application, the equipment includes a reservoir for the chemical agent, a pump, hose, and nozzles. Since the surface-applied chemicals are usually removed by flushing with water, additional equipment includes a source of water and water delivery system.

## **Input Streams**

Input streams for chemical decontamination consist of the surface contaminated solid materials.

## **Output Streams**

Output streams include the treated solids with reduced surface contamination and contaminated chemical cleaning and rinse solutions.

## **Advantages**

The advantages of chemical decontamination include (1) it can result in reclassification of large waste items, making them much easier and cheaper to dispose, (2) the waste wash can be regenerated and reused, and (3) immersion in chemical baths generates low volumes of waste.

## **Disadvantages**

The disadvantages of chemical decontamination include (1) limited to surface and near-surface deposits, (2) surface contamination on internal surfaces is usually more difficult to remove than external surface contamination, (3) the secondary waste streams must be treated, and (4) water flushing can generate large volumes of waste, and can also cause significant splashing and spread of contamination if not controlled carefully.

## **Technology Status**

Proven: All techniques are well developed and have been used with radioactive wastes.

## **4.5 Evaporation**

Evaporation is the physical conversion of a material from a liquid to a gaseous state. Evaporation is commonly used in industrial operations and hazardous waste treatment. Usually evaporation is used to remove some or most of a solvent from a mixture of dissolved solutes and suspended solids. The solution to be treated may be either a liquid or a slurry mixture and may contain low to high levels of dissolved materials and suspended solids. During the evaporation process, the concentration of some solutes may exceed their solubility. Crystallization of these solutes will occur in the saturated mixture, resulting in increased suspended solids. Drying is the complete removal of the solvent to form a solid material from the liquid stream.<sup>6</sup>

Output streams from evaporation are a relatively pure solvent stream and a more concentrated mixture of dissolved materials in a smaller volume of solvent. The volume of the concentrated output stream is smaller than the input stream. The solvent must be much more volatile than the solutes, otherwise, the vaporized stream of solvent will also contain significant levels of solutes.

If the solutes are not significantly less volatile than the solvent, then distillation is required to achieve high purity separation.

Evaporation is most commonly used to vaporize water from aqueous solutions or slurries. This process is widely used in the nuclear industry to reduce the volume of liquid radioactive waste and achieve good decontamination of the evaporated water stream. Most hazardous and radioactive contamination resides in the concentrated stream. The concentrated output stream is easier to dispose of than the untreated waste stream, because it is lower in volume. Volume reduction factors for the concentrated output stream typically range from 100 to 500. Decontamination factors of the vapor stream range from  $10^4$  to  $10^6$ , depending on the waste stream composition, evaporator design, and operation. Some radionuclides with higher volatilities, which are more difficult to separate from the evaporated water stream, include iodine, boron, and tritium. These more volatile radionuclides may have decontamination factors of 100.

In order to improve disentrainment of liquid and improve decontamination factors, many evaporators are equipped with vapor-liquid separation devices at the vapor outlet. These devices can include disengagement chambers, columns, beds of packing material, cyclones, baffles, and demisters.

Several limitations exist for evaporation processes, especially in the nuclear industry. These limitations include relatively high operating costs due to (1) energy intensive operation and (2) operational and maintenance problems. Although evaporation is a simple process, common problems can include corrosion, salting, scaling, fouling, entrainment, and foaming. Since most liquid feedstreams contain constituents that will cause at least one of these problems, pretreatment is often required before evaporation. These problems can also be mitigated by proper evaporator design, operation, and construction materials.

Corrosion in evaporation processes can be much more severe than in many other processes. Corrosion can occur due to high temperatures, high velocities (which cause erosion corrosion), vapor-liquid concentration gradients, suspended solids (erosion corrosion), feedstream chemical composition, and pH. Measures used to minimize corrosion include filtration and addition of chemical inhibitors and pH buffers. Construction materials compatible with some corrosive streams include stainless steels, titanium, and heat treated, finished or clad metals. Operational remedies to limit corrosion can include lower fluid velocities and operation under a vacuum to reduce evaporation temperatures.

Scaling occurs when suspended solids or precipitates deposit on evaporator and piping internal surfaces. Scale deposits reduce heat transfer and can increase corrosion. Hard scale compounds include sulfates and silicates of calcium and magnesium. Carbonates and hydroxides of calcium and magnesium form soft scale. Measures to limit scale formation include addition of crystal seeds as nuclei for precipitation to occur. Forced circulation and additives also reduce scale formation. Scale removal can be expensive and labor intensive, and the maintenance requires facility outages. Scale may be removed by mechanical or chemical means.

Most radioactive liquid wastes tend to foam. Foaming is caused by the presence of detergents, high pH levels, suspended matter, salt levels, or other conditions such as temperature gradients that cause viscosity and surface tension variations. The agitation and boiling common in evaporation units increases foaming, which can result in carryover of radioactive elements and other contaminants. Methods used to minimize foaming include hydrodynamic methods, coils, liquid level control, jets, antifoaming agents, and baffles.

Many different evaporators have been designed for different feedstreams and evaporator functions to obtain the desired evaporation and minimize problems inherent to evaporation processes. Solar evaporation is the simplest of all evaporation systems and can be effective and inexpensive. Water is evaporated from sludges and other mixtures in surface ponds without artificial heat input. The ponds are usually lined to limit leaching of contaminants into the underlying soil or groundwater. Capital investment and operating expenses are low. Nonhomogeneous or other difficult to treat streams may be processed using solar evaporation. Several disadvantages include dependence on climatic conditions, large land requirements, attractiveness to waterfowl, and dependence on the integrity of the liner.

Many variations of mechanical evaporator designs are available. The most common designs used for radioactive liquid wastes include:

- X Pot, kettle, or pan evaporators
- X Natural circulation systems
- X Forced circulation systems.

Pot, kettle, or pan evaporators are simple single vessel systems used for batch operation. Heat transfer and evaporation occur in the same vessel. Natural circulation systems are those where the fluid circulates by natural convection and turbulence, without added pumping of the fluid through the evaporator to improve heat transfer. Heat transfer and evaporation may occur in separate steps. Forced circulation designs rely on pumps to circulate the fluid from a reservoir through a heat transfer section. In forced circulation, heat transfer and evaporation are separate steps. Flash evaporation occurs when the heated fluid returns to the reservoir, which is at a lower pressure.

Depending somewhat on the design, radioactive liquid waste evaporators may be operated as batch, semibatch, or continuous processes. In semibatch operation, liquid waste is continuously fed into the process to maintain a constant level, until the desired concentration factor and density is achieved. Modified semibatch processing is also done, where the feed is stopped after the charge has reached one-half of the desired concentration. This reduces the time span for the final concentration step, reducing tendencies for fouling, corrosion, or scaling.

Other designs that have also been used less frequently for radioactive liquid waste treatment

include vapor compression evaporators, wiped-film evaporators, evaporators/crystallizers, nonboiling evaporators, and submerged combustion evaporators. Submerged combustion evaporators make use of combustion gases bubbling through the liquid as a means of heat transfer, rather than using heat transfer surfaces.

Since these three evaporator designs are most commonly used for treating radioactive wastes, they are discussed in more detail in the following sections.

<u>Section</u>	<u>Technology</u>
4.5.1	Pot and Kettle Evaporators
4.5.2	Natural Circulation Evaporators
4.5.3	Forced Circulation Evaporators

#### **4.5.1 Pot and Kettle Evaporators**

Pot and kettle type evaporators are the simplest of the many types of mechanical evaporators. Heat transfer and evaporation occur inside a single vessel that is externally heated by a heating jacket, or internally heated by a heating coil. Steam heating tubes are typically U or V shaped and are mounted on a removable plate in the vessel wall for easy removal for cleaning. Operation is usually a batch or semibatch process. Heating may be done using steam or electrical resistance heating.

##### **Input Streams**

Input streams are liquid wastes with dissolved contaminant concentrations that range from less than 1% to saturated levels, as high as the contaminant solubilities will allow.

##### **Output Streams**

Output streams include vaporized or recondensed water, and a concentrated, reduced volume liquid that contains the majority of the radioactive and hazardous contaminants. The liquid product can be saturated, or a portion of the solutes may be precipitated or crystallized out of solution. Periodically, waste products may occur from maintenance, particularly scale, fouling, or other deposits removed from the vessel or the heating elements.

##### **Advantages**

The advantages of pot and kettle evaporators include (1) simple design, (2) comparatively inexpensive, (3) limited space requirements in a facility, and (4) the variation that uses removable steam heated coils is easy to clean by cold shocking or by removing the coils making the design especially useful for evaporating scale-forming liquids.

## **Disadvantages**

The disadvantages of pot and kettle evaporators include (1) pot or kettle evaporators are not suitable for high throughput processes, (2) designs are usually batch or semibatch operations that can incur frequent cycling, and (3) the units have a high holdup and residence time.

## **Technology Status**

Proven: Pot or kettle evaporators have been used frequently at small facilities that have small liquid waste streams that require treatment.

### **4.5.2 Natural Circulation Evaporators**

Natural circulation evaporators include a number of different designs including rising film and falling film long tube vertical (LTV) heaters, recirculating LTV evaporators, short tube evaporators, propeller calandria, and horizontal tube evaporators. In rising film evaporators, feed enters at the bottom of a vertically oriented heat transfer tube bundle. The tubes are externally steam heated and can be 20 to 35 ft (6 to 11 m) long. Heating and boiling of the feed begins in the tubes. As the boiling in the tubes progresses, the velocities increase. At the tube outlets, the high velocity vapor and liquid impinges on deflector plates above the tube sheet in a separation chamber or vapor body. Vapor exits the top of the vapor body, and the concentrated liquid product drains from the bottom of the vapor body. In recirculating LTV evaporators, this concentrated product is partially recycled to obtain higher concentration factors. The heated tube bundle is separate from the vapor body in recirculating evaporators for easier access during cleaning and maintenance. If the feedstream is shut off and the entire product is recycled, the recirculating evaporator can become a batch process.

Falling film LTV evaporators have a vertically oriented tube bundle for heat transfer and a vapor body at the bottom rather than the top of the tube bundle. Liquid feed enters the tubes at the top and falls downward in the tubes as a film. Heat transfer and evaporation occur within the tubes. After exiting the bottom of the tube bundle, the vapor and concentrated liquid are separated in the vapor body. Vapor exits the vapor body and concentrated liquid exits from a reservoir at the bottom of the vapor body. The concentrated product can be partially recycled for improved concentration factors. Variations in falling film evaporator designs include using bundles of heat transfer plates rather than tube bundles.

Short tube evaporators are an earlier design type and have limited current use. Short [4 to 6 ft (1.2 to 1.8 m) long], vertical heat transfer tube bundles are located within a vertical body. The tubes are partially or completely submerged in the feed liquid. Turbulence of boiling and density gradients of the evaporating liquid in the tubes causes natural circulation of liquid through the tubes. Vapor exits the top of the body and the product is drained from the bottom. The propeller calandria is a variation of short tube evaporators. A propeller in the fluid downtake provides some forced circulation to the heating elements. This variation can increase short tube evaporator

capacities by a factor of two.

Horizontal tube evaporators are less common in radioactive waste treatment processes. These are similar to kettle evaporators, but incorporate natural circulation and design features such as liquid sprays.

### **Input Streams**

Input streams can include liquid wastes with dissolved contaminant concentrations ranging from less than 1% to saturated levels, as high as the contaminant solubilities will allow.

### **Output Streams**

Output streams include vaporized or recondensed water, and a concentrated, reduced volume liquid that contains the majority of the radioactive and hazardous contaminants. The liquid product can be saturated, or a portion of the solutes may be precipitated or crystallized out of the solution. Periodically, waste products may occur from maintenance, particularly scale, fouling, or other deposits removed from the vessel or the heating elements.

### **Advantages**

Many variations of this general type of evaporator are available. Some advantages of the various types include:

Long tube evaporators - (1) Low cost, (2) large heating surface, (3) low holdup, (4) small floor space, (5) good heat transfer at reasonable temperature differences (rising film), (6) good heat transfer at all temperature differences (falling film), (7) most applicable for clear, foaming, or corrosive liquids, low temperatures (falling film), and (8) most applicable for large evaporation loads.

Short tube evaporators - (1) High heat transfer at high temperature differences, (2) low headroom, (3) easy mechanical descaling, (4) relatively inexpensive, and (5) most applicable for clear, scaling liquids with crystalline product (propeller circulated).

Horizontal tube evaporators - (1) Low headroom, (2) large vapor-liquid disengagement area, (3) low cost (for straight-tube), (4) good heat transfer, (5) easy descaling (bent-tube), and (6) vacuum operation available.

### **Disadvantages**

Disadvantages of the various types of natural circulation evaporators include:

Long tube evaporators - (1) High headroom, (2) unsuitable for salting or scaling liquids,

(3) poor heat transfer for rising film designs at low temperature differences, (4) recirculation usually required for falling film version, (5) rising film units are sensitive to operating conditions, and (6) poor feed distribution in falling film units.

Short tube evaporators - (1) Poor heat transfer at low temperatures, low temperature differences or viscous liquids, (2) high floor space and weight, and (3) high holdup.

Horizontal tube evaporators - (1) Unsuitable for salting or scaling liquids (straight-tube), and (2) high cost (bent-tube).

## **Technology Status**

Proven: Natural circulation evaporators are well developed and in use in many industries including food processing, water desalinization, and hazardous, mixed, and radioactive waste liquid treatment. Many natural circulation evaporators are in use at nuclear research installations and power plants.

### **4.5.3 Forced Circulation Evaporators**

Forced circulation evaporators use additional mechanical energy to improve the heat transfer and agitate the liquid, and remove or prevent scaling, fouling or other deposits. This added energy may be from pumps for liquid recirculation or scrapers or wipers for deposit removal. Liquid velocities are typically higher to improve heat transfer and limit scale deposition on heat transfer surfaces. Tube velocities range from 5 to 10 ft/sec (1.5 to 3 m/sec). Higher tube velocities are possible if erosion corrosion is not prevalent. The heat transfer unit is typically separate from the evaporation and separation chamber. Typically, fluid is pumped through the heat exchanger and then discharged to the evaporation chamber where vapor flashes under lower pressure. Some types are designed for boiling in the heat transfer tubes, but these types are not suited for salting or scaling fluids. Vapor is vented from the evaporation and separation chamber. Concentrated product from the bottom of the chamber is partially recycled.

A variation of the forced circulation evaporator is the multistage evaporator, such as the Bohler type evaporator. Two stages are linked using a direct contact condenser so that the heat of condensation of the vapor from the first stage serves to heat and evaporate the fluid in the second stage.

## **Input Stream**

Input streams can include liquid wastes with dissolved contaminant concentrations ranging from less than 1% to saturated levels, as high as the contaminant solubilities will allow. The input streams can contain salting or scaling solutes or suspended solids, or be relatively viscous.

## **Output Streams**

Output streams include vaporized or recondensed water, and a concentrated, reduced volume liquid that contains the majority of the radioactive and hazardous contaminants. The liquid product can be saturated, or a portion of the solutes may be precipitated or crystallized out of solution. Periodically, waste products may occur from maintenance, particularly scale, fouling, or other deposits removed from the vessel or the heating elements. In some cases, significant amounts of precipitated or crystallized solids may be included with the concentrated product.

## **Advantages**

Advantages of forced circulation evaporators are (1) high heat transfer, (2) positive circulation, (3) relative freedom from salting, scaling, or deposition, (4) corrosive or viscous solutions can be readily treated, and (5) the product can include crystalline material.

## **Disadvantages**

Disadvantages of forced circulation evaporation can include high cost, higher power requirements, higher holdup or residence time, plugging of tube inlets, poor circulation from higher than expected head losses, erosion, corrosion, and salting in tubes where boiling occurs.

## **Technology Status**

Proven: Forced circulation evaporators are commonly used in many industries including nuclear research and power generation. Many forced circulation evaporators are in use at nuclear installations worldwide. In recent years, a particular forced circulation design has gained favor in the nuclear power industry. This design features a large flash chamber with a conical bottom, a vertical external reboiler, and mechanical disentrainment followed by a distillation tower. Undissolved solids are controlled and removed by the forced circulation and the conical bottom. Another recent design, the evaporator/crystallizer, is designed to concentrate about 50 wt% solids in the concentrated liquid.

## **4.6 Separation**

This section contains information on technologies that can be used to separate metals, suspended solids, or organics from aqueous waste streams. Reverse osmosis, ion-exchange, and precipitation are used to remove metals from aqueous streams. Centrifugation, drying, and dewatering are used to separate and concentrate the solids from an aqueous stream. Carbon adsorption, distillation, and steam stripping are used to separate organics from an aqueous stream. These technologies have been used in industry, and many have been used with radioactive wastes.<sup>6</sup>

Each separation technology and their applicability to particular waste types are discussed as follows:

<u>Section</u>	<u>Technology</u>
4.6.1	Reverse Osmosis
4.6.2	Ion-Exchange
4.6.3	Carbon Adsorption
4.6.4	Precipitation
4.6.5	Centrifugation
4.6.6	Drying (Thermal)
4.6.7	Dewatering (Filtration)
4.6.8	Distillation
4.6.9	Steam Stripping

#### **4.6.1 Reverse Osmosis**

When a semipermeable membrane separates two concentrated solutions of different dissolved solids, pure solvent (usually water) will flow through the membrane into the concentrated solution until an equilibrium is reached in chemical potential on both sides of the membrane. The pressure at which equilibrium is established is known as the osmotic pressure. In reverse osmosis, pressure greater than the osmotic pressure (300 to 1500 psig) is applied to the concentrated solution to cause the solvent to flow from the concentrated side of a semipermeable membrane to the diluted side. The high pressure counteracts the osmotic pressure of the dissolved waste and acts as a driving force to concentrate the solution. The clean solution (the permeate) passes through the membrane leaving a concentrated waste stream (the retentate or concentrate), which must be further treated or disposed. In most cases, when the solids concentration reaches about 5 to 10 wt%, osmotic pressure becomes too high to continue the treatment. Reverse osmosis removes 90 to 95% of total dissolved inorganic solids, 95 to 97% of most dissolved organics.

Pretreatment of waste should be accomplished prior to reverse osmosis systems because these systems are susceptible to chemical attack, fouling, and plugging; all of which interfere with effective water treatment. The most important factor that affects a reverse osmosis system performance is membrane fouling. Unfortunately, the extent of membrane fouling cannot be determined during pilot tests but must be analyzed during onsite "slipstream" evaluation. Fouling can be inhibited by pretreatment that should include (1) removing suspended solids by using coagulation followed by filtration or by using 5  $\Phi$ m prefilters, (2) prefiltering feed with activated carbon to remove all oil and similar organics, (3) adding dispersants to inhibit or control the formation of compounds that will precipitate, coat the membrane, and block water passage, (4) adjusting and controlling temperature and pH, and (5) chlorinating (followed by dechlorinating the aromatic polyamide membrane systems) to disinfect and prevent slime growths or contamination of the equipment. Fouling can also be decreased by maintaining turbulent flow or using nonferrous materials to decrease the amount of iron-corrosion products in the feed.

Although membranes in desalination service may have lifetimes of over five years, membrane life in waste-treatment applications is probably much shorter.

The basic components of a reverse osmosis unit are membrane elements, a membrane support structure, a containing vessel, feed and collection tanks, a high-pressure pump, and instrumentation. A system to periodically clean the membranes will also be required and consists of a cleaning solution tank, pump, and receiving tank for the cleaning waste stream.

Membranes are assembled into modules for use in a treatment system. The modules come in several forms: (1) tubular, (2) spiral wound, (3) hollow fiber, and (4) plate and frame. Each type has advantages and disadvantages in processing efficiency, equipment size, operating temperatures, chemical resistance, and water pretreatment requirements. Some advantages and disadvantages of the different types of treatment systems are listed in Table 4-5.

The most commonly used membrane materials are cellulose acetate, aromatic polyamides, and thin-film composites. The process limitations of each material are listed below.

**Table 4-5.** Advantages and Disadvantages of Reverse Osmosis Modules.<sup>6</sup>

Module Type	Advantages	Disadvantages
Tubular	<ul style="list-style-type: none"> <li>X Easiest type to clean chemically or mechanically if membranes become fouled</li> <li>X Can process high-suspended-solids feed with minimal pretreatment</li> <li>X Good hydrodynamic control</li> <li>X Individual tubes can be replaced</li> <li>X High Pressure (1500 psig) equipment available</li> </ul>	<ul style="list-style-type: none"> <li>X Relative high volume required per unit membrane area</li> <li>X Relatively expensive</li> </ul>
Spiral Wound	<ul style="list-style-type: none"> <li>X Compact</li> <li>X Excellent membrane surface/volume ratio</li> <li>X Less expensive than tubular and hollow fiber modules</li> </ul>	<ul style="list-style-type: none"> <li>X Susceptible to plugging by particulates</li> <li>X Badly fouled membranes are difficult to clean– basically limited to chemical cleaning</li> </ul>
Hollow Fiber	<ul style="list-style-type: none"> <li>X Compact</li> <li>X Good membrane surface/volume ratio</li> <li>X Economical</li> </ul>	<ul style="list-style-type: none"> <li>X Susceptible to plugging by particulates</li> <li>X Badly fouled membrane modules are hard to clean–limited to chemical and mechanical methods</li> </ul>
Plate and Frame	<ul style="list-style-type: none"> <li>X Good membrane surface/volume ratio</li> <li>X Well-developed equipment</li> </ul>	<ul style="list-style-type: none"> <li>X Susceptible to plugging at flow-stagnation points</li> <li>X Potentially difficult to clean</li> <li>X Expensive</li> </ul>

<u>Membrane Material</u>	<u>pH Limits</u>	<u>Temperature Limits EF (EC)</u>	<u>Other Limitations</u>
Cellulose acetate	2.5-7	32-122 (0-50)	Biologically degradable
Aromatic polyamides	4-11	32-115 (0-46)	Cannot tolerate chlorine
Thin-film composites	<1-13	32-175 (0-79)	Can tolerate moderate chlorine levels (100 ppm)

## **Input Streams**

Input streams for reverse osmosis are primarily feed streams containing dissolved inorganic solids of 0.05% to 5% (0.5 to 50 g/L) of water with a low suspended solids content. Below this range, ion-exchange is more effective; above this range, evaporation is preferred. Typical membranes can treat most inorganic species and some organic compounds (in the molecular weight range of 500 to 1500). However, the membrane and process conditions must be chosen for the specific application. Reverse osmosis will not reliably treat wastes with high organic contents because they may dissolve the membrane and prevent separation of toxic contaminants. Usually, organics require filtration as an extra treatment step to achieve better decontamination of organics.

## **Output Streams**

The output streams from the process include (1) a relatively pure permeate (usually water) stream generally suitable for recycling, (2) a concentrated waste stream that can range from 10 to 70% of the influent stream volume, (3) solutions from cleaning the membranes, and (4) discarded membranes from periodic replacement to maintain process efficiency.

## **Advantages**

General advantages of reverse osmosis include (1) the separation process does not require an energy-intensive phase change as required for distillation or evaporation, therefore, operating costs associated with energy consumption are relatively low, (2) capital costs are also relatively low, (3) reverse osmosis equipment does not require a large amount of space, and (4) because reverse osmosis is a straight forward mechanical process, it requires a low degree of operator skill.

## **Disadvantages**

General disadvantages of reverse osmosis include (1) the membrane systems require a liquid that has a low-level of particulate contamination, since, in most types of systems, the particulates will plug pores and reduce the efficiency, and (2) many membranes are susceptible to chemical attack by materials dissolved in the water being treated.

## **Technology Status**

Proven: Reverse osmosis is a well developed technology. Systems have been used in industrial settings for many years with applications to separation, concentration of product streams, and waste water treatment. Most applications for reverse osmosis have been in the electroplating industry for removal and recovery of metals, in the wastewater treatment for removal of metals and hazardous materials for discharge or recycle of water, and in conversion of brine water to potable water.

The technology has also been applied in nuclear conditions to a more limited extent. Reverse osmosis has been used for removal of the radionuclides from low-level aqueous wastes, such as laundry and general process streams. Other radionuclide applications have used precipitation methods to form complex nuclides of uranium, plutonium, americium, strontium, and cesium. The waste is then passed through reverse osmosis or ultrafiltration modules for removal of the nuclides. Some adaptation will be required for liquids containing alpha contamination.

#### **4.6.2 Ion-Exchange**

The ion-exchange process consists of a reversible interchange of ions of the same sign between a solution containing dissolved solids and a solid phase ion-exchange media (resins or zeolites). Hence, ion-exchange differs from other systems of waste treatment as it is a process for substituting other ions for certain ions in the waste stream.

Ion-exchange media are relatively insoluble granular materials that have acid or basic radicals exposed on parts of their surface. These radicals can be exchanged for ions of the same positive or negative sign in the solution in contact with the granular materials. This exchange is done without any physical change in the granular material other than a possible increase in volume. The same number of ions will be removed from the ion-exchange media as are removed from the solution and added to the ion-exchange media. Therefore, the capacity of the media to exchange charged radicals is based on the number of ion radicals available on the exposed granular surface.

Both common and synthetic ion-exchange media are available. However, the synthetic resins make large scale ion-exchange practical and feasible. Common materials that act as ion-exchangers include natural zeolites (clinoptilolite or greensand), clay (montmorillonite), sulfonated coal (crushed anthracite treated with concentrated sulfuric acid and peat). The most common synthetic resins are polystyrene-based. Divinylbenzene (DVB) is used as a crosslinking agent with the styrene. Higher DVB crosslinkage levels provide a more stable resin, but result in slower ion-exchange kinetics, leading to lower flow rates and larger resin inventories. A newer resin structure, called macroporous, was designed to retain some advantages of the more highly crosslinked gel resin while minimizing its disadvantages. The structure of synthetic ion-exchange resins used in nuclear power plants is based on styrene-divinylbenzene copolymers. Common types of synthetic exchangers are listed in Table 4-6.

Sometimes, the beds are regenerated with strong acids (typically sulfuric acid) and strong bases (typically sodium hydroxide). The strong resins require extensive regeneration, and the weak resins are slow in dissociating weakly ionized or neutral salts. When the resin bed becomes depleted, the resins are treated as radioactive waste. The average life of the resin ranges from about a week for radioactive waste to a year for primary coolant. Condensate resin has an average life of one to two months, or longer when the system is cleaned ultrasonically.

Ion-exchange resins and zeolites have a selective affinity for the removal of specific ions from the solutions. This selectivity varies with ionic strength, relative amounts of ions present, the kind of

resin and temperature.

Basic equipment requirements for this process are columns with liquid distribution internals and pumps. A nonregenerated system will require a sluicing system or another method for removal of the resin. Regenerated systems require tanks for the regenerant and other support systems for volume reduction of the liquid waste such as evaporation. Several ion-exchange equipment designs are currently employed including the following:

**Fixed-bed concurrent** - The operation cycle consists of (1) service: removal of the polluting ions from the feed solution passing down through the column, until leakage of the ion being removed reaches an unacceptable level, (2) backwash: upflow through the column at a flow sufficient to fluidize the resin bead 50 to 100% to avoid channeling, and to remove any suspended solids what may have filtered out on the resin bed during

**Table 4-6.** Common Types of Synthetic Exchangers.<sup>6</sup>

Type of Resins	Functional Group	Drained Density lb/ft <sup>3</sup>	Operating pH Range	Max Exchange Capacity Meq/g	Meq/ml	Regeneration
Strong acid	-SO <sub>3</sub> <sup>-</sup> H <sup>+</sup> Sulfonic acid	49–53	0–14	4.8	2.0	Excess strong acid
Weak acid	-COO <sup>-</sup> H <sup>+</sup> Carboxylic acid	45	7–14	11	4.0	Weak or strong acid
Strong base type I	-CH <sub>2</sub> N(CH <sub>3</sub> ) <sub>3</sub> <sup>+</sup> OH <sup>-</sup> Quaternary ammonium	45	0–14	4.3	1.3	Excess strong base
Strong base type II	-CH <sub>2</sub> N(CH <sub>3</sub> ) <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH <sup>+</sup> OH <sup>-</sup>	45	0–14	3.4	1.4	Excess strong base
Weak base	-N(CH <sub>3</sub> ) <sub>2</sub> H <sup>+</sup> OF <sup>-</sup> Tertiary ammonium	32	0–6	9	2.5	Weak or strong base
Intermediate base	Mix of above two	43	0–14	8.8	2.7	Strong base

service, (3) regeneration: passing either acid (for cation) or caustic (for anion) down through the column to displace the pollutant ions, and (4) displacement and rinse: displacement of regenerant from the column with a water rinse.

Fixed-bed countercurrent - The countercurrent method uses a service flow in the opposite direction to the regeneration. This provides higher uptake and regeneration efficiencies and produces less chemical waste and more concentrated recovered products upon regeneration.

Short-bed - This system uses short beds of fine-mesh ion-exchange resin, low exchanger loadings, fast cycle times, and countercurrent regeneration. The significant advantages claimed for this system include (1) compact size, (2) efficient regeneration, (3) decreased regenerant wastes, (4) short off-stream times, and (5) the ability to treat and produce relatively concentrated, as well as dilute, solutions.

Mixed-bed - This system uses two types of resins, usually a mixture of strong-acid cation and strong base anion, to produce an exceptionally high purity effluent. However, the regeneration is an inefficient and time-consuming process. Regeneration requires that resins be separated during the backwash cycle using density differences of the resins prior to regeneration. A sequence of a cation bed in front of an anion bed can replace the mixed bed system. This mode offers better removal of specific radionuclides and makes regeneration easier.

Moving-bed - This is a continuous countercurrent ion-exchange system where a portion of the resin is continuously removed, regenerated, and returned to the process during operation. This has the advantage of maintaining a consistent effluent water quality and eliminating long periods of down time for regeneration.

The performance of the resin is measured by the decontamination factor (DF) that is used as the main guideline for efficiency. Some major factors that effect DF are (1) operation temperature (selectivity generally decreases with increasing concentration and temperature), (2) decrease in capacity of the resin, (3) residence time, (4) flow distribution, (5) contaminant concentration, (6) insoluble particulates, colloids, high silica content, and neutral molecules such as iodine, and (7) contamination from organics or biological growth.

The mixed-bed demineralizer is the primary choice for treating radioactive waste. A well-designed ion-exchange system that reduces the level of radionuclides (in the ionic form) by factors of 10 to 100. Ion-exchangers used in the nuclear industry reduce both corrosion and neutron-induced activities. Operating temperatures are maintained below 140°F (60°C). The bed contains stationary anion and cation resins, with particle sizes ranging from 0.4 to 0.7 mm, and dimensions ranging from 2 to 8 ft (0.6 to 2.4 m) in diameter, 3 to 6 ft (0.9 to 1.8 m) in depth, and volumes of 200 to 1350 gallons (0.8 to 5.1 m<sup>3</sup>) of resin. Anion and cation reactions occur simultaneously. The H<sup>+</sup> and OH<sup>-</sup> ions removed from the resin react with each other, reducing the concentration of the electrolyte.

Ion-exchange rarely represents an option for the ultimate disposal of hazardous wastes since the process generates chemical wastes, and discarded ion-exchange media wastes that usually require

further treatment. Its role is usually to reduce the magnitude of a waste by converting a hazardous waste into a form that can be reused, reducing the residual waste stream bearing the toxic substance for disposal.

### **Input Streams**

Ion-exchange can be used to treat aqueous solutions containing (1) soluble metal species, (2) inorganic anions (sulfates, nitrates, cyanides, etc.), (3) organic acids (carboxylics, phenols, etc.), and (4) salt from organic amines formed at high pH. Liquid radioactive waste contaminants treated by ion-exchange include iodine (I-131), lithium, cesium (Cs-137), cobalt (Co-60), manganese (Mn-54), zinc (Zn-65), chlorine, and boron.

### **Output Streams**

The outputs produced from ion-exchange include (1) relatively pure treated wastewater, (2) discarded ion-exchange media, and (3) chemical regenerative solutions containing radionuclides and other metal ions extracted from the treated waste. Treatment of radioactive mixed and low-level wastes creates a liquid radioactive waste of high salt content and spent resin in the form of a sludge of low-level or mixed waste.

### **Advantages**

Advantages to ion-exchange include (1) process is able to achieve higher purity for treated water than other processes, (2) can often remove unwanted ions preferentially, (3) numerous manufacturers of ion-exchange equipment, which keeps costs competitive, (4) processes and equipment have been tested over many years, (5) manual and completely automatic units are available, (6) temperature effects from 32 to 95EF (0 to 35EC) are negligible, and (7) the process can easily treat both large and small quantities.

In addition, portable and disposable ion-exchange units are available that permit treatment at facilities with a low annual volume of liquid wastes that gives this method an advantage over other transfer technologies.

### **Disadvantages**

Disadvantages associated with ion-exchange include (1) chemicals for regeneration may be expensive, corrosive, or dangerous, (2) large quantities of chemical waste are produced if excess regenerant is required, (3) there are limitations on the concentrations that can be treated, (4) down time is required for regeneration (semibatch), (5) resins are not completely specific to a particular substance, (6) resins are prone to fouling by some organic substances, (7) biological growth can contaminate the bed, (8) insoluble particulates, colloids, and high silica content cause plugging (suspended solids should be kept below 50 mg/L), and (9) automated plants require expert maintenance, and nonautomated plants require knowledgeable operation and frequent

attention.

## **Technology Status**

Proven: Ion-exchange has been used (1) to clean up radionuclides in boiling water reactors and pressurized water reactors, (2) as polishing step for reverse osmosis treated radioactive wastewater, (3) to treat large volumes of liquids with low concentrations of radioactivity to reduce radioactivity to a level within established standards for release of the treated waste to the environment, and (4) to purify low- to intermediate-level liquid waste solutions generated in processing operations.

### **4.6.3 Carbon Adsorption**

Carbon adsorption is used to remove organic, and sometimes inorganic, compounds from liquid or gas streams. The EPA recommends carbon adsorption as a best demonstrated available technology for wastewaters to remove dissolved organics at concentrations less than about 5% and, to a lesser extent, dissolved metal and other inorganic contaminants.

The basic principle of operation for carbon adsorption is the mass transfer and adsorption of a molecule from a liquid or gas onto a solid surface. Activated carbon is manufactured in such a way as to produce extremely porous carbon particles whose internal surface area is large (500 to 1400 m<sup>2</sup>/g of carbon). This porous structure attracts and holds (adsorbs) organic molecules as well as certain metal and inorganic molecules.

Adsorption occurs because (1) the contaminant has a low solubility in the waste, (2) the contaminant has a greater affinity for the carbon than for the waste, or (3) a combination of the two occurs. The actual mechanisms for adsorption include physical adsorption, produced by van der Waals forces; chemical adsorption, produced by the formation of chemical bonds; and electrostatic adsorption, resulting from Coulombic forces between ions and charged functional groups. The amount of contaminants that can be adsorbed by activated carbon ranges from 0.10 to 0.95 gram per gram of carbon.

The adsorbate can be exposed to the activated carbon in a number of different ways. Contacting schemes for aqueous waste streams include mixed-batch, mixed-flow, packed columns, or pulsed/moving beds. Packed columns are most common for treating wastewaters, where granular activated carbon is packed into the column, and the wastewater flows through the stationary bed. The flow can be either down or up through the vertical columns. Typical residence times range from 30 to 100 minutes. The contaminants in the wastewater are adsorbed most rapidly and effectively by the upper layers of carbon during the initial stages of operation. These upper layers are in contact with the wastewater at its highest concentrations of contaminants. The small amounts of contaminants that are not adsorbed in the first few layers of the activated carbon bed are removed from the solution in the lower or downstream portion of the bed. Initially, none of the contaminants escape from the carbon bed.

As the wastewater flows through the column and the adsorption capacity is reached in the initial layers, the adsorption zone (the location in the column where the majority of adsorption is occurring) moves down the column. As the adsorption zone reaches the end of the carbon bed, the concentration in the effluent rapidly approaches the influent concentration. This point in the process is referred to as breakthrough. At breakthrough, the adsorptive capacity of the carbon bed is exhausted, and little additional removal of contaminants occurs.

Once the carbon bed is spent and can no longer remove contaminants from the waste, it is taken offline. The activated carbon is then either regenerated by thermal or chemical methods for further use or treated by incineration and disposed of. If carbon adsorption is used to treat toxic or hazardous materials, the spent carbon is usually incinerated.

Regeneration is accomplished thermally by heating the carbon to a temperature between 1500 and 1700°F (816 and 927°C) at which most of the adsorbed contaminants are volatilized and destroyed but that is not high enough to burn the surface of the carbon. About 4 to 9% of the carbon is lost in this process. Steam can also be used to regenerate carbon by volatilizing adsorbed organics. Chemical regeneration involves the use of an acid, alkali, or organic solvent to redissolve contaminants for further treatment and disposal. A loss of performance occurs with each regeneration of spent carbon because metals (such as calcium, magnesium, and iron) plug small pores in the carbon and prevent some organic contaminants from being desorbed at the thermal regeneration temperature. In each thermal regeneration process, some carbon becomes spent, requiring treatment and disposal. As a result, makeup carbon has to be added to the regenerated carbon being placed back in service.

### **Input Streams**

Inputs are aqueous or gaseous waste streams contaminated with organics. Activated carbon can adsorb most RCRA hazardous organics. Carbon adsorption should be considered as a potential removal process for organic contaminants that are nonpolar, have low solubility, or have high molecular weight. Classes of organic compounds amenable to adsorption on activated carbon include aromatic solvents, polynuclear aromatics, chlorinated aromatics, phenolics, high-molecular-weight aliphatic amines, aromatic amines, surfactants, soluble organic dyes, automotive fuels, chlorinated solvents, and aliphatic and aromatic acids. Some inorganic compounds will also adsorb to activated carbon, but the technology is not widely used for this application. This is caused by problems in the regeneration process when high-levels of adsorbed inorganics are present.

### **Output Streams**

Outputs are aqueous or gaseous waste streams with reduced levels of organic contaminants and discarded activated carbon media.

## **Advantages**

Advantages of carbon adsorption include (1) carbon adsorption is effective for removing organic compounds otherwise untreatable by biological methods and (2) most organics can be reduced to concentrations in the 1 to 10  $\mu\text{g/L}$  level.

## **Disadvantages**

Suspended solids, oil, and grease can reduce the effectiveness of carbon adsorption by clogging and coating the pores, as well as by competing for adsorption sites, thereby interfering with the treatment of contaminants of concern. This treatment interference occurs with suspended solids at levels greater than about 50 mg/L, and with oil and grease at or above 10 mg/L. Aqueous waste streams may require pretreatment to address hard-water, or precipitation problems. Frequently, excessive heat loss will occur in adsorption columns due to suspended-solids accumulation, biological growth in the bed, or fouling of the influent screen. For hazardous waste streams, extensive application specific, bench-scale testing is usually required to implement carbon adsorption and regeneration processes.

## **Technology Status**

Proven: Carbon adsorption has been used for treatment of commercial hazardous waste, as well as in the radioactive waste treatment industry.

### **4.6.4 Precipitation**

Precipitation is a process where all or some of a substance dissolved in a liquid is removed from a waste stream by chemical coprecipitation or by adsorption to form small particles containing the substance suspended in the liquid. Chemical coprecipitation is a process where either a soluble substance is converted into an insoluble form by a chemical reaction or by changes in the composition of the solvent to diminish the solubility of the dissolved substance. Adsorption takes place when small amounts of precipitate are added that have an affinity for the dissolved species to be removed. Cyanides need to be removed prior to precipitation because cyanide complexes are formed that keep the metals in the solution.

Hydroxide precipitation is effective in removing As, Cd, Cr(III), Cu, Fe, Mn, Ni, Pb, and Zn. The process converts soluble metal ions into less soluble hydroxide compounds. When the hydroxide compounds are added to the waste stream, the pH is raised to a suitable level for optimum precipitation of the hydroxides. Unfortunately, each metal has its own optimal solubility curve. For most cases, treatment at a pH between 9 and 11 will result in precipitation of most metals from the solution in sufficient quantities to meet regulatory limits. The most common precipitating agents are calcium hydroxide (lime), sodium hydroxide (caustic), and magnesium oxide or magnesium hydroxide. Common chemicals used for metals precipitation along with many advantages and disadvantages are listed in Table 4-7.

Sulfide precipitation converts soluble metal ions into insoluble metal sulfides. This can be done by using soluble sulfides (sodium sulfide or sodium hydrosulfide) or insoluble sulfides (ferrous sulfide). Soluble sulfides produce relatively high concentrations of dissolved sulfide resulting in a rapid precipitation of dissolved metals. By using insoluble sulfides, the sulfide is released when in the presence of other metals to form metal sulfides. The excess ferrous sulfide is filtered or settled with the metal sulfide precipitates.

Carbonate precipitation has been used to precipitate some metals from wastewaters. The effluent metal concentrations are comparable to hydroxide precipitation, with the benefits of lower pH and denser, more filterable sludge.

Some metals such as aluminum, iron, and chromium, have unique characteristics that make their removal more difficult. Aluminum and iron become highly soluble if the pH is raised too high. Chromium can be present in either a hexavalent form ( $\text{Cr}^{+6}$ ) or a trivalent form ( $\text{Cr}^{+3}$ ). Hexavalent chromium is toxic and will not precipitate at alkaline pH as chrome hydroxide, whereas  $\text{Cr}^{+3}$  will. Therefore,  $\text{Cr}^{+6}$  must be reduced to  $\text{Cr}^{+3}$  prior to precipitation. This can be done with acid and a strong reducing agent, such as sulfur dioxide or sodium thiosulfate. Once this reduction is completed, the chromium can be removed along with the other metals present. Discussions of the individual characteristics of various metal ions and their removal from water are presented in several EPA publications.

Other reactions of interest are the redox reactions that typically occur in aqueous metal wastes that are relatively devoid of organic compounds. The most common redox reaction is the use of sulfur-based reduction techniques for chromium using soluble sulfite salts (sodium bisulfite, metabisulfite, or hydrosulfite).

The precipitated solids are typically removed by flocculation followed by sedimentation, filtration or centrifugation. Filtration and centrifugation are discussed elsewhere and will not be covered by this section. Flocculation agents are typically added to cause small, unsettleable particles suspended in a liquid medium to agglomerate into larger, more settleable particles, thus increasing sedimentation efficiency. Only radioactivity associated with the small, suspended particles is removed from the liquid waste by flocculation.

Sedimentation is the physical process in which particles suspended in a liquid settle out through the action of gravity. Sedimentation is used to treat a variety of aqueous radioactive wastes by removing existing settleable particles.

Although flocculation, precipitation, and sedimentation are individual process steps, they are interrelated and are often combined into a single overall treatment process. This process can be operated in a batch or continuous mode. For batch systems, a feed system, pumps, and reaction tank for mixing and settling are required. Filters may also be needed if the precipitant is amenable to filtration. Continuous operations are also available, but the equipment is more complex.

## **Input Streams**

Inputs are liquid wastes containing arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, zinc, fluoride, phosphate, sulfate, organic fatty acids, and dissolved radioactive wastes. They can also be used on liquids with dissolved radioactive waste, colloidal and suspended radioactive particles. Discussions of the individual characteristics of various metal ions and their removal from water are presented in several EPA publications.

## **Output Streams**

The output streams produced by this process are (1) liquid with a reduced metal content, and (2) a two-phase liquid-solid stream with the majority of the waste concentrated in the solid phase. Precipitation removes only radioactivity contained in the dissolved solids amenable to precipitation.

## **Advantages**

The advantages of precipitation include (1) process is applicable to wastewaters containing a wide range of dissolved metals, as well as other inorganic substances, (2) process is applicable to mixed waste for separating radionuclides from other hazardous constituents in wastewaters, and (3) specific conditions of pH, temperature, and precipitating reagent addition will allow selective removal of part or essentially all of the radioactive component as a precipitate.

## **Disadvantages**

The disadvantages of precipitation include (1) precipitation/flocculation/sedimentation is generally limited to dilute solutions, (2) the precipitate, or agglomerate, must be separated from the liquid, (3) sedimentation can be slow, and the clarified liquid must generally be treated by filtration to remove unsettled precipitate, and (4) continuous sedimentation equipment involves more maintenance than simple sedimentation in the precipitation process tank.

## **Technology Status**

Proven: Precipitation/flocculation/sedimentation is a conventional, operational technology. Chemical additives have been identified for removal of numerous radioactive species and also for removal of hazardous metals.

**Table 4-7. Common Precipitation Processes.**<sup>6</sup>

Precipitation Chemical Used	Metals Precipitated	Process pH	Advantages	Disadvantages
Calcium hydroxide (Lime)	As, Cd, Cr(III), Cu, Fe, Mn, Ni, Pb, and Zn  Removal efficiency >99% for Cr, Cu, Pb, and Fe; 98.6% for Zn; and 97% for Ni	9.4	Commonly used  Effective  Economical to use  Sludge dewateres easily	Generates largest sludge volume  Interferences with complexing agents when stabilizing metal hydroxide sludges  Overdose can result in poor effluent quality  Sludges generally not desirable for reclamation
Sodium hydroxide (Caustic)	As, Cd, Cr(III), Cu, Fe, Mn, Ni, Pb, and Zn  Removal efficiency >99% for Cd, Cr, Pb, Ni, and Zn; 98% for Cu; and 76% for Ag	9-11	Generates smaller hydroxide sludge volume  Provides excellent neutralization efficiency  Sludges suitable for reclamation	More expensive than lime  Requires larger settlers and dewatering apparatus because finer solids are formed
Magnesium oxide or Magnesium hydroxide	As, Cd, Cr(III), Cu, Fe, Mn, Ni, Pb, and Zn	8-9	Effective in treating waste streams containing lower concentrations of metals ( $\leq 50$ mg/L)  Lower sludge volumes  Ease of dewaterability  More effective in batch treatment systems	High reagent costs (Must add three to four times the stoichiometric amount to increase the pH to 8-9)

Precipitation Chemical Used	Metals Precipitated	Process pH	Advantages	Disadvantages
Soluble sulfides (Sodium sulfide) (Sodium hydrosulfide)	As, Cd, Cr(III), Cu, Fe, Mn, Ni, Pb, and Zn  Removal efficiency 82% for Pb; 88% for Cr; 93% for Zn; 95% for Cd; and 98% for Cu and Ni	>9	Solubilities of metal sulfides are lower than metal hydroxides  Chromates do not require the additional reduction step  Not sensitive to most chelating agents  Effective treatment at lower concentrations  Sludges suitable for reclamation	Generation of hydrogen sulfide gas at acidic conditions  Potential of having excess sulfide remaining in solution after treatment  Rapid formation of precipitate is hard to filter
Insoluble sulfides (Ferrous sulfide)	As, Cd, Cr(III), Cu, Fe, Mn, Ni, Pb, and Zn  Removal efficiency better than soluble sulfides for Cu, Cd, Ni, and Zn	8.5-9	Solubilities of metal sulfides are lower than metal hydroxides  Effective treatment at lower concentrations  Removal efficiencies are greater in multi-metal systems than in single-metal systems  Sludges suitable for reclamation	Generation of hydrogen sulfide gas at acidic conditions

Precipitation Chemical Used	Metals Precipitated	Process pH	Advantages	Disadvantages
Carbonates (Calcium carbonate) (Sodium carbonate) (Carbon dioxide)	As, Cd, Cr(III), Cu, Fe, Mn, Ni, Pb, and Zn  Removal efficiency comparable to hydroxide precipitation		Denser, more filterable sludge	Less effective in removal of Ni and Zn than hydroxide precipitation
Soluble sulfites (Sodium bisulfite) (Metabisulfite) (Hydrosulfite) (Sulfur dioxide)	Cr(VI) , Cr(III), Ba, Se, selenides and selenates  Removal efficiency >98% when followed by addition of hydrazine and sodium hydroxide	2-3	Reduces Cr(VI) to Cr(III) to allow Cr to be precipitated with hydroxide solutions	Process uses excess reducing agents due to the presence of dissolved oxygen  May not get complete chromate reduction since process depends on reaction time, pH, concentration and type of agent

#### 4.6.5 Centrifugation

Centrifugation is a unit system for separation of light and heavy phases where the heavy phase, usually a solid, is separated from the lighter liquid by spinning such that the force of gravity, used in sedimentation processes, is replaced by centrifugal force. Centrifuges can be roughly divided into low-speed bulk units that separate large quantities of solids from the liquid phase, and high-speed separators for small quantities of solids or liquid-liquid extractions. The designs vary, but generally involve a waste feed to a bowl filled with a stack of spinning funnels. The funnels are inverted, and as they spin the lighter phase migrates toward the center while the heavier phase is thrown to the wall of the bowl.

#### Input Streams

Inputs are two-phase aqueous wastes. The second phase may be liquid or may be solid. Centrifugation is a process that may be used to remove suspended solids from liquid radioactive waste streams.

## **Output Streams**

Two primary outputs produced by this process are (1) a liquid phase containing little of the second liquid or solid phase and (2) a solid or second liquid phase that normally contains the bulk of the waste as a concentrate. Generally, dilute slurry of 2 to 5% solids can be processed by centrifugation into a slurry of from 15 to 50% solids.

## **Advantages**

Advantages of centrifugation include (1) the separation of two-phase mixtures that are close in density is greatly enhanced by centrifugation as opposed to gravity settling, (2) centrifugation can dewater sticky, gelatinous slurries, (3) it is useful for solids contents greater than 0.5 wt% and is suitable for pretreatment before filtration or treatment of filter backwash solutions, and (4) the bulk centrifuges work with solutions in the range of 10 to 75 wt% solids while the high-speed units work well with 0.5 to 20 wt% solids.

## **Disadvantages**

Disadvantages of centrifugation include (1) plugging of centrifuges and resulting maintenance is a drawback, (2) below 0.5 wt% solids, separation is ineffective, and (3) the liquid effluent from centrifuges require secondary treatment.

## **Technology Status**

Proven: Centrifugation is a conventional, operational technology with application to waste processes.

### **4.6.6 Drying (Thermal)**

Drying can be accomplished by either passive or active systems.

Passive systems, such as drying beds or ponds, function by spreading the sludge over a relatively large area and removing water by (1) drainage through a porous support layer below the sludge, and (2) surface evaporation. Variations from the basic concept include decanting liquid from the top to hasten evaporation from the solids or placing a cover over the bed to prevent intrusion of rain. These beds are typically allowed to sit until the sludge begins to cake and crack. The cake, containing as much as 40% solids, is then removed for further treatment or disposal.

Active systems, such as evaporators, crystalizers, rotary dryers and spray dryers, operate by applying a heat source to remove water. This unit operation is typically used as a part of an integrated treatment system, such as with a fluidized bed dryer. However, in-drum drying is in use, and a spray dryer is being developed at DOE facilities.

## **Input Streams**

Inputs are wet solids, sludges, and slurries.

## **Output Streams**

Outputs from drying include (1) heavy stream contains concentrated sludges or solids with residual liquid; and (2) a light stream containing expelled gases, vapors, and possibly particulates.

## **Advantages**

Passive systems have the following advantages: (1) low capital cost, (2) low energy consumption, (3) relatively insensitive to sludge variability, (4) higher solids content in cake than mechanical methods, and (5) requires little or no operator attention.

Active systems have the following advantages: (1) high-level of system control, and (2) system can be engineered to hasten processing for a particular waste.

## **Disadvantages**

The disadvantages of a passive system include: (1) larger land requirement than mechanical methods, (2) climatic changes must be considered in design, (3) cake removal is usually labor intensive, (4) possible seepage beyond pond, (5) may be unsightly or odors could permeate to surrounding area, and (6) higher potential for environmental exposure.

The disadvantages of an active system include: (1) capital equipment cost is relatively high, (2) maintenance can be significant, (3) high energy consumption, and (4) higher level of operator interaction is required.

## **Technology Status**

Proven: Passive systems have been used successfully for many years. Evaporators, crystalizers, rotary dryers, spray dryers, etc., have been used extensively by the chemical industry for many years. Applications of active systems at DOE sites include: (1) an in-drum method consisting of an immersed heating element to promote evaporation from a wet solid waste (Hanford), (2) a spray dryer for the disposal of waste salt solutions (Rocky Flats), and (3) a disposable hot-air evaporator (INEL). Additionally, a method of using a microwave heat source for drying radioactive waste is being investigated for commercial application.

### **4.6.7 Dewatering (Filtration)**

Dewatering is distinguished from drying in that dewatering involves pumping and/or gravitationally draining water from wet solids with higher solids content, possibly after

centrifuging. Several types of dewatering equipment are available, including: (1) strainers - metal or fiber screens set across a duct or pipe to catch larger solids, (2) belt filter presses - two porous conveyer belts that are pressed together to squeeze the water out of the sludge, (3) rotary vacuum filters - water drawn by 10 to 20 in. of mercury vacuum through the cloth- or metal-mesh-covered drum to leave a cake build up on the outside of the drum, (4) sludge clarifiers - used to filter the finer particles through a sludge bed to produce a fluid stream essentially free of all tramp material, and (5) centrifuges and other types of filtration that are covered in other sections of this document.

### **Input Streams**

Inputs are any pumpable streams composed of solids suspended in a fluid, e.g., slurries, sludges, and suspensions.

### **Output Streams**

Outputs are solids with retained liquid; fluid with reduced amount of suspended solids. Degree of separation dependent on solid and fluid properties and on the type of filtration system.

### **Advantages**

The advantages of strainers include (1) low equipment cost, (2) low power requirements, and (3) does not require skilled personnel to operate.

The advantages of belt filter presses include (1) high pressure machine is capable of producing dry cake, and (2) low power requirements.

The advantages of rotary vacuum filters include (1) does not require skilled personnel, (2) has low maintenance requirements for continuous operating equipment, and (3) provides a filtrate with a low suspended solids concentration.

The advantages of sludge clarifiers include (1) capable of reducing the solids content of the filtrate by filtering through the sludge bed, (2) does not require skilled personnel to operate, (3) low equipment costs, and (4) low power requirements.

### **Disadvantages**

The disadvantages of strainers include (1) requires frequent cleaning, and (2) requires down time to clean strainers.

The disadvantages of belt filter presses include (1) sensitive to incoming feed characteristics, (2) machines hydraulically limited in throughput, and (3) short media life as compared with other devices using cloth media.

The disadvantages of rotary vacuum filters include (1) consumes the largest amount of energy per unit of sludge dewatered in most applications, (2) requires continuous operator attention, and (3) auxiliary equipment (vacuum pumps) is loud.

The disadvantages of sludge clarifiers are subject to carryover if design flowrates are exceeded.

### **Technology Status**

Available: Various configurations are readily available. Disposable units are also marketed.

### **4.6.8 Distillation**

Distillation involves application of heat to a liquid mixture, vaporization of part of the mixture and removal of heat from the vaporized portion. The resulting condensed vapor, called the distillate, is richer in the more volatile components, and the residual unvaporized bottoms are richer in the less volatile components. Most commercial distillations involve some form of multiple staging to obtain a greater enrichment than is possible by a single-stage vaporization and condensing operation. In simple distillation, a single equilibrium stage is used to obtain a desired separation, and the operation may be either batch or continuous. Simple continuous distillation (flash distillation) has a continuous feed to an equilibrium stage; the liquid and vapor leaving the stage are in equilibrium. Flash distillation is used in applications where a crude separation is adequate. The component separation in simple distillation is limited by thermodynamic partitioning constraints; therefore, multiple staging must be used to increase the separation efficiency. Multiple staging in a column design is achieved by returning part of the condensed overhead vapors to the top of the column, thereby bringing this reflux liquid into intimate contact with the rising vapors. Either a tray or a packed column is normally used to provide the necessary gas-liquid interfacial area for mass transfer. The degree of component separation for a given system configuration is dependent upon the operating conditions, the number of stages, and the amount of reflux.

Batch (pot) distillation is applied to spent solvent wastes where a crude separation is acceptable, and the wastes are highly concentrated and yield significant amounts of recoverable material upon separation. For wastes with constituents having a large relative volatility, batch distillation is capable of providing a good separation. Batch distillation is particularly applicable for wastes with high solids concentrations since the more volatile constituents are separated leaving the solids in the still bottoms. In this way, the quantity of waste requiring subsequent land disposal or incineration may also be effectively reduced.

A batch distillation unit consists of a boiler, a condenser, and a product receiver. The boiler is a device that provides the heat required to vaporize the liquid fraction of the waste. The rising vapor is collected at the top of the column, cooled, and condensed. The liquid product stream is then routed to a product receiver.

Continuous distillation differs from batch distillation in that it is designed to achieve a higher degree of distillate purity. It can be operated to produce multiple product streams for recovery of more than one solvent constituent from a waste, while generating minimal amounts of residue to be land disposed. In general, this technology is used where recovery of multiple constituents is desired and where the waste contains minimal amounts of suspended solids.

A continuous unit consists of a boiler, a stripping section, a rectification section, a condenser, a reflux system, and a product receiver. The boiler is the device that provides the heat required to vaporize the liquid fraction of the waste. The stripping section is composed of a set of trays or packing in a vertical column. In the stripping section, vapor rising from the boiler is brought in contact with the downflowing liquid feed. Through this contacting, the lower boiling point constituents are concentrated in the vapor. In the rectification section, the vapor rising above the feed tray is contacted with the downflowing condensed liquid product (reflux). The rising vapor is collected at the top of the column, cooled, and condensed. The liquid product stream is then routed to a product receiver.

Column internals are designed to accommodate the physical and chemical properties of the wastewater to be treated. Two types of internals may be used in steam stripping: trays or packing. Each tray represents one equilibrium stage. In the packed steam stripping column, the individual equilibrium stages are not discernible, but the number of equivalent trays can be calculated from mathematical relationships. Tray types include bubble cap, sieve, valve, and turbok-grid. Trays have several advantages over packing including (1) trays are less susceptible to blockage by solids, (2) they have a lower capital cost for large diameter columns  $\geq 1$  m ( $\geq 3$  ft), and (3) they accommodate a wider range of liquid and vapor flow rates. Packing types include raschig rings, pall rings, saddles, and sulzer-structures. Compared to trays, packing has the advantages of (1) having a lower pressure drop per theoretical stage, (2) being more resistant to corrosive materials, (3) having a lower capital cost for small diameter column  $< 1$  m ( $< 3$  ft), and (4) being less susceptible to foaming because of a more uniform flow distribution.

### **Input Streams**

The incoming streams would be wastewater with volatile organic compounds (VOCs) (batch or continuous) or solids and sludges with VOCs (batch only). Radioactively contaminated mixed wastes with metals and organics can be treated as well to remove the organic constituents from the rest of the waste.

### **Output Streams**

The output streams to the distillation system are the overheads that contain a mixture of the organic phase and water rich in organics, and the bottoms that are wastewater having little organics. In addition to the VOCs, if the wastewater stream contained dissolved metals and radionuclides [both an EPA toxic metal (Dxxx) and solvent waste] distillation would separate the organic material from the rest of the waste.

## **Advantages**

Distillation is preferred over steam stripping if the concentration of VOCs and toxic organics are greater than 10% by weight.

## **Disadvantages**

The disadvantages of distillation are that the capital and operating costs are larger than that for air and steam stripping. In comparison with other treatments for organics, distillation is considered a complex system due to the complex process controls, such as temperature, pressure, and reflux ratios. Also, since the packing depth and tower diameter are functions of the incoming feed concentrations, the required removal, the vapor loading and liquid loading rate, the packing characteristics, temperature, and pressure, the distillation tower may be confined to specific waste stream conditions.

## **Technology Status**

Available: Distillation has been successfully demonstrated in the nuclear industry, especially in the treating of liquid scintillation vials.

### **4.6.9 Steam Stripping**

Steam stripping is a distillation process that provides for the separation of constituents based on differences in volatility. More volatile constituents are separated from less volatile constituents by vaporization by means of steam heat. This treatment is applicable to wastewaters that contain best demonstrated available technology (BDAT) organics that are sufficiently volatile so they can be removed by the application of steam. These BDAT organics include 1,1,1-trichloroethane, 1,1,2-trichloro-1,2,2-trifluoromethane, acetone, n-butyl alcohol, cyclohexanone, ethyl acetate, ethyl ether, methanol, methyl isobutyl ketone, carbon disulfide, isobutanol, and methyl ethyl ketone. The basic principle of operation for steam stripping is the volatilization of hazardous constituents through the application of heat. The constituents that are volatilized are then condensed and either reused or further treated. The integral part of the theory of steam stripping is the principle of vapor-liquid equilibrium. If the difference between the vapor pressure is extremely large, a single separation cycle or single equilibrium stage of vaporization and condensation may achieve a significant separation of the constituents. If the difference between the vapor pressures is small, then multiple equilibrium stages are needed to achieve effective separation. The parameter that is used to determine the extent of the vapor pressure differential between constituents is relative volatility, expressed as the ratio of the vapor-to-liquid concentration for one constituent divided by the ratio of the vapor-to-liquid concentration of the other constituent.

In a continuous steam stripping unit, some pretreatment may be needed for the wastewater. If suspended solids exist in the wastewater, they should be removed from a waste stream by

filtration prior to steam stripping in order to avoid fouling the packing or plugging tray towers.

A steam stripping unit consists of a boiler, a stripper section, a condenser, and a collection tank. The boiler provides the heat required to vaporize the liquid fraction of the waste. The stripping section is composed of a set of trays or packing in a vertical column. The feed (waste influent) enters at the top. The stripper process uses multiple equilibrium stages, with the initial waste mixture entering the uppermost equilibrium stage. The boiler is located below the lowermost equilibrium stage so that the vapor generated moves upward in the column, coming into contact with the falling liquid. As the vapor comes into contact with the liquid at each stage, the more volatile components are removed or "stripped" from the liquid by the vapor phase. The concentration of the emerging vapor is slightly enriched.

Column internals are designed to accommodate the physical and chemical properties of the wastewater to be stripped. Two types of internals may be used in steam stripping: trays or packing. Each tray represents one equilibrium stage. In the packed steam stripping column, the individual equilibrium stages are not discernible, but the number of equivalent trays can be calculated from mathematical relationships. Tray types include bubble cap, sieve, valve, and turbok-grid. Trays have several advantages over packing, including (1) trays are less susceptible to blockage by solids, (2) they have a lower capital cost for large diameter columns  $\geq 3$  ft ( $\geq 1$ ), and (3) they accommodate a wider range of liquid and vapor flow rates. Packing types include raschig rings, pall rings, saddles, and sulzer-structures. Compared to trays, packing has the advantages of (1) having a lower pressure drop per theoretical stage, (2) being more resistant to corrosive materials, (3) having a lower capital cost for small diameter column  $< 3$  ft ( $< 1$ m), and (4) being less susceptible to foaming because of a more uniform flow distribution.

### **Input Streams**

Steam stripping is most applicable for (1) the removal of small amounts of VOCs in large amounts of water, (2) components that form low boiling point azeotropes with water, (3) compounds that are thermally unstable or reactive at high temperatures, (4) compounds that cause excessive fouling, and (5) compounds that present explosion or ignition hazards in direct-fired heaters.

### **Output Streams**

Output streams from steam stripping include stripped waste and condensed volatile constituents based on the process inputs as discussed below.

If the inputs to this process are wastewater with VOCs and steam, the outputs would be a stripped waste (bottoms), which consists of water nearly depleted of organics, and the volatilized constituents (overheads), which consist of organics and water. If the waste is wastewater with organics, metals, and radionuclides, the bottoms would consist mostly of water with all metals and radionuclides, while the overheads would consist of organics and water. In addition to the VOCs, if the wastewater stream contained dissolved metals and radionuclides [both an EPA toxic (Dxxx)

metal and solvent waste] steam stripping would separate the organic material away from the rest of the waste.

### **Advantages**

The advantages of steam stripping as compared to air stripping include (1) ability to separate aqueous wastes contaminated with more soluble, less volatile compounds, not readily air-strippable, including acetone, methanol, and pentachlorophenol, (2) ability to handle higher concentrations, up to several percent by weight, of volatile organic compounds in an aqueous waste, and (3) ability to treat nonaqueous wastes such as spent solvents contaminated with nonvolatile impurities.

### **Disadvantages**

The disadvantages of steam stripping include (1) the capital and operating costs for steam stripping are larger than those for air stripping, (2) in comparison with other treatments for organics, steam stripping is considered a complex system due to the complex process controls, such as temperature, pressure, and reflux ratios, and (3) since the packing depth and tower diameter are functions of the incoming feed concentrations, the required removal, the steam loading ratio, the liquid loading rate, the packing characteristics, temperature, and pressure, the stripping tower may be confined to specific waste stream conditions.

### **Technology Status**

Proven: Steam stripping has been successfully demonstrated for the decontamination of a groundwater containing ketones and alcohols as well as chlorinated solvents at 1,000 ppm. Baron-Blakeslic and the EPA are promoting characterization of specific steam stripping processes.

## **4.7 Incineration**

Incineration is widely used to thermally destroy the organic constituents of a waste, to reduce the waste volume, and to produce more easily-handled ash products. Waste constituents that can be efficiently destroyed by incineration include organic or combustible substances that are hazardous, toxic, carcinogenic, or infectious. The remaining ash products are more compact, inert, homogeneous and more readily immobilized for disposal. Incineration will not destroy radioactive elements, but may change the molecular structure or the physical form of radioactive constituents.<sup>6</sup>

Many different types of incineration processes can be used for treating municipal wastes, liquid and gaseous industrial wastes, sludges, agricultural wastes, and hospital wastes. Incineration has also been used in many countries to treat low-level radioactive mixed wastes. For mixed wastes, incineration destroys the combustible and hazardous constituents, but does not destroy the

radioactive elements. Incineration can, however, reduce the volume of mixed wastes and make the resulting ash more homogeneous and easily treated using immobilization processes for final disposal. Indeed, some incineration processes produce relatively inert slag, glass, or vitrified ash products that are stable and easily disposed.

Most incinerator processes include a main or primary chamber, a secondary chamber, and air pollution control equipment. In the primary chamber, solid, liquid and/or gaseous wastes are heated either directly or indirectly. Upon heating, volatile compounds are devolatilized. The amount of air present in the main chamber determines the classification of the process. In starved or controlled air units, the amount of air available for combustion is at or below the stoichiometric level. A portion of the combustible wastes are oxidized to provide heat for the devolatilization step. When the main chamber is operated with more than the stoichiometric level of air, the unit is operated in the excess air mode.

Two effluent streams from the main chamber are (1) devolatilized gases, combustion products and entrained particulate (fly ash), and (2) the remaining inert and uncombusted material, which may be dry or water-quenched bottom ash, slag, glass, or vitrified ash. The composition and form of the incinerator bottom ash, fly ash, and flue gas depends on the waste feed characteristics, and the design and operating conditions of the incinerator.

Incinerator off-gases generally require secondary combustion in a secondary combustion chamber or afterburner to achieve more complete destruction of devolatilized organic compounds and combustion byproducts. The off-gases are also typically vented to pollution control equipment to remove entrained particulate and acid gases. Effluent streams from the pollution control equipment include the treated flue gas (vented to the atmosphere) and may include (depending on equipment used) dry fly ash, particulate-laden filter elements, used filter bags, and scrubber liquor that contains absorbed acid gases and scrubbed particulate. The solid and liquid effluent streams, like the incinerator ash, must be treated and suitably disposed. In some incinerator processes, these streams are recycled back to the incinerator, or otherwise suitably treated.

In many routine applications, the heat content of the waste can be recovered in waste heat boilers that are used to cool the off-gases prior to the gases arriving at the pollution control equipment. For mixed waste applications, waste heat recovery is usually secondary in importance to maintenance-free operation and containment of radioactive materials, so waste heat recovery is not emphasized beyond the cooling required for protecting the air pollution control equipment.

Advantages common to most incinerator processes include:

- X Destruction of combustible hazardous materials
- X Size and volume reduction of the waste
- X Production of more easily-handled effluents
- X Ability to process various waste forms and flowrates.

Many incinerator processes have common disadvantages. Specific advantages of certain technologies may include the lack of any of the following disadvantages:

- X Inability to destroy radioactive elements of mixed waste
- X Required preparation of the waste prior to incineration
- X Occasional-to-frequent maintenance
- X Leaks of ambient air into the process, or process materials into the surroundings (secondary and tertiary containment requirements)
- X Required further processing of various bottom ash, fly ash, scrubber liquor, filter elements, and other products of operation and maintenance
- X Lag time between emergency incinerator shutdown and final burnout and processing of waste charged at the time of shutdown
- X Sensitivity to problems from out-of-design temperature or other operating conditions (slagging, particulate carryover, incomplete combustion, etc.)
- X Buildup of residual slag, dust, and other materials that require manual cleanout
- X Dependence on the air pollution control system to control gaseous and particulate emissions, even in the event of catastrophic failure of system components (required backup systems).

<u>Section</u>	<u>Technology</u>
4.7.1	Controlled Air
4.7.2	Industrial Boiler

#### **4.7.1 Controlled Air**

Controlled air (starved air) incinerators are those that are designed for substoichiometric conditions in the primary zone (main, or pyrolysis chamber).

The hearth is typically stationary, especially in batch processes. In continuous processes, the number of moving parts may be limited, as in the "pulse hearth." A pulse hearth is pneumatically jolted horizontally a distance of a few inches several times per minute. This agitates the waste bed, exposing more new surface area for combustion, and gradually pushes the bottom ash into the ash recovery system.

Other incinerator designs, such as the rotary kiln, are typically operated in a starved air mode. The primary feature of controlled air incinerators is low volumes of air and gas flow (and low velocities, usually around 1 fps) to reduce entrainment of particulate from the waste bed. Controlled air incinerators usually have at least one secondary (afterburner) section or chamber for more complete combustion of the off-gases.

Solid waste is fed into the refractory-lined primary chamber, which is controlled at temperatures ranging between 950 to 1500EF (510 to 816EC). The combustible and volatile fractions in the waste devolatilize, pyrolyze, and partially combust with air provided at between 30% and 100% of the stoichiometric air requirement. Often the stoichiometry increases toward the far end of the waste bed to encourage more complete burnout of the remaining char. The combustion reactions provide the necessary heat for devolatilization and pyrolysis. The soot and gaseous combustion and pyrolysis products are vented to refractory-lined secondary chamber, which is controlled at 1800 to 2700EF (982E to 1482EC) using auxiliary gas burners. Excess air is provided in the secondary chamber to ensure complete combustion. Liquid waste can be incinerated in either the primary or secondary chambers. The bottom ash is not intended to be slagged or fused. An off-gas treatment system is required to provide emission control.

### **Input Streams**

Feedstreams can include low and high heating value wastes, packaged or dispersed solids, sludges, low and high heating value organic liquids. Auxiliary gas or other fuel is required.

### **Output Streams**

Output streams include (1) bottom ash, including tramp metal and other noncombustibles not removed from the feed, and (2) treated flue gas and solid/liquid products from the air pollution control system.

### **Advantages**

Advantages of controlled air incineration include (1) a wide range of solid, liquid, sludge, and gaseous wastes may be treated, (2) a variety of supplementary fuels can be used for auxiliary fuel, (3) the low air velocity in the primary chamber minimizes the particulate entrainment, (4) the low stoichiometry in the primary chamber helps limit excessive temperatures, thermal and fuel NO<sub>x</sub> formation, wall cooling requirements, and thermal stress, and (5) the stationary refractory has a long life.

### **Disadvantages**

Disadvantages of controlled air incineration include (1) some pretreatment and sorting of wastes is required, (2) more extensive sizing and sorting will improve operation, (3) the unit is not well suited for wastes containing fusible ash, large bulky wastes, or large quantities of noncombustible

wastes, (4) the refractory is subject to buildup of gamma emitting Americium, and (5) wear, erosion and corrosion of some system components, especially the feed system, the ash removal system, and seals, is likely.

## **Technology Status**

Proven: Controlled-air incineration is an operational and conventional technology for nonnuclear and some nuclear applications as well.

### **4.7.2 Industrial Boiler**

This is another application of cofiring hazardous waste in boilers and industrial furnaces (BIF). This approach has been developed in recent years because some industrial furnace and boiler applications have the desired characteristics for treating certain hazardous waste streams. New BIF regulations are currently being promulgated by the EPA to allow (and regulate) permitted hazardous waste cofiring in industrial furnaces and boilers.

In industrial boilers, hazardous waste may be cofired by special permit with the routinely used fuel (typically oil, gas, or coal) for that specific boiler. Since the waste is cofired with other high-heating value fuels, high temperatures and long residence times are often feasible to achieve high destruction efficiencies of hazardous organic components. The heating value of the waste stream is recovered in the boiler steam generation process, and fuel requirements for the boiler are reduced. The actual waste injection design and operation for the boiler depends on the characteristics of the waste.

## **Input Streams**

Input streams consist of liquid or gaseous wastes, sludges, or slurries. Constituents may include practically any organic materials such as solvents, aromatics, halogenated compounds, or oxygenated compounds.

## **Output Streams**

Output streams will include (1) bottom ash, which will be fairly homogenous, and (2) treated flue gas and solid/liquid products from the air pollution control system.

## **Advantages**

Advantages of industrial boilers include (1) the high temperature flame region in the burner zones is efficient in destroying hazardous organic materials, (2) the heating value of the waste stream is recovered in the boiler steam generation process, and (3) fuel requirements for the boiler are reduced.

## Disadvantages

Disadvantages of industrial boilers include (1) atomizer upsets and other upset conditions such as low oxygen or low temperature firing can produce significantly degraded combustion efficiency, (2) hazardous compounds in the waste may not be efficiently destroyed, or significant formation of hazardous products of incomplete combustion (PICs) may occur during upset conditions or due to the cooling effect of water walls or banks steam tubes where combustion reactions may still be occurring, (3) few industrial boilers are equipped with sufficient air pollution control equipment to suitably treat and dispose of the increased amounts of acid gases, devolatilized metals, or particulate, (4) since the primary purpose of industrial boilers is steam (or hot water) generation, they are not designed or operated for suitable containment of radioactive materials, (5) the levels and flowrates of hazardous constituents into the boiler is limited by permit conditions to those levels where suitable process operation and allowable emissions are proven by trial burns, (6) emissions of surrogate indicators [CO and total hydrocarbons (THC)] must be continuously monitored, and (7) the firing of hazardous wastes must be suspended during any process upsets or when emissions exceed allowable limits.

## Technology Status

Available: The technology is available.

## 4.8 Vitrification

Vitrification systems are designed primarily to immobilize hazardous or radioactive substances within a non-leachable, long-life solid glassy or rocklike form that can meet acceptance criteria for shipping and storage. Some technologies, such as the slagging furnace and the plasma heated melter, can both incinerate organic waste components, and also vitrify or glassify the inert waste components. Such combined functions can make these technologies attractive for treating certain wastes, but less easy to categorize. These have been grouped according to their perceived primary function, even when they can serve combined functions. Treatment systems whose primary function is to destroy the organic waste components by combustion are generally classified as incinerator processes. Technologies primarily designed for vitrification are discussed in this section. Some other technologies that are sufficiently different from those classified as incinerators or vitrification systems are grouped separately as thermal degradation or volatilization systems.<sup>6</sup>

Vitrification design technologies that are currently commercially available are discussed in this section and are as follows:

<u>Section</u>	<u>Technology</u>
4.8.1	Glass Furnace (Joule Heated Melter)
4.8.2	Microwave Melter

The glass furnace technologies are at a fixed site such that generators would need to ship their wastes. The microwave melter is a mobile unit that is able to come on site.

#### **4.8.1 Glass Furnace**

A glass furnace is a refractory-lined reactor containing a pool of molten glass. The glass is initially melted by auxiliary heating and then maintained in a molten state 1700 to 2800EF (927 to 1538EC) by joule heating depending on the glass chemistry. Using joule heating, an electric current is passed through the molten material between submerged electrodes. Energy is imparted to the material according to the current and the resistance of the material. Depending on temperature, the electrodes may be inconel or high-molybdenum steel.

Waste may be introduced into one end of the furnace above the molten glass along with combustion air. Liquid and gaseous wastes may be introduced through injectors. Shredded solids and sludges may be introduced through a screw conveyor system, and containerized waste may be fed by a ram feeder. Radiant and contact heat from the molten glass provides the necessary heat to devolatilize and combust organic waste materials above and on the glass pool. Air jets located at different heights on opposing sides of the furnace wall create turbulence for mixing above the molten glass and provide oxygen for combustion.

Exhaust gas is vented out the opposite end of the furnace. In one design, the exhaust is passed through disposable filters. As the filters become loaded with particulate, they are pushed forward into the glass melt by new replacement filters. This recycles the entrained particulate captured on the filters back into the melt and eliminates the filter waste stream. The exhaust gas will generally require acid gas scrubbing in addition to the particulate removal.

Depending on the glass chemistry and the waste makeup, some of the solid products of combustion and inert materials are melted and dissolved into the glass matrix. Materials that are either too refractory to melt or that cannot chemically bond into the glass matrix are physically encapsulated in the glass. The glass-waste mixture can be continuously removed or batch discharged to solidify into a hard, glassy waste form that can be non-leachable.

In one variation, the waste feed and combustion air are introduced into the pool of molten glass via a drop tube. This confines more of the combustion reactions below the surface of the pool, enhances intermixing of the waste and combustion gases with the glass, and promotes higher particulate retention.

#### **Input Streams**

Input streams consist of combustible solids, inert solids, low and high heating value organics, aqueous organics, and sludge wastes. Raw materials include those necessary for glass-making, and filters that are disposed of into the glass melt.

## **Output Streams**

Output streams consist of solidified glass, treated combustion gas, and solid or liquid wastes from the off-gas scrubbing system. Depending on the chemistry and operating temperatures, the solidified glass may be aluminosilicate (low temperature) or borosilicate (medium temperature) glass.

## **Advantages**

The advantages of glass furnaces include (1) glass furnaces will produce a fairly stable output that may readily meet waste acceptance criteria for shipping and storage, (2) the operating temperatures result in high efficiency in destruction of organics, while still being lower than the temperatures in other melters (reducing NO<sub>x</sub> and volatile metals emissions), (3) off-gas processing residues can be recycled through the furnace, and (4) since the heat is maintained by joule heating, the volumes of off-gas are smaller, resulting in smaller sized air pollution control equipment and lower capital costs.

## **Disadvantages**

The disadvantages of glass furnaces include (1) the waste with high moisture content may require to be pretreated to minimize moisture, (2) waste feed variation is limited, and the waste must be well characterized, to prevent variations (such as in metals content) that may affect the electrode operation, (3) low melt resistivity will cause increased current (shorting), and high resistivity will limit the current, (4) dense solids, such as metals, may form a separate phase and tend to settle out of the glass, (5) liquid pools of metals on the bottom of the chamber (called salamanders) may also cause electrode shorting, (6) glass chemistry is dependent on waste composition, (7) due to the addition of glass raw materials, operating costs are higher, and waste volume reduction is less significant, and (8) depending on operating conditions, the electrodes may be rapidly consumed.

## **Technology Status**

Available: Glass furnaces are an operational technology. The technology as applied to hazardous and mixed waste treatment is emerging.

### **4.8.2 Microwave Melter**

Microwave heating can be used for two purposes: destruction of organics or melting of inorganics. Microwave heating occurs through the internal friction produced inside a dielectric material when its molecules vibrate in response to an oscillating microwave field. Microwave penetration depth is a function of material composition, temperature, and frequency of the microwave energy. There are three primary mechanisms involved in heating materials using microwave energy: frictional heat caused by the vigorous vibration of dipolar molecules due to the oscillation of the electromagnetic field, frictional heat caused by the vigorous vibration of

magnetic materials due to oscillation of the magnetic component of the field, and the generation of heat by the electrical component of the field. One, two, or all three mechanisms may be operating at any given time during processing. Tests were conducted using FCC-approved microwave frequencies for industrial, scientific, and medical use, 915 and 2450 MHz. Several microwave penetration depth experiments were conducted with wet and dry sludges to understand where the microwave heat is deposited. The economic application in hazardous waste reduction, detoxification, and recovery for microwave heating is still being investigated.

Microwave technology can also treat soil in situ. This process is known as in situ radio frequency (IRF) heating. IRF consists of a microwave oven built around a block of contaminated soil.

EET Corporation in Knoxville, Tennessee, has developed a thermal process to solidify inorganic wastes using microwave energy. The process produces a synthetic mineral matrix, incorporating hazardous or radioactive components of the waste in the crystal structure. The process is an “in-drum” system and has demonstrated volume reductions up to 80% with sludges.

Synthetic minerals also offer a leach resistant, stable matrix especially suited for hazardous and radioactive wastes. Also, the process equipment does not come in contact with the high temperatures because the heat produced during operation is confined in the container which is insulated from the ancillary equipment.

### **Input Streams**

Input streams are organics, inorganics, radionuclides, and TRU waste. Media state includes sediment, refuse, sludge/slurry, and soil.

### **Output Streams**

Output streams are inorganics, ceramic-like blocks, sludge/slurry, and soil.

### **Advantages**

Advantages of microwave heating include (1) toxic organics are decomposed in much the same way as in incineration but at lower temperatures, (2) microwave technology may be able to more easily treat small quantities of highly toxic materials that cannot be handled by other means, (3) moving parts are limited, (4) the waste may be processed in the final storage container, thus eliminating the need to handle and transport hot chemicals from heated casings of the wiped-film evaporator or extruder into the storage container, (5) microwave heating of radioactive dielectric materials requires no local heating elements because the microwave heat is absorbed directly, (6) less waste is usually generated than from other incineration processes, thus minimizing storage and transportation costs, (7) this technology is effective for both wet and dry materials and has the potential to replace evaporation steps for slurries, and (8) microwave energy can be transmitted through waveguides from generators that can be safely located outside a radioactive

hot cell where routine maintenance can be performed.

### **Disadvantages**

The disadvantages of microwave heating include (1) when equipment is operating at the highest powers, microwave arcing must be prevented by minimizing sharp metallic edges and points in the microwave cavity that attract arcs, (2) uneven melting has not been resolved, (3) melting of the containers is also a problem, (4) the final waste form is not as robust as from other incineration and vitrification technologies, and (5) the ability of the final waste form to meet waste acceptance criteria is not known.

### **Technology Status**

This technology is commercially available for treatment of low-level radioactive waste.

For application to mixed wastes, this technology is still being tested and is under development. Argonne National Laboratory (ANL) has reported 80% destruction of trichloroethene (TCE) in a commercial oven with an activated charcoal filter. The Tokai Works (Japan) has used a microwave melter to transform incinerator ash and acid residues into ceramic-like blocks. This melter was used to treat surrogate material at a rate of 10 lb/hr (5 kg/hr). Bench-scale tests of in-drum vitrification of transuranic (TRU)-contaminated wastes have been performed at DOE's Rocky Flats Plant.

The Oak Ridge National Laboratory (ORNL) Waste Handling and Packaging Plant is proceeding with the development of a microwave process to the pilot-scale level so that fair comparisons can be made vs. other processes such as the wiped-film evaporator and the extruder. The ORNL is also developing a process that uses microwaves to solidify liquid radioactive wastes in the 55 gallon metal drums in which they are stored. The process boils the waste dry and melts the salt residue. The waste contains elements with atomic numbers heavier than that of uranium (e.g., TRU waste). They have also developed a method to eliminate microwave arcing. This process can solidify the waste into salt cakes; the salt cakes meet the available or expected criteria for ultimate disposal of TRU waste at the DOE's planned Waste Isolation Pilot Plant in New Mexico. ORNL researchers are currently operating a one-third scale microwave applicator. They plan to build a 60 kW pilot scale system to demonstrate processing in a 55 gallon drum.

## **4.9 Immobilization/Stabilization**

The technologies presented in this section are designed to immobilize chemical or radioactive hazards by providing a solid waste form, limiting surface area available for leaching, and limiting the solubility or detoxifying the constituents of the waste. All of these processes use either inorganic or organic additives, which serve as chemical bonding agents, waste form or process performance enhancers, and/or containment. The application and selection of an immobilization technology is often driven by EPA's hazardous waste treatment standards, waste handling

concerns, or the waste acceptance criteria of a disposal facility.<sup>6</sup>

Specific types of immobilization/stabilization processes and their applicability to particular waste types are discussed as follows:

<u>Section</u>	<u>Technology</u>
4.9.1	Portland Cement Systems
4.9.2	Encapsulation
4.9.3	Absorption

### **4.9.1 Portland Cement Systems**

These systems use Portland Cement as a solidification/stabilization agent for immobilization of wastes. In this type of system, cement and an aqueous waste, or cement, water, and a waste are mixed to form a solid waste form. Other solid materials such as ion-exchange resin, filter sludges or mechanical assemblies are either added to the mixture or are encapsulated in the cement.

Portland cement is a mixture of powdered oxides of calcium, silica, aluminum, and iron, produced by kiln burning of materials rich in calcium and silica at high temperatures 1400 to 1500EC. When the anhydrous cement powder is mixed with water, hydration occurs and the cement begins to set. Additives, such as lime (CaO), soluble silicates, clays, emulsifiers, etc., are often used to improve process or waste form performance. The chemistry involved is complex because many different reactions occur depending on the composition of the cement mixture.

As the cement begins to set, a colloidal gel of indefinite composition and structure is formed. Over time, the gel swells and forms a matrix composed of interlacing, thin densely packed silicate fibrils. Constituents present in the waste slurry (e.g., hydroxides and carbonates of various metals) are incorporated into the interstices of the cement matrix. The high pH of the cement mixture tends to keep metals in the form of insoluble hydroxide and carbonate salts.

Two types of systems have been used in the past for solidification of wastes. The first type uses "in-drum" mixing. The solidification agent and solid wastes are mixed and placed into a disposal container. Liquids are then added and either the container is rotated or a mixer placed into the container to mix the wastes. The second type mixes wastes, cement and finely sized solids in an external mixer. The wastes are then placed into containers through hoses or chutes. Mechanical assemblies can be placed into a container prior to adding the waste.

### **Input Streams**

Cement systems have been used to solidify a wide variety of wastes such as dilute aqueous liquids, evaporator concentrates, filter sludges, soils, and ion-exchange resins. The wastes typically have

a large fraction of water to add to the cement. Cement systems can also be used to encapsulate larger wastes.

### **Output Steams**

The output from this type of system is a solidified waste form, usually contained in 55 gallon drums.

### **Advantages**

Advantages of Portland Cement Systems include (1) this type of solidification has been used extensively for treatment of LLW in the nuclear power industry, (2) the material and technology is well known and available, (3) most aqueous wastes chemically bond to matrix, (4) compared to other solidification and stabilization technologies, the cost is relatively low, (5) the waste form provides good self shielding, (6) the process does not cause vapor problems, (7) the cement powder has a long shelf life, (8) the waste form has good impact and compressive strength, low leachability for some radionuclides, and does not leave free water if properly formulated, (9) the process can provide rapid controllable setting, without differential setting, and (10) in-container and in-line mixing processes are available.

### **Disadvantages**

Oil and grease in both cement-based and lime/pozzolan-based systems result in the coating of waste particles and the weakening of the bond between the particle and stabilizing agent, thereby decreasing the resistance of the material to leaching. Organic compounds in the waste interfere with the stabilization chemical reactions and bond formation, thus inhibiting the curing of the stabilized material. Sulfate and chloride compounds interfere with the stabilization chemical reactions, weakening bond strength and prolonging setting and curing times. Sulfate and chloride compounds may reduce the dimensional stability of the cured matrix, thereby increasing leachability potential.

Systems with external mixers require cleanup immediately after completion of solidification. Systems with mixing inside the disposal container can have regions of undetected nonsolidification of the waste. In some cases, solids can be produced that do not meet the leachability (i.e., EPA's Toxicity Characteristic Leaching Procedure) or strength requirements for disposal. Recovery from these types of upsets is difficult.

Often, cement based systems significantly add to total waste volume. Solidified waste forms have high densities that can complicate handling and transportation of the waste.

### **Technology Status**

Proven: Portland Cement has been used extensively for treatment of LLW in the nuclear power

industry. Portland Cement based systems are frequently used to satisfy RCRA hazardous waste treatment standards, where stabilization has been determined to be the BDAT.

#### 4.9.2 Encapsulation

Encapsulation processes can take the form of macroencapsulation, microencapsulation, or both. Microencapsulation is the containment of individual waste particles in a polymer or asphalt matrix. Macroencapsulation is the encasement of a mass of waste in a thick polymer coating. The waste mass may have been microencapsulated prior to macroencapsulation. Several polymeric matrices are available for use in these encapsulation processes. These include asphalt, polyethylene, thermosetting plastics (such as urea formaldehyde type resins), sulfur polymer cement, and resins that can be polymerized under ambient temperature in the presence of a catalyst. The EPA believes that encapsulation technologies are primarily applicable to wastes containing hazardous metal constituents. The Agency has established a treatment standard of macroencapsulation for radioactive lead solids.

Microencapsulation processes typically involve the following unit operations in series:

- X Predrying of the waste to remove entrained moisture.
- X Mixing of the heated waste with molten encapsulating agent (asphalt, polyethylene, thermosetting resins).
- X Cooling of the hot mixture to allow the mixed mass to harden into a solid mass.

Generally, ratios of matrix to waste used in microencapsulation are high compared to those of pozzolanic stabilization processes (i.e., the ratio is in the 1:1 to 1:2 range for encapsulation). Mixing via extrusion is generally done at 250 to 265EF (120 to 130EC) depending on the melting characteristics of the matrix and the type of equipment used for mixing. A few processes differ from the above description in that polymerization of monomers mixed with waste is conducted at ambient or near ambient temperatures in the presence of catalysts. The monomer (or monomeric mixture) then polymerizes at room temperature, coating the individual particles.

The macroencapsulation process of hazardous waste solids usually involves two steps. In the first step, the hazardous wastes may be chemically treated by using low-cost dehydrating agents such as lime, kiln dust, or Portland Cement. This operation does not increase volume of the solids significantly because only a small amount of dehydrating agent is needed to dewater the solids. The resulting mixtures are friable, and they can easily be ground. In the second step, the dehydrated sludges are ground and the particles may be microencapsulated, typically by a polybutadiene binder. Then the mass is macroencapsulated, or coated, typically by high-density polyethylene. The typical apparatus for macroencapsulation processes features heated or cooled molds, a method of waste and hardened product manipulation, and hydraulics for mold actuation. The molds typically contain electrical band heaters and water cooling channels. After the polymer

coating hardens, the mold is split to facilitate product demolding.

Several types of organic polymer solidification systems have been used or proposed in the past. These systems include urea-formaldehyde (UF), vinyl ester styrene (VES), polyester, polyethylene, and other similarly based systems. Only the UF and VES based systems have been used routinely for treatment of LLW. The UF based systems had significant amounts of liquid remaining after treatment and are no longer used. Therefore, the only polymer system in current use is the VES based system. VES immobilizes the waste by encapsulating it in a plastic matrix. When liquid waste is processed, it is dispersed in the binder and, when the binder hardens, the waste becomes trapped in the small cells that are formed. These polyester-type resin based polymers are particularly attractive because of their ability to immobilize free water in the cell structure of the matrix.

In the VES system, a waste container is partially filled with vinyl ester resin binder. Liquid waste is mixed with styrene catalyst and a promoter. The mixture is added to the container and mixed. The mixture solidifies in about one hour.

### **Input Streams**

Encapsulation technologies are primarily applicable to wastes containing hazardous metals, such as lead solids, heavy metal sludges, and incinerator ash.

VES systems can be used to solidify a wide variety of wastes such as dilute liquids, evaporator concentrates, filter sludges, and ion-exchange resins.

### **Output Streams**

Encapsulation processes produce a solid waste form.

The output from VES systems is a solidified waste form, usually contained in 55 gallon drums.

### **Advantages**

Advantages of encapsulation include (1) the process can be effective for some soluble and toxic materials not readily treated by other stabilization technologies, (2) for compatible wastes, pollutant containment may be significantly improved over other processes, and (3) high waste-to-polymer volume ratios can be obtained.

Advantages of VES include (1) the process is adaptable to many liquid and solid wastes, (2) the process does not leave free standing water, (3) the final waste form has a relatively low leachability, high compressive and impact strength, and good radiation stability, (4) the process is appealing due to the ease of working with liquid components, and (5) in-container mixing is available.

## **Disadvantages**

Disadvantages of encapsulation include (1) the presence of greases, oils, chelating agents, entrained moisture, organic solvents, hydrated salts (sodium sulfate, magnesium sulfate, metal chlorides), or oxidizers (such as nitrites, chlorates, or perchlorates) may interfere with the setting or level of performance of the matrix material, (2) heating of mixtures of waste with polymers or asphalt can cause hydrocarbon emissions, and (3) processing is more difficult (e.g., higher temperatures, specialized equipment) than for pozzolan and pozzolan-portland cements and therefore more expensive.

Disadvantages of VES include (1) binder shelf life is limited to six months, (2) hazards are associated with monomer, catalyst, and promoter handling, (3) some wastes may interact chemically and prevent or affect polymerization, (4) the materials are relatively expensive, and (5) the mixing method is critical for success.

## **Technology Status**

Proven: The EPA's best demonstrated available technology for radioactive lead solids is macroencapsulation. Various encapsulation processes have been used to stabilize commercial hazardous waste, as well as radioactive LLW.

VES systems have been used in commercial LLW systems for several years.

### **4.9.3 Absorption**

The immobilization of oily products is done using absorption with a high molecular weight polymer.<sup>23</sup> As oil is absorbed and immobilized, it can be mixed into a cementitious material and stabilized in the cement. This gives a structural material like cement with the oil contained and not available for leaching through the pores in the concrete.

The polymer is a multicomponent polymer engineered to absorb a broad range of oily products from hexane, gasoline, diesel fuel, chlorinated solvents, polar materials like acetates, ether, methylisobutyl, ketone, and other low viscosity fluids that adsorbents work poorly with. Once absorbed into the molecular structure, the liquid cannot be squeezed out.

## **4.10 Metal Recovery**

Some metals in waste streams are worth recovering from waste streams for reuse. First, the concentrations and physical form of recoverable metals is important. Second, the purity of the recovered metals determines if the metals can be recycled. Recovery purity depends on variables such as the recovery process and concentrations of the desired metals and undesired components.

The most common types of contaminated metals include mild steel, stainless steel, aluminum,

copper, nickel, and brass. Smaller amounts of heavy metals occur. Metals take up little volume in waste streams but can be a considerable fraction of the total weight of the waste streams.

The approach is to first use surface decontamination as much as possible. Estimations are given that 75% of all metal will be successfully decontaminated. Melt refining can then be used to remove radionuclide contaminants from metals or alloys by preferential oxidation. The oxidized contaminants are then separated from the metal. Uranium and transuranic elements are readily oxidized. Metal melters may be heated by electrical induction heating or by plasma arc. When contaminated metal and slagging material is placed in the furnace and melted, a slag phase forms and floats on top of the metal phase. Fluxing agents may improve the slag separation. As the radioactive contaminants oxidize, the metal phase is left relatively free of contamination. The slag and metal phases are removed separately from the melter through separate taps. The slag phase containing the bulk of the contamination can be cooled into a vitrified slag. Any combustible and volatile materials including volatile metals and metal oxides are either contained by vacuum melters and enter into the slag or they enter an off-gas system.

Commercially, 1 to 20 ton melt capacity exists. Current disposal costs of nuclear power plant metals are \$400/cu ft. A typical power plant has 100 tons of stainless steel that could be sent for recycle. By sending it for recycling, the disposal cost is avoided and the materials are then fabricated into usable products. Acceptance criteria require that no materials exceed 25mR/hr.

### **Input Streams**

Any metals, metal oxides or metal salts preferably sorted according to stainless steel, carbon steel, etc. with no non-metals mixed in. Also, it is preferred that the material be free of paint, and gross rust but contaminants can include combustible, hazardous and radioactive materials.

### **Output Streams**

Output streams are de-listed metals, or radioactive metal products for use as containers and barriers by industry. Also contamination rich slag, and off-gasses are created.

### **Advantages**

Advantages include the phase separation of decontaminated metals from the more contaminated, slag forming non-metals and metal oxides. The slag can be processed further to concentrate and recycle radioactive elements and its final form can be vitrified glass or basaltic material.

### **Disadvantages**

Disadvantages include some waste sorting and size reduction of metal components, and the process operates at high temperatures and volatilization of metals and metal oxides will need to be addressed. The purity of the recovered metal is highly dependent upon process variables and may

require further processing.

### **Technology Status**

Metal melting in the metals industry is a well established and conventional technology. Treatment of low-level radioactive wastes has been done commercially since 1992.

## **4.11 Physical/Chemical Treatment**

<u>Section</u>	<u>Technology</u>
4.11.1	Neutralization
4.11.2	Oxidation/Reduction
4.11.3	Steam Reforming
4.11.4	Alkaline Hydrolysis for Biological Materials
4.11.5	Supercritical Water Oxidation
4.11.6	Quantum- CEP
4.11.7	Thermal Desorption

### **4.11.1 Neutralization**

Neutralization is used to adjust basic or acidic waste to an acceptable pH range (usually between pH 6.0 and pH 9.0). The pH is adjusted by adding alkaline wastes or chemical reagents to acidic wastes and vice versa. Neutralization is used to treat wastes in order to reduce or eliminate their reactivity and corrosiveness. The process can be operated either batch or in a continuous mode depending upon application. Equipment needs are modest consisting of pumps, tanks, mixers, and pH instrumentation for control. Besides modest capital requirements, operating costs can be inexpensive. The only major requirement is that adequate mixing should be provided to ensure complete reaction. As an option, a second reactor stage may also be provided. Equalization takes place during the second stage where further mixing occurs, allowing time for the neutralization reactions to reach equilibrium. Care must be taken to ensure compatibility of the waste with the treatment chemicals to prevent formation of significant solids or hazardous byproducts. Liquids, slurries, and sludges are all amenable to treatment by neutralization. In situ neutralization involves injecting dilute acids or bases into the ground to either optimize pH for further treatment or to neutralize plumes so that further treatment is not necessary.

### **Input Streams**

Neutralization can be used on either organic or inorganic, spent acidic and alkaline wastes. The process can be used on liquids, slurries, sludges, and even gases under appropriate conditions.

## **Output Streams**

The residual includes a neutralized (pH between 6 and 9) effluent containing dissolved salts and possibly suspended solids. Residuals can be in the form of a liquid, sludge, slurry, or gas.

## **Advantages**

Advantages of neutralization include (1) the process is simple, using readily available equipment, (2) it is reliable and can be automated, (3) the process can be applied in situ, (4) it can be applied either continuously or as a batch operation, and (5) overall treatment costs are normally quite modest.

## **Disadvantages**

Disadvantages of neutralization include (1) construction materials must be resistant to corrosivity of the wastes and reagents, (2) the potential exists for hazardous violent, and or exothermic, reactions to occur in the neutralization process, and to produce air emissions in some cases, and (3) the byproducts can be hazardous.

## **Technology Status**

Available: This technology is readily available.

### **4.11.2 Oxidation/Reduction**

Reduction-oxidation (redox) reactions chemically transform reactants to increase the oxidation state of one reactant, and decrease the oxidation state of the other reactant. This process is used to destroy, or at least reduce the toxicity, of many toxic organics and heavy metals. This method can also be done in situ. The use of reducing agents is less common than oxidizing agents because of the high reactivity of the reducing agents.

Redox reactions can be used to detoxify, precipitate, or solubilize metals and decompose, detoxify, or solubilize organics. Oxidizing agents commonly employed include hypochloride or chlorine, ozone, hydrogen peroxide, and permanganate. Commonly employed reducing agents include sulfur dioxide, sodium borohydride, sulfite, ferrous ion, and hydrazine.

The effectiveness of redox processes in treating wastes depends not only upon characteristics of the specific waste but also on system design and operating parameters. Depending on the particular species of interest, the waste characteristics of importance are the total concentration of other oxidizable/reducible species present, the concentration of metal salts, and the concentration of oil and grease. The presence of other oxidizable/reducible species will increase the demand for reagents, thus potentially reducing the effectiveness of the process. Likewise, metal salts, particularly lead and silver salts, can react with various oxidizing agents to form insoluble

compounds such as chlorides, chlorates, hypochlorites, peroxides, and sulfites. This can cause excessive consumption of the oxidizing agent and reduce the effectiveness of treatment. Finally, oil and grease can potentially cause problems because of fouling of monitoring and control instrumentation such as pH and oxidation/reduction potential (ORP) probes. For efficient process operation, waste characterization and homogeneity of waste composition are important considerations.

The important system design and operating parameters include residence time, reagent choice and amount, the degree of mixing, system pH, operating temperature and choice of catalyst, if required. The selection of appropriate system residence time is important to ensure complete reaction while minimizing devolatilization of waste components or byproducts.

The choice of reagent and addition rate are influenced by several factors. The amount of reagent required will vary with the agent chosen. Enough reagent must be added to ensure complete reaction with all available species, while the specific amount depends upon the nature of the reactant species in the waste and the detailed redox chemistry involved. In practice, reagent addition is in excess of stoichiometric requirements to account for variability in waste composition and mixing, and ensure complete reaction.

The degree of mixing must be sufficient to prevent stagnation and concentration gradients in the reagent-waste mixture. Proper mixing will ensure maximum contact between reagent and the waste. It can also limit the production of solids from side reactions. These solids could potentially resist further reaction, decreasing the effectiveness of the process.

The selection of the optimum system operating pH is important to maximize the effectiveness of the redox chemistry. In addition, selection of the proper pH can eliminate or minimize unwanted side reactions. Finally, selection of proper pH may be required to maintain reactant species, such as cyanide, in the proper form and prevent their unwanted release.

Selection of appropriate operating temperature is important because it affects the rate of the redox reactions and the solubility of the reagent and waste. Reaction rates increase with temperature, and in most cases solubility also increases with temperature. Thus, typically the process is operated at elevated temperatures to improve the reaction kinetics and reduce the required system residence time.

In some cases, the use of an appropriate catalyst may allow operation at a lower temperature and/or improve the level of destruction of the target waste components. Typical catalysts for oxidation include copper nitrate and copper bromide.

The redox process can be operated in either the batch or continuous mode. Equipment requirements are modest, consisting of standard process equipment. This includes equipment such as chemical feed systems, tanks, pumps, agitators, and instrumentation for control and monitoring. At a minimum, instrumentation will consist of pH and ORP monitors. The latter

would be used to monitor the effectiveness of the process. However, since ORP is nonspecific, waste characterization and homogeneity of waste composition is important to ensure the effectiveness of the process.

For proper treatment and disposal of the waste, additional system operations such as pretreatment and post-treatment may be required. Pretreatment might include size reduction and filtration, while post-treatment might include clarification or filtration. The requirements will depend on the specific waste being treated.

### **Input Streams**

This process can be used on aqueous wastes, liquids, sludges, and slurries. Contaminants amenable to treatment include cyanide, aldehyde, mercaptans, phenols, benzidine, unsaturated acids, pesticides, benzene, arsenic, iron, manganese, chromium VI, mercury, lead, silver, chlorinated organics, and unsaturated hydrocarbons.

### **Output Streams**

Effluents will include liquids, gases, and possibly solids. The gases will include primarily carbon dioxide and water vapor. The liquids will be aqueous systems containing primarily salts and simple inorganic acids or bases. The solids will include precipitates formed during the process.

### **Advantages**

Advantages of oxidation/reduction include (1) the process is simple, and uses readily available equipment and reagents, (2) capital, operating, and maintenance costs can be low, (3) the process can be operated either continuously or batch, and (4) is applicable to a wide variety of waste constituents.

### **Disadvantages**

Disadvantages of oxidation/reduction include (1) implementation is sometimes difficult because the system must be designed for the specific application, (2) laboratory and/or pilot-scale testing is required, (3) the reagents themselves are often hazardous, (4) the possibility exists for undesirable side reactions or the production of hazardous byproducts, (5) process control is difficult if waste composition varies significantly, and (6) the process cannot be used to treat solids.

### **Technology Status**

Available: This technology is available.

### **4.11.3 Steam Reforming**

Steam reforming is a newly patented waste processing technology which was originally utilized primarily for the processing of medical and hazardous wastes. This technology is often called “steam detoxification” as it “detoxifies” or renders hazardous or pathological materials “nonhazardous.”

Steam reforming (detoxification) systems produce a final waste form similar to incinerator ash. However, the processing methodology employed is significantly different from an incinerator and the system is in fact not classified as an incinerator by the U.S. Environmental Protection Agency. Steam reforming systems, unlike all types of incinerators, do not employ combustion in an oxygen atmosphere to reduce waste. Instead, they employ a super-heated steam (1100°F) which reforms (reduces) the waste down to small gas size particles which can then be burned in a special reactor that is devoid of oxygen.

Organic material is reduced to a small volume of ash. The drum is supercompacted once all the waste in the drum is processed. Typical volume reductions as high as 100:1 are obtained for most organic materials. Resins exhibit volume reductions of approximately 6:1. Steam reforming is ideally suited for the processing of many problematic wastes, including mixed wastes, and those exhibiting medium to high activity levels.

### **4.11.4 Alkaline Hydrolysis for Biological Materials**

The WR<sup>2TM</sup> Process\* is a form of “reductive cremation” in which vertebrate, invertebrate, and microbial tissues are hydrolyzed for 12-18 hours at ~230-260°F with dilute aqueous alkali under pressure in a hermetically sealed stainless steel tank. The process hydrolyzes the proteins, nucleic acids, and lipids of all tissues, including hairs and feathers, thereby producing a sterile solution of the natural building blocks of tissues. The alkali itself is consumed in the process by generating the salts of the hydrolysis products. The resulting sterile aqueous solution is rapidly metabolized by the microbes used in water treatment plants. No infectious fungi, bacteria, or viruses survive this process intact because they themselves are made up of proteins and nucleic acids in combination with lipids. The only byproducts of the process are the mineral constituents (ash) of the bones of vertebrates. They are soft enough after the organic matter has been degraded to be easily ground up and recovered as calcium phosphate powder. The WR<sup>2TM</sup> Process solubilizes embalmed or fixed tissues\*\* with equal efficiency and, in addition, destroys the fixatives as well. None of the potentially hazardous chemicals used in such fixation processes can be detected after the alkaline hydrolysis process. Thus, the WR<sup>2TM</sup> Process not only compares favorably with incineration, but is free of its potential for air pollution. By contrast, all products resulting from the WR<sup>2TM</sup> Process can be truly biodegraded or recycled without stressing the environment in any way.

#### **4.11.5 Supercritical Water Oxidation**

Supercritical water oxidation (SCWO), also known as hydrothermal oxidation, destroys toxic and hazardous organic wastes in a compact, totally enclosed system. SCWO destroys organic wastes using an oxidant in water at temperatures and pressures above the critical point of water, 705°F (374°C) and 218 atm. At these conditions, organic materials and gases become highly soluble in water. This makes it possible to carry out rapid, complete oxidation using water as a carrier medium. High densities and measured concentrations lead to excellent process stability. Typical products from a SCWO process include carbon dioxide, water, and inorganic salts or acids. All effluents can be stored for analysis and verification of waste destruction prior to release. Destruction efficiencies in excess of 99.99% can be achieved.

#### **Input Streams**

Input streams for this technology would include organic low-level radioactive or mixed wastes such as ion-exchange resins.

#### **Output Streams**

The output stream would consist of carbon dioxide, oxygen, nitrogen, water, hydrochloric acid, sulphuric acid, salts, metallic oxides, and radionuclides.

#### **Advantages**

Destruction efficiencies are 99.99% destruction of total organic carbons. The process is run at low temperatures compared to thermal treatments 930 to 1200°F (500 to 650°C). There are no off-gas products besides CO<sub>2</sub>, N<sub>2</sub> and some CO. The temperatures are too low for the formation of NO<sub>x</sub> and SO<sub>x</sub>. The liquid effluent may be recycled back into the system minimizing secondary waste streams. A mobile 500 gpd unit has a small footprint of approximately 20 x 40 ft.

#### **Disadvantages**

A protective liner is used in corrosive waste streams such as those containing hydrochloric acid or sulfuric acid. This liner may need to be replaced for every 200 hours of operation. The process occurs in a pressurized vessel requiring stringent safety and maintenance operations.

#### **Technical Status**

Treatment of highly chlorinated mixed wastes has been demonstrated using surrogates. Treatability studies could be done on-site of the generators or done at General Atomics mixed waste treatment facility.

#### **4.11.6 Quantum-Catalytic Extraction Process (Quantum-CEP)**

The Quantum-Catalytic Extraction Process (Quantum-CEP) is used to treat ion-exchange resins, a radioactive by-product from nuclear power plants. Quantum-CEP uses molten metal as a catalytic and solvent to break down wastes to their elements. Quantum-CEP reconfigures these elements into useful gases, ceramics and metals. This process separates out radionuclides and encases them in a stable material for disposal. The process destroys hazardous and toxic materials and reduces the volume of and stabilizes radioactive elements for final disposal. The process typically reduces the volume of complex radioactive materials by more than 300:1 and simple radioactive materials by as much as 1000:1.<sup>32</sup>

##### **Input Streams**

Input streams for the CEP can include solids, liquids, sludges, or gases. These include industrial biosolid waste (wastewater treatment residuals), spent electronic components (metals, ground computer, circuit boards), chlorobenzene, isocyanate wastes, chlorinated wastes and solvents.

Input streams for the Quantum-CEP include radioactively contaminated scrap metal, and ion-exchange resins from nuclear power plants.

##### **Output Streams**

Output streams for the CEP include synthesis gas (used for methanol, ammonia, acetic acid, and synthetic fuels), nitrogen (separated out for ammonia and plastics), ceramics (used in concrete, roofing shingles, and abrasives), ferroalloys (for scrap metals and alloy steel), and hydrogen chloride (for plastics, steel making, and solvent production).

Output streams resulting from Quantum-CEP feed consisting of radioactive ion-exchange resins may include gases, ceramics, and metals in final form ready for disposal.

##### **Advantages**

Advantages of this technology include the following: 1) catalytic incineration is excellent for lower temperature combustion and destruction of gaseous materials, and (2) proven volume reductions from 300:1 to 1000:1, 3) results in a solid, stable waste form ready for disposal, 4) results in other useful products, 5) broad application for hazardous and radioactive materials, including the treatment of large volumes of ion-exchange resins produced at nuclear power plants.

##### **Disadvantages**

Disadvantages of catalytic extraction include (1) the combustible waste concentration in the stream should never exceed the lower flammability limit in order to guard against explosion and fire, (2) some materials including phosphates and compounds of metals such as arsenic, mercury,

zinc, and lead can poison the catalyst, (3) the pressure drop through some catalyst beds may limit the throughput, (4) if the stream contains high particulate loadings, prefiltration or electrostatic precipitation is required, (5) cleaning and eventual replacement of the catalyst are required, (6) replacement catalyst may be expensive, (7) other contaminants may foul or suppress catalyst operation, and (8) during system operation, high preheat temperatures accompanied by the increase in temperature (due to combustion) may result in high operating temperatures in the catalyst bed causing overheating of the bed and loss of bed activity.

### **Technology Status**

Available: This technology is available at several facilities as discussed in the next section.

#### **4.11.7 Thermal Desorption**

Thermal desorption technology is used to stabilize hazardous hydrocarbon waste. The thermal desorber exposes the waste to high temperatures in an inert atmosphere.

#### **Input Streams**

Input streams for this technology would include hazardous hydrocarbon wastes.

#### **Output Streams**

The output stream consists of a dry, powdery residue.

#### **Advantages**

The resulting residue is stable and can be containerized and disposed.

#### **Disadvantages**

A disadvantage to this technology is that it requires substantial power to run the operation and high temperatures are realized.

#### **Technical Status**

This technology is currently available.

## 5. Commercial Vendors Available

This section discusses the activities and treatment technologies available at thirty-nine different companies. These thirty-nine companies were identified as vendors that have the capability of providing a technology for treating waste at their facility, bring a mobile unit into the field for on-site treatment, or provide a unique product or treatment of commercially-generated LLW or MLLW. The companies presented in this report provide treatment services to the commercial sector. There are many more companies that provide waste treatment for the DOE or other Federal agencies. Also, the companies presented have waste treatment technologies available today. Many other companies provided information that they are developing various technologies. As new processes are developed and proven in the commercial sector and other companies with waste treatment available to the commercial sector are identified, those companies will be entered into the document as it is periodically updated. This is in no way an endorsement of the companies presented nor is the list complete.

Table 5-1 shows a list of commercial vendors with their associated technology category for treating LLW and/or MLLW.

Table 5-2 provides the company name, address, phone and fax numbers for companies that can provide a treatment for commercially-generated LLW and/or MLLW.

### 5.1 ADCO Services, Inc.

ADCO Services, Inc. (ADCO), located in Tinley Park (a southern suburb of Chicago, Illinois), is a low-level radioactive waste broker. An overview of ADCO's capabilities is listed below.

Packaging, labeling, manifesting, transportation, processing, compaction, and disposal of various types of long-lived LLRW including, but not limited to, the following:

- X dry active waste
- X aqueous liquid waste
- X animal carcasses/biological waste
- X incinerator ash
- X mixed wastes
- X liquid scintillation media
- X sealed sources/measurement gauges
- X NORM waste.

**Low-level Radioactive and Mixed Waste Treatment Vendors**

(Page 1 of 2)

Company	sol/liq Yes/No	mobil	LLW	MLL	Sizing	Compaction	Super-Comp	Filtration	Decon	Evaporator	Separator	Incinerate	Vitrification	Immobilization/Stabilization	Metal Recovery	Phys/Chem Treatment	LSV
ADCO Services, Inc.	S	N	X		X	X											
ALARON Corporation	S	N	X		X		X		X								
Allied Technology Group, Inc.	S	N	X		X	X	X										
Applied Health Physics, Inc	S	Y	X			X			X								
Applied Radiological Control	S	Y	X						X								
B&W Nuclear Env. Services, Inc.	S	N	X				X										
Bartlett Nuclear, Inc.	S	Y	X		X				X								
Chem-Nuclear Systems, Inc.	S/L	Y	X			X		X	X		X			X			
Corpex Technologies	S	Y	X						X								
Diversified Scientific Services, Inc.	L	N		X								X					X
Diversified Technologies Services	S	Y	X								X			X			
EET Corporation	S	N	X										X				
Eichrom Industries, Inc.	L	Y	X								X						
Envirocare	S	N	X	X	X									X			
Environmental Alternative's Inc.	S	Y	X						X								
Fluid Tech. Inc.	S/L	Y	X		X				X					X			
Framatome Technologies, Inc.	S/L	Y	X		X				X	X	X						
Frank W. Hake Associates	S	N	X			X			X								
Gencorp Aerojet	S	N	X			X			X								

5-2

**Table 5-1.** Commercial vendors and their associated LLW or MLLW treatment applications.

**Low-level Radioactive and Mixed Waste Treatment Vendors**

(Page 2 of 2)

Company	sol/liq Yes/No	mobil	LLW	MLL	Sizing	Compaction	Super-Comp	Filtration	Decon	Evaporator	Separator	Incinerate	Vitrification	Immobilization/Stabilization	Metal Recovery	Phys/Chem Treatment	LSV
General Atomics	S/L	N	X	X	X												X
GTS Duratek	S/L	N	X										X				X
Imbititive Technologies	L	Y	X											X			
INET Corporation	S	Y	X				X										
Interstate Nuclear Services	S	Y	X						X								
Manufacturing Sciences Corporation	S	N	X												X		
M4 Environmental	S	N	X	X											X	X	
Nuclear Fuel Services	S	Y	X	X	X	X		X	X					X	X	X	
Nuclear Metals, Inc.	S	Y	X			X			X						X		
Nuclear Sources and Services, Inc.	S/L	N	X	X		X		X	X		X			X	X	X	X
NUKEM Nuclear Technologies	S	Y	X			X				X	X			X			
Perma-Fix of Florida	S/L	Y	X	X					X					X		X	X
Scientific Ecology Group, Inc.	S/L	Y	X	X	X	X	X		X	X	X	X	X	X	X	X	
Sevenson Environmental Services,	S	Y	X											X			
Southwest Research Institute	S	N	X	X										X			
Thermo NUtech	S	Y	X								X						
Thomas Gray and Associates, Inc.	S	Y	X				X										
US Ecology	S	Y	X		X		X		X								
VECTRA	S/Y	Y	X			X								X			
Waste Reduction by Waste Reduction, Inc.	S/L	Y	X														X

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**Table 5-1.** (Continued).

Number	Company	Address	Phone	Fax
1	ADCO Services, Inc.	47650 Duvan Drive, Tinley Park, IL 60477	708-429-1600	708-429-9759
2	ALARON Corporation	RD 2 Box 2140A, Wampum, PA 16157-9320	803-791-9900	803-791-9911
3	Allied Technology Group, Inc.	47375 Fremont Blvd., Fremont, CA 94538	510-490-3008	510-651-3731
4	Applied Health Physics, Inc.	2986 Industrial Blvd., Bethel Park, PA 15102-0197	412-831-3000	412-835-9559
5	Applied Radiological Control, Inc.	500 Chastain Center Blvd., Suite 525, Kennesaw, GA 30144-5559	770-429-1188	770-449-8531
6	B&W Nuclear Env. Services, Inc.	2220 Langhorn Rd., Lynchburg, VA 24501	804-948-4600	804-948-4801
7	Bartlett Nuclear, Inc.	P.O. Box 1800, Plymouth, MA 02360	800-225-0385	508-830-0997
8	Chem-Nuclear Systems, Inc.	140 Stoneridge Drive, Columbia, SC 29201	803-256-0450	803-771-0842
9	Corpex Technologies, Inc.	P.O. Box 13486, Research Triangle Park, NC 27709-3486	423-691-4877	423-691-4990
10	Diversified Scientific Services, Inc.	657 Gallaher Road, Kingston, TN 37763	423-376-0084	423-376-0087
11	Diversified Technology Services, Inc.	2680 Westcott Blvd, Knoxville, TN 37931	423-539-9000	423-539-9001
12	EET Corporation	11217 Outlet Drive, Knoxville, TN 37932	423-671-7800	423-671-7789
13	Eichrom Industries, Inc.	8205 S. Cass Avenue, Suite 107, Darien, IL 60559	708-963-0320	708-963-0381
14	Envirocare	46 West Broadway, Suite 240, Salt Lake City, UT 84101	801-532-1330	801-537-7345
15	Environmental Alternatives, Inc.	P.O. Box 160, West Chesterfield, NH 03466-0160	603-256-6440	603-256-6741
16	Fluid, Tech, Inc.	4335 W. Tropicana, Las Vegas, NV 89103	702-871-1884	702-871-3629
17	Framatome Technologies, Inc.	3315 Old Forest Road, P.O. Box 10935, Lynchburg, VA 24506-0935	804-832-3000	804-832-3663
18	Frank W. Hake Associates	1790 Dock Street, Memphis, TN 38113	901-774-2850	901-942-2207
19	Gencorp Aerojet	Old Highway 11-East, P.O. Box 399, Jonesborough, TN 37659	423-753-1252	423-753-8645
20	General Atomics	3550 General Atomics Ct., San Diego, CA 92121-1194	619-455-4495	619-455-4111
21	GTS Duratek	8955 Guilford Road, Suite 200, Columbia, MD 21046	410-312-5100	301-621-8211
22	Imbibitive Technologies	1108 Dundas Street, London, Ontario, Canada N5W 3A7	419-453-0988	519-659-4713
23	INET Corporation	8450 Central Avenue, Newark, CA 94560	510-797-9600	510-794-7066
24	Interstate Nuclear Services Corporation	295 Parker Street, P.O. Box 51957, Springfield, MA 01151	413-543-6911	413-543-6989
25	Manufacturing Sciences Corporation	8917 N.E. Etna Road, Woodland, WA 98674	360-225-6013	360-225-6224
26	M4 Environmental	151 Lafayette Drive, Oak Ridge, TN 37830	800-693-0060	423-220-4195
27	Nuclear Fuels Services, Inc.	205 Banner Hill Road, Erwin, TN 37650	423-743-1706	423-743-0140
28	Nuclear Metals, Inc.	2229 Main St., Concord, MA 01742	508-369-5410	508-369-4045
29	Nuclear Sources and Services, Inc.	P.O. Box 34042, Houston, TX 77234	713-641-0391	713-641-6153
30	NUKEM Nuclear Technologies	260 Berryhill Road, Suite 500, Columbia, SC 29210	803-731-1588	803-731-8435
31	Perma-Fix of Florida, Inc.	1940 N.W. 67th Place, Gainesville, FL 32653	800-365-6066	904-372-8963
32	Scientific Ecology Group, Inc.	P.O. Box 2350, 1560 Bear Creek Road, Oak Ridge, TN 37830	423-367-8010	423-378-8481
33	Sevenson Environmental Services, Inc.	9245 Calumet Ave., Suite 101, Munster, IN 46321	219-836-0116	219-836-2838
34	Southwest Research Institute	6220 Culebra Road, San Antonio, TX 78228-0510	210-522-2341	210-522-5122
35	Thermo NUtech	5635 Jefferson Street NE, Albuquerque, NM 87109	505-345-9931	505-761-5410
36	Thomas Gray and Associates, Inc.	1205 West Barkley Avenue, Orange, CA 92668	714-997-8090	714-997-3561
37	US Ecology	109 Flint Rd., Oak Ridge, TN 37830	423-482-5532	423-482-5605
38	VECTRA	One Harbison Way, Suite 209, Columbia, SC 29212	803-781-0426	803-781-9316
39	Waste Reduction by Waste Reduction, Inc.	212 Pinewoods Avenue, Troy, NY 12180-7244	518-262-5380	518-271-2040

**Table 5-2.** Company names, addresses, phone numbers and fax numbers.

ADCO also provides services such as:

- X decontamination and decommissioning
- X decay in storage of LLW with half-lives of 120 days or less.

In 1985, a wholly owned subsidiary called PWN Environmental (located in San Diego, California) began providing similar services to the western part of the country. Additionally, PWN offers biohazardous and chemical waste disposal services.

## **5.2 ALARON Corporation**

ALARON Corporation (ALARON) provides sizing, supercompaction and decontamination capabilities for treatment of LLW. ALARON has an NRC license to handle the following materials:

- X Byproducts and source materials with atomic numbers 1-96, up to 100 curies
- X Up to 250 grams of special nuclear material and 10 grams of plutonium
- X Up to 1,000 kilograms of depleted uranium in any form.<sup>7</sup>

In addition, ALARON can provide supercompaction of DAW at a capacity of 200,000 ft<sup>3</sup> (5,700 m<sup>3</sup>) annually. ALARON also has sizing capability whereby they can

cut metal through segmentation and dense packaging. This method can provide up to 80% volume reduction.

ALARON's decontamination process involves its patented DECOHA chemical decontamination process in cleaning contaminated stainless steel, carbon steel, lead, aluminum, and other metals. ALARON also provides various abrasive and non-abrasive mechanical decontamination systems.

ALARON is teamed with Nuclear Metals, Inc. for treatment of LLW using metal melt technology. See Nuclear Metals, Inc. for more information. ALARON is involved with the fabrication of RAM-LOC™ shielding utilizing the generator's contaminated metals. This, too, is done through Nuclear Metals, Inc.

## **5.3 Allied Technology Group, Inc.**

Allied Technology Group, Inc. (ATG) is capable of processing LLW through compaction and supercompaction. ATG operates a fully-licensed supercompactor at their facility in Richland, Washington.<sup>7</sup> ATG has designed their own mobile supercompactor with unique features. The supercompactor has a horizontal ram for low vertical profile. It is capable of compacting 75 drums per shift, while being operated by two technicians. ATG's annual capacity is 500,000 ft<sup>3</sup> (14,170 m<sup>3</sup>) per year using sizing, shredding, in-barrel compaction, and supercompaction.

#### **5.4 Applied Health Physics, Inc.**

Applied Health Physics, Inc., located in Bethel Park, Pennsylvania, provides decontamination services on-site for cleaning metals contaminated with low-levels of radioactivity. This chemical decontamination process is limited to small items at the clients site. Depending upon the situation, one or more of the 50 health physicists on staff can analyze and decontaminate facilities or equipment using any of the decontamination methods listed an Section 3.

#### **5.5 Applied Radiological Control, Inc.**

Applied Radiological Control, Inc. (ARC) is a company located in Kennesaw, Georgia. This company is capable of providing on-site decontamination services. They utilize chemical decon, whereby contaminants are oxidized and removed from metal components.

#### **5.6 B&W Nuclear Environmental Services, Inc.**

B & W Nuclear Environmental Services, Inc. operates a supercompactor for reducing volumes of LLW for generators at its Lynchburg, Virginia, facility.

#### **5.7 Bartlett Nuclear, Inc.**

Bartlett Nuclear, Inc. (Bartlett), located in Plymouth, Massachusetts, provides on-site decontamination services for LLW generators. Bartlett utilizes a plastic bead decontamination system. The Bartlett PlasBlast System uses a high velocity stream of plastic particles (PlasTek) to decontaminate. The primary benefits of the PlasTek particles are that they do not remove or abrade the surface being cleaned and PlasTek is incinerable. Using this system, plant components with critical dimensions and surfaces are easily decontaminated without impacting the integrity of the base material. Bartlett provides mobile tool and equipment decontamination trailers for on-site support. Either glass or plastic abrasive systems, high pressure water booths, or ultrasonic tanks can be provided.<sup>7</sup>

Bartlett has also developed a cleaning agent called BY\*PAS decontamination chemical, which is approved for use at many nuclear reactor sites.

Bartlett's Sonatol Process uses an inert organic solvent and a carefully designed surfactant in an ultrasonic bath to remove loose and tightly adhered radioactive particles from surfaces. In this process contaminants are transferred to disposable filters with 0.2 micrometers filtration. The advantages of this solvent are that its inert, non-toxic, and non-flammable, non-hazardous and detergent action. Sonatol controls include optical particle detectors, real-time monitoring, capability of selecting partial or full decontamination, and the process optimizes cycles time.

Bartlett also provides sizing equipment for cutting stainless steel. Bartlett's plasma arc metal cutters can cut stainless steel from four inches thick to the thickness of light gauge sheet metal.

## **5.8 Chem-Nuclear Systems, Inc.**

Besides operating the Barnwell Low-Level Radioactive Waste Management (Disposal) Facility in South Carolina, Chem-Nuclear Systems, Inc. (CNSI) provides a wide range of LLW processing services to the commercial sector. CNSI's corporate office is in Columbia, South Carolina. Their services for low-level radioactive waste treatment include supercompaction, decontamination, filtration, separation, and immobilization/stabilization.

Compaction and repackaging services are offered through Chem-Nuclear at their Barnwell, South Carolina Consolidation Facility.

CNSI is capable of decontaminating components at nuclear facilities. CNSI is fully capable of mechanical or chemical decontamination depending upon the needs of the customer.

CNSI's waste processing capabilities for the commercial sector include advanced dewatering. This process involves the filtration of suspended solids and demineralization of available liquid. THERMEX™ (their most recently developed liquid treatment process), may involve ion-exchange for resins, reverse osmosis, ultrafiltration, dewatering, demineralization, or any combination of those mentioned. THERMEX™ is used to separate impurities from wastewater. THERMEX™ is currently used at two locations in the country and CNSI administers the demineralization process at fifteen power plants in the United States. The impurities from these processes are concentrated and transported to Barnwell. There, they are thermally treated to create a sludge that can be ultimately disposed of at the Barnwell disposal facility.

CNSI's immobilization/stabilization process (solidification) involves adding cement to the waste creating a waste form that meets the disposal criteria at the Barnwell facility. This method of stabilization is not preferred, however. If possible, CNSI would evaporate all liquids, thus reducing the volume prior to disposal rather than adding cement which increases the volume to be disposed.

CNSI wholly owns Diversified Scientific Services, Inc., whose capabilities are discussed later in this report.

## **5.9 Corpex Technologies**

Corpex Technologies, Inc. (Corpex) is located in Research Triangle Park, North Carolina. This company can provide on-site decontamination services. Corpex utilizes chemical decon, whereby the low-level radioactive contaminants on the metal are oxidized and removed from surfaces of metal components.

Corpex™ chemical decontamination processes remove radioactive contaminants from a wide range of substrates including liquids, metals, concrete, and soil. Corpex's decontamination processes minimize the volume of radioactive waste generated and significantly reduces exposure

of decontamination personnel.

Corpex™ chemical decontamination processes have been proven to be effective in the:

- X decontamination of smearable and fixed contamination on lead shielding in the form of sheet, bricks, shot, and wood, resulting in the free release of significant amounts of lead and the generation of a minimal volume of mixed waste in the process.
- X decontamination of large metal objects such as pump motors, impellers, and turbine rotors resulting in the free release of the objects as scrap.
- X decontamination of soil where radionuclides were attached to soil grains resulting in radionuclide extraction near neutral pH with little destruction to the soil matrix and significant reduction in waste.
- X decontamination of hot cells to acceptable operating levels remotely without damage to hotcell surfaces and with minimum exposure to decontamination personnel.
- X decontamination of radioactive liquid drain pipes, access tunnels, walls, and concrete serving laboratory hot cells through a proprietary delivery system that accomplishes the decontamination rapidly with minimum exposure to personnel.

Corpex's Stergo™ technology offers products that are non-biodegradable, non-hazardous absorbents which, when added to radwaste containers, absorb and retain aqueous based liquids without adding to the waste volume. Stergo™ absorbents are available in granulated powder and in pads manufactured in sizes to fit commonly used radwaste containers.

Stergo™ is a solid, granular, cross-linked polymer that rapidly absorbs and retains large quantities of aqueous-based liquids. This product rapidly absorbs liquid and is ideal for placing between primary and secondary containers for transport or storage. Stergo™ increases the volume of the fluid it absorbs by less than 1%. Stergo™ is available in a variety of shapes and sizes including rolls and pads.

### **5.10 Diversified Scientific Systems, Inc.**

Diversified Scientific Services, Inc. (DSSI) operates the only licensed industrial boiler facility that produces electrical power from the thermal treatment of liquid mixed waste in the United States. DSSI's boiler produces electrical power from the thermal destruction of liquid waste. The resulting residue (ash) is considered a DSSI generated waste and is disposed of by DSSI at an appropriately licensed and permitted disposal facility.

DSSI is a WMX Technologies, Inc. company, operated by Chem-Nuclear Systems, Inc. (CNSI). DSSI's annual treatment capacity is approximately 800,000 gallons of waste per year at 80%

capacity factor. DSSI's Internet HomePage is located at <http://www.dssi-tn.com>.

DSSI is licensed/permitted by the State of Tennessee Divisions of Radiological Health, Air Pollution Control, Water Pollution Control, Solid Waste Management, and the U. S. Environmental Protection Agency. DSSI can accept all RCRA hazardous waste codes (*except D003, F020, F021, F022, F023, F026, and F027*), including waste containing small quantities of radioisotopes with atomic numbers 1 through 83, 88, 90, 92-96.<sup>4</sup> The liquid waste streams DSSI accepts include but are not limited to:

- ! Organic Solvents
- ! Aqueous Liquids
- ! Scintillation Cocktail
- ! Paints and Paint Thinners
- ! Used Oil
- ! Freon.

DSSI will accept both small and large volumes of liquid waste delivered in either containers or tanker trucks provided that they meet 49 CFR 173 Department of Transportation (DOT) specifications for transportation of hazardous materials. Examples of containers include:

- ! Lab-packs, 5, 16, 30, 40, 55, 85, and 110 gallon or equivalent containers which may be in overpacks;
- ! DOT approved tote tanks in various sizes and capacities;
- ! Glass vials (contained in drums or other DOT approved packing);
- ! Plastic vials (in drums or other DOT approved packing);
- ! Rectangular, DOT approved shipping containers (e.g. B-25s);
- ! Miscellaneous small containers such as sample bottles and jars.

### **5.11 Diversified Technology Services, Inc.**

Diversified Technology Services, Inc. (DT) has a mobile treatment unit for sludge dewatering, drying, volume reduction, and polymer solidification for treating 1000 lbs/hr of solids. DT offers the use of thermosetting polymers for in-situ solidification of wastes and reverse osmosis processes for volume reduction of liquid wastes. DT offers on-site treatment using self-contained, skid-mounted equipment.

DT uses their patented VERI™ (Vinyl Ester Resin In Situ) System for solidification of bead resins, incinerator ash, powdered ion-exchange media, media used in decon services, and filters in carbon steel disposal liners up to 200 ft<sup>2</sup>. This NRC-approved process produces a waste form that is more stable and reliable than cement or bitumen solidification.

VERI™ was originally developed to solidify bead resins produced by nuclear plant ion-exchange systems. Recent additional VERI™ applications have included solidification/encapsulation of:

- X incinerator ash
- X powdered ion-exchange media
- X ion-exchange media used in decontamination services (e.g. LOMI)
- X filter elements (no HICs or special liners are needed for even the hottest filters)
- X evaporator bottoms.

In the future, Diversified expects to use this technology to solidify carbon media, filter aids, and sludges. Containers solidified with vinyl ester resin are acceptable at all U.S. commercial low-level waste disposal sites.

The VERI™ System is skid mounted and easily-transportable. Valving, controls, and CRT are all remote to the disposal liner. Major components include:

- X Polymer batch tank with mixer and pump(s) remotely-located from the disposal liner (avoids contamination, promotes ALARA);
- X Universal dewatering/solidification fill head that is camera-equipped and compatible with any liner used in the industry;
- X Carbon steel disposal liner fitted with universal (proprietary) dewatering/solidification internals.

A typical solidification follows these steps:

1. A sample is taken of the waste to be solidified, and a small-scale PCP verification test is done to determine proper formulation of the solidification agent.
2. Waste, in a carbon steel liner fitted with dewatering internals, is dewatered through the dewatering/solidification fill head. Initial gross dewatering takes about 1 hour.
3. VERI™ media is mixed in a separate tank (remote from the disposal container for ALARA exposure), then pumped into the waste liner through the fill head. As media flows down through the resin beads, it coats them, completely wiping off any water not removed by dewatering. Flowing binder forces the water ahead of itself toward the low point of the liner, where it is pumped away.

In filter encapsulation, large spaces between filter elements let media flow

immediately to the bottom of the container. The container then fills from the bottom up, immersing the filters, and pushing air ahead of itself out of the container (unlike cement which, pumped from the top, can trap large air pockets). Because the viscosity of the VERI™ binder is

similar to water, it easily penetrates voids, cracks and crevices that might be bridged over by concrete. The binder's low surface tension (lower than water) aids in wetting all surfaces, and inhibits formation of air bubbles and pockets.

4. After the introduction of VERI™ media, solidification in the disposal liner progresses without further operator intervention. Unlike cement solidification, the VERI™ process generates no water during its curing stage. Bead resin solidification results in a shippable product 2-3 hours after binder media is introduced. Encapsulated filters are ready to ship in 1 hour. Solidification is confirmed by temperature readout.

DT's portable High Velocity Vacuum (HVV™) System dewateres all commonly used ion-exchange and filtration media. The HVV™ System uses a high-velocity vacuum to remove residual FSW from a disposal liner. This single-out vacuum has no complex controls, control panels, blowers, heaters or other complicated equipment. A schematic of the HVV™ System is shown in figure 5-5.

### **Interface**

The HVV™ System requires minimal plant interface:

Service Air:	100 (+/-) 20 psi for 1 hour
Electric:	110v, 15 amp, single phase

DT's Waste Processing System (WPS™) purifies liquid waste by passing it through a series of filters and ion-exchangers. Process media are sluiced into reusable pressure vessels for processing, and out of the vessels into a disposal liner when depleted. A schematic of the WPS™ System is shown in Figure 5-6.

### **Dimensions:**

Floor space:	73.5 ft <sup>2</sup> (7 ft by 10.5 ft)
Height:	86 in.
Weight:	20,000 lbs empty 33,000 lbs filled with water and media

### **Setup:**

Time:	12 hours (approximately)
Support:	Overhead crane - 8 hours, Forklift - 4 hours

### **Plant Interface:**

Svc Air:	100 ∇ 20 psig
Svc water:	10-50 gpm @ 100 ∇ 20 psig

Electricity: 110V standard  
480V, 3-phase, 30-amp (if booster pump required)  
Floor drains: In the process area

**Process Rate:**

50-125 gpm with standard WPS™ equipment

## **5.12 EET Corporation**

EET Corporation (EET) has developed a thermal process to solidify inorganic wastes using microwave energy. The process produces a synthetic mineral matrix, incorporating hazardous or radioactive components of the waste in the crystal structure. The process is an in-drum system and has demonstrated volume reductions up to 80% with sludges.

There are three primary mechanisms involved in heating materials using microwave energy: friction heat caused by the vigorous vibration of dipolar molecules due to the oscillation of the electromagnetic field, frictional heat caused by the vigorous vibration of magnetic materials due to oscillation of the magnetic component of the field, and generation of heat by electrically conductive materials due to the current generated by the electrical component of the field. One, two, or all three mechanisms, may be operating at any given time during processing.

Sludges, soils, and other inorganic materials can be processed in the unit on a semi-continuous basis. The system is designed to accept any size of conventional drum or can be modified to accept nonstandard containers. The process operates by feeding waste material into the container using a screw feeder while applying the microwave energy. The molten waste is isolated in the container during the operation. This processing method offers advantages over other thermal processes including greater energy transfer efficiency by directly coupling the microwave energy to the waste, instantaneous energy control, high waste loadings, and high final product densities. Synthetic minerals also offer a leach resistant, stable matrix especially suited for hazardous and radioactive wastes. Also, the process equipment does not come in contact with high temperatures because the heat produced during operation is confined in the container which is insulated from the ancillary equipment.

## **5.13 Eichrom Industries, Inc.**

Eichrom Industries, Inc. (Eichrom) provides the commercial generator with a system to separate nuclear materials from acidic solutions (pH <2). Eichrom has developed an array of products for the treatment and separation of radioactive and conventional metals. Based on ion-exchange treatment technologies, Eichrom's Diphonix™ ion-exchange resin system preferentially interacts with metal ions in liquid solutions, providing a cost effective way of removing metals, including uranium, transuranics, strontium and cesium, from process or waste solutions. Metal is selectivity

retained even in the presence of a high concentration of competing anions, such as sodium, calcium, and magnesium.

Eichrom's Diphonix resin is a high performance, gel-type cation resin with a special selectivity for metal ions in process water. This product is available in a variety of bead sizes. Eichrom personnel can help a commercial LLW generator select the proper size for their particular application.

The physical characteristics of this diphosphonic acid functional group ion-exchange resin is the following:

- X Physical form: amber, translucent, hard spherical beads in a tightly controlled size range
- X Phosphorus content: 1.2 - 1.6 mmol as per dry gram of resin
- X Bead size ranges: 20 - 50 mesh (300 - 850 micron), 50 - 100 mesh (150 - 300 micron) and 100 - 200 mesh (75 - 150 micron)
- X Moisture content: Varies with % cross-linkage specified. Moisture content of beads may also vary depending upon solution chemistry.

### **5.14 Envirocare of Utah, Inc.**

Envirocare of Utah, Inc. (Envirocare) owns and operates a treatment and disposal facility 75 miles (120 km) west of Salt Lake City, Utah. This company not only provides disposal capabilities for limited amounts and types of low-level radioactive waste, but they also obtained a RCRA Part B Permit, and, in 1993, they received their Mixed Waste Treatment Permit. Envirocare provides sizing and immobilization services for mixed waste.

In addition to providing disposal services for low-activity radioactive and mixed waste, Envirocare also operates a Mixed Waste Treatment Facility. The technologies available at this facility are chemical stabilization, chemical oxidation, chemical reduction, chemical deactivation, and neutralization. The corresponding treatment codes from 40 CFR 268.42 Table 1 apply to these activities: STABL, CHOXD, CHRED, DEACT, and NEUTR. The basic components of the treatment facility are solid separation and size reduction equipment, a blender unit, a mixing unit, reagent, and process water storage tanks.

Envirocare can accept wastes with EPA waste codes D001 to D043, F001 to F012, F019, F024, F028, K011, K050 to K052, K061, K069, and many P- and U- listed wastes.

The maximum capacity of the mixed waste treatment system is 150 tons per day. Only one waste stream can be processed through the mixed waste treatment facility at a time. These limits restrict the ability and incentive of Envirocare to process small quantity waste streams. Waste can be

received at the Mixed Waste Treatment Facility in a variety of containers such as dump trucks, roll-off containers, and 55 gallon drums.

In preparing materials for treatment, Envirocare may be required to reduce the particle size of the material to make treatment more efficient. Envirocare provides particle size reduction, separation and treatment of soil or soil-like media, 2-phase sludges, slags, and other debris.

### **5.15 Environmental Alternatives, Inc.**

Environmental Alternatives, Inc. (EAI) is an advanced technology surface cleaning, decontamination and waste minimization services company. Their specialty is CO<sub>2</sub> blast cleaning.

CO<sub>2</sub> blast cleaning is a decontamination process that uses dry ice pellets as a cleaning medium. The pellets are propelled onto a surface by compressed air or other compressed gasses. As the pellets impact the surface, they sublime, returning to their natural state in the atmosphere as a gas. Cleaning occurs as the turbulence caused by sublimation flushes the surface and lifts the contaminants away. The CO<sub>2</sub> gas and contaminants are then entrained in an airstream and captured with HEPA filters. The CO<sub>2</sub> gas is filtered then released. Compared with other decontamination processes, CO<sub>2</sub> blast cleaning does the following:

- X cleans and decontaminates without producing secondary waste
- X is 100% environmentally safe
- X causes no substrate damage
- X reduces the volume and handling costs of radioactive waste.

The CO<sub>2</sub> blast cleaning process can be used to decontaminate a variety of plant tools and equipment. Simple tools like hammers and wrenches can be cleaned in minutes to free-release levels. Complex areas such as chainfalls and motors are easily cleaned. Even sensitive equipment such as monitors, meters, and electric hand tools can be decontaminated safely, quickly, and easily-without damage.

All of EAI's mobile units and equipment are self-contained and requires no support from the customer.

### **5.16 Fluid Tech, Inc.**

Fluid Tech, Inc. (FTI) is a company located in Las Vegas, Nevada, that provides sizing, decontamination, and immobilization services to LLW generators.

FTI utilizes several shredders for sizing of miscellaneous debris, trash, paper, and wood. Their shredders are not capable of handling metal or stainless steel. Support requirement for a customer are as follows:

## Dimensions

Floor space: approximately 25 ft<sup>2</sup> (6 ft by 4 ft)  
Height: 6 ft tall

## Setup

Support: overhead crane

## Plant Interface

Electricity: 440 V

FTI requests a 15 foot high ceiling for clearance for the shredders and mixers.

Mixers are required for combining solidification agents specially produced by FTI. Their drums require 10-12 feet of clearance to operate properly. The mixers (and shredders) are equipped with covers, hooked to filtration systems to control dust.

Solidification agents developed and used by FTI include the following:

- X Aquaset - is a water activated, granular solidification agent used for the treatment of aqueous liquids containing small amounts of dissolved and suspended solids, detergents, chelating agents, resins, and up to 5% oils. Aquaset does not require stirring, and is utilized by simple addition to the aqueous liquid waste. Usually only 100 - 150 pounds of Aquaset are required to solidify 45 - 48 gallons of liquid waste in a 55 gallon drum.
- X Aquaset II/Aquaset II-H - is a powdered solidification agent used either alone or in combination with Petroset or Petroset II. Aquaset II finds its greatest utility in solidifying aqueous solutions extremely high in dissolved solids, such as neutralizing acids and bases, and those organic liquids that are water soluble.
- X Petroset/Petroset-H - is chemically similar to granular Aquaset, but instead is a finely-divided powder. Its application requires power mixing, either by an impeller (drum mixing) or a ribbon blender or pugmill. It can be used to treat waste with a high solids content, including heavy sludges. With the addition of water, dry solid wastes can be successfully treated to meet TCLP leach-resistance standards.
- X Petroset II - is a finely ground, organophilic solidification/stabilization agent. It is used in treating waste with high amounts of organic constituents such as oils.

FTI also provides decontamination services on-site or will bring contaminated material to their facility for decontamination. FTI will provide chemical or mechanical decon depending upon the need of the customer.

## 5.17 Framatome Technologies Inc.

Framatome Technologies, Inc. (FTI), formerly B&W Nuclear Technologies, provides a diverse selection of LLW services and waste processing to LLW generators.

FTI provides unique NuResin™ and CleanResin™ systems for treating ion exchange resins from nuclear power plants.

NuResin™ utilizes patented processes to clean and separate resin with levels of cross-contamination as low as 0.01%. NuResin's counterflow regeneration process then returns resin to a better-than-new condition. NuResin has been field-proven to regenerate resin to 98%, or greater, efficiency of its recoverable capacity.

CleanResin™ is FTI's patented resin cleaning system that quickly and efficiently removes resin fines, particulate and insoluble corrosion products while preserving resin bead integrity. The cleaned resin bed is returned to service with a reduced in service differential pressure and resin fines leakage. In PWR applications, various pre-treatments may be applied to assist in removing particulate within plant condensate and/or blowdown resin.

CleanResin's process will benefit BWR plants by reducing the volume of liquid radwaste generated in the cleaning process by up to 90%. In addition, the CleanResin system is remotely operated, reducing personnel exposure during the processing of highly contaminated resins. FTI provides these technologies as mobile systems, delivering turnkey services to clean resin beds at the power plant.

FTI also provides solidification of liquid waste to process low-level radioactive waste. FTI's solidification services include a portable trailer containing equipment designed to solidify waste in drums. The system is an air-operated, planetary mixer for mixing solidification media. FTI also uses and provides Aquaset® and Petroset® solidification media.

FTI and Zenon Environmental, Inc. provide membrane separation technologies. This process consists of a combination of ultrafiltration and reverse osmosis technologies. Mobile ultrafiltration/reverse osmosis units are housed in iso-containers and are available in small and large scale systems.

FTI's evaporator system design reduces waste into a concentrated residue. The combustion evaporator is submerged beneath the waste employing a propane flame up to 3.0 MM BTU/hr. The distillate is conditioned using separators and scrubbers for safe discharge into the environment.

Blending of liquid waste performed by FTI is utilized to immobilize low-level radioactive liquid for transport and disposal. The waste concentrate is absorbed using absorbents such as SpagSorb® organic absorbents. FTI's blending services include portable and stackable trailers containing equipment designed to blend and package liquid waste and absorbents. The system also utilizes a dust eliminator for safe operation.

## 5.18 Frank W. Hake Associates

Frank W. Hake Associates (Hake) is a company located in Memphis, Tennessee, that will provide sizing, compaction, and decontamination services to a LLW generator. Hake specializes in the sizing, decontamination and release of large components. They process over two million pounds of metals, wood, building rubble and soils per year.

Hake uses the process of segmentation to remove a radioactive portion of an item of waste resulting in a clean waste or maximize non-contaminable metal volume reduction. The segmentation processes and a brief description of each is provided as follows:

- X Plasma Arc Cutting- a D.C. arc, between a tungsten electrode and a conducting metal is established in a gas stream at temperatures over 40,000°F.
- X Oxyacetylene Cutting- a flowing mixture of a fuel gas and oxygen is ignited at the orifice of a torch.
- X Thermite Reaction Lance- an iron pipe is packed with a combination of steel, aluminum, and magnesium wires and a flow of oxygen is maintained. Temperatures can reach 10,000°F.
- X Arc Saw- a circular, toothless saw blade that cuts any conducting metal without physical contact with the work piece.
- X Abrasive Cutter - electrically and pneumatically powered, well formed of resin-bonded particles of alumina and silicon carbide.
- X Circular Cutter- self-propelled, circular saw that cuts as it moves around the outside circumference of a pipe on a track.

Hake employs a standard drum compactor at their facility. The compactor is a standard 50,000 pound drum unit.

Hake is also capable of decontaminating LLW. Hake employs chemical and ultrasonic baths for decontaminating tools and other components. Hake's chemical immersion bath utilizes several chemical agents at metered concentrations including acids, bases, and chelating agents. Ultrasonic baths are used to clean small tools and equipment. Contamination is removed through agitation action produced through the formation and collapse of countless water bubbles. Detergents and mild chemical agents can also be added to the baths for increasing cleaning efficiency.

## 5.19 Gencorp Aerojet

Gencorp Aerojet (Aerojet) is a company that can provide treatment services for LLW in the areas of compaction and decontamination. Most of Gencorp's decontamination experience is in clean up of depleted uranium and thorium and equipment contaminated with the same.

## 5.20 General Atomics

General Atomics (GA) has developed hydrothermal oxidation (HTO) systems for the treatment of a wide range of waste materials, including mixed wastes. HTO destroys organic wastes in a compact, totally-enclosed system using an oxidant in water above the critical point of water (705°F or 374°C and 218 atm). At these conditions, organic materials and gases become highly soluble in water, making it possible to carry out rapid, complete oxidation using water as the carrier medium. The GA HTO systems demonstrated destruction of many organic materials, ranging from hydrocarbons and common organic compounds (e.g., benzene, cellulose, ethylene glycol) to highly chlorinated cleaning solvents and other halogenated compounds (e.g., 1,1,1-trichloroethane, creosote, Freon 22). A variety of inorganic substances have also been included as feeds (e.g., aluminum metal and oxide, boric acid, cerium chloride). These have been treated as part of numerous complex feeds, including motor oil, paper and wood fibers, paint, and sewage sludge, among others. All effluents from the HTO process can be stored for analysis and verification of waste destruction prior to subsequent processing of any residual radioactive materials.

GA offers several reactor sizes for treatability studies of mixed waste treatment operations, either directly or through their recent acquisition of MODAR, Inc. A MODAR pilot plant was recently used to successfully process Trimsol, a highly chlorinated cutting oil containing surrogate radioactive metals. Pilot-scale units are available at GA for treatability studies or can be transported to a customer site for on-site treatment of mixed wastes. GA also has a variety of other HTO units including smaller systems that are suitable for preliminary bench-scale studies or routine, small-volume applications.

## 5.21 GTS Duratek

GTS Duratek (GTSD) and CNSI have formed a limited partnership, DuraChem™, to vitrify radioactive wastes from the commercial nuclear power industry.<sup>7</sup> These wastes include:

- X Dry active waste
- X Ion-exchange resins
- X Cartridge filters
- X Carbon absorption media
- X Evaporator concentrates

X Ion specific liquid radwaste media.

DuraChem™ was established to process LLW from the commercial nuclear power industry into a low-volume, non-leaching stable waste form. DuraChem's DuraMelter™ vitrification system is located in Barnwell, South Carolina. The unit converts LLW into a glass waste form which is approximately one-fifteenth of the original volume.

The DuraMelter™ economically converts radioactive, hazardous, asbestos, and medical wastes into durable glass. The high operating temperature of the vitrification process, typically 2100°F (1150°C), destroys organic compounds leaving the remaining contaminants bonded in a stable, highly leach-resistant waste form that is chemically similar to natural materials.

Key aspects of DuraChem™ include:

- X Volume reduction over base volume approaching 90%
- X No mixed waste or Class C concerns
- X No impacts to generators' operation
- X Stable final waste form.

GTS Duratek operates its RCRA Part B permitted Dura-Therm™ Recycling Facility near Houston, Texas, which uses patented thermal desorption technology to stabilize hazardous hydrocarbon waste. The thermal desorber exposes the waste to high temperatures in an inert atmosphere which vaporizes water and other volatile compounds, leaving a dry, powdery residue. The thermal desorption technology can also be applied to low-level radioactive sludge or dry active waste to achieve substantial volume reduction. The resulting residue can be containerized as is or vitrified for disposal.

## 5.22 Imbibitive Technologies

Imbibitive Technologies (IT) is a company based in Canada and can provide a product (Imbiber Beads)™ to immobilize oily low-level radioactive waste. Imbiber Beads™ are a high molecular weight, non-biodegradable polymer that meet EPA requirements for immobilization of compatible hazardous materials for landfilling.

There are two methods for using these imbiber beads. The first method involves the use of a 55 gallon steel drum with a mix containing 65-70 pound of Imbiber Beads™ with 3-4 volumes of wick/volume beads and 1.5 Aquabiber<sup>R</sup> to immobilize up to 1/2% incidental water in the oil. In the past, this dry mix was sent by Dow Chemical in 55 gallon open head DOT steel drums, but is now available only in 65 pound fiber drums. In the second method, the Imbiber Beads™ are used to immobilize oil and then mixed into a cementitious material and cast. This makes a structural material like cement with the oil contained in the Imbiber Beads™ and not available for leaching the pores of the concrete.

## 5.23 INET Corporation

INET Corporation (INET) in Newark, California, has the capability of providing on-site supercompaction. INET, jointly with Scientific Ecology Group, Inc., owns one mobile supercompactor called Superpack®.<sup>7</sup> This compactor is a single-stroke, hydraulically operated compactor that provides a force of 2200 tons (4,400,000 pounds) for compacting 55 gallon or 52 gallon drums.

The compactor is transported in two separate parts, with the press mounted on the lowboy and the hydraulic pumping system module, designed as a modified containerized shipping package, carried on a flatbed trailer. Once the unit reaches the waste processing location, the pumping module is placed on the rear of the lowboy and connected to the press system. The setup is completed by the positioning of automatic input and output conveyors and drum handling systems. With proper preplanning and support, the entire compaction system can be completely setup for operation in one or two days.

### INET's Compactor Technical Data:

Dimensions:	Length	35 ft
	Width	8 ft 2 in.
	Height	13 ft 1 in.
Weight:	Press	35 tons
	Lowboy with press	50 tons
	Pumping module	8 tons
Press force:	2200 tons	
Press stroke:	37 inches	
Waste package size:	55 gallon drum	
	52 gallon drum	
Hydraulic pumps:	Two-dual gear/piston	
	55KW each	
Hydraulic operating pressure:	3,850 psi (maximum)	
Cycle time:	2 minutes, 30 seconds/drum	
Electrical service:	220 amp	
	480 volt	

System control voltage: 24 volt

Air purification: Standard HEPA unit

Input/output conveyors: Hydraulic or electric

Operating control: Computer based system with process safety locks

Remote video monitors available.

**Typical waste drum volume reduction (VR) performance:**

BWR nuclear power station	VR 3.65
Heavy metal components (electric motors, valves)	VR 5.0
Wood blocks	VR 3.6
Cement blocks	VR 3.5
Metal pipes	VR 7.6
Plastic sheet	VR 3.0

**5.24 Interstate Nuclear Services Corporation**

Interstate Nuclear Services Corporation (INS), located in Springfield, Massachusetts, is a company with the capability of providing decontamination services to a LLW generator. The INS Model MDF-120 decon unit has the following features:

- X recycling grit blast cabinet
- X recycling water laser blast system
- X trailer HEPA filtration provides secondary containment
- X integrated spill containment at all process areas
- X receiving areas accept 55 gallon drums and B25 boxes
- X heavy duty HVAC system and zoned halon fire protection
- X plasma cutting and other process configurations available
- X INS trained and certified operators
- X all decon media recycled within facility
- X fixed facility performance in a cost effective mobile system.

**System Support**

Electrical	240 volt, 3 phase, 100 amp
Water	3/4 inch threaded hose connection
Air	1 inch pipe, 100 psi, 85 SCFM dry compressed, Rec. 20HP compressor

INS also supports a Dry Ice Blast Decontamination System. The features of this system include the following:

- X zero secondary waste stream
- X excellent decontamination factors
- X the only field-proven portable system
- X simplified design provides excellent reliability
- X variable control for aggressiveness for various materials
- X INS operators available for on-site operations and training.

The specifications for this unit are as follows:

Dimensions	16 in. x 8 in. x 20 in.
Weight	51 pounds
Media capacity	25 pounds
Media consumption	1-3 lb/min trigger time
Propellant	service air, N <sub>2</sub> , other gasses
Propellant use rate	90-180 cfm
Operating pressure	25-400 psig
Utility requirements	air only, no electric required.

This process includes dry ice, which is manufactured at a specific density and geometry. The media is accelerated to high velocity with compressed air and directed at the surfaces to be cleaned. When the particles impact, they convert from a solid to a gas. The transformation eliminates generation of secondary wastes encountered in traditional pressurized media blast operations.

## **5.25 Manufacturing Sciences Corporation**

Manufacturing Sciences Corporation (MSC) has operated a metal recycling facility in Oak Ridge, Tennessee, since 1984, creating valuable products from radioactive scrap metal. Their specialized facility recycles tons of depleted uranium, beryllium, copper, nickel, and steels into useable products, including barrels and boxes, every year. MSC operates induction furnaces, a rolling mill, and fabrication centers to reclaim these valuable metals. The facility is over 115,000 ft<sup>2</sup> of highly automated unloading, material tracking, sorting, sizing, decontaminating, melting, surveying, and other equipment dedicated to recycling. This facility offers customers the following:

- X all indoor storage
- X 90-day turnaround from receipt to final disposition
- X highly-efficient decontamination and automated survey techniques
- X fabrication of useable products from non-decontaminated metals

- X material tracking system that accurately controls the disposition of materials from each order
- X fully-enclosed vacuum induction furnace for melting and casting high-quality end products.

MSC accepts shipments from the customer or provides transportation services to deliver empty containers to the site and return loaded containers to MSC. Base pricing for transportation services include the use of a 40ft or 45ft flat-beds or enclosed trailers. Special equipment such as lowboys and additional axle trailers are also available and will be quoted upon request.

MSC containers are also available for their customer's use. They can supply 8ft x 8ft x 20ft end-loading vans, 8ft x 8ft x 20ft top loading vans, 4ft x 4ft x 6ft boxes, and other types of containers upon request.

Materials requiring chemical decontamination enter the facility via a monorail system or from a conveyor from the unload sort area. Material is loaded into baskets which are dipped in a series of chemical tanks and a spray washer via a monorail hoist system. The monorail system and the chemical decontamination process is controlled automatically by a programmable logic controller. On completion, the basket is transferred to a tipper station where the material is inspected and tipped into a box for subsequent transfer to the survey area or foundry via the monorail system. Fumes from the process are extracted through a scrubber system to the HEPA filters.

### **MSC Material Acceptance Criteria**

MSC new metals recycling facility is designed to receive and process primarily metals. However, there are resources available to address non-metals such as wood, paper, plastic, etc. that result as part of the shipping process.

Metals will be decontaminated and clean material released to the secondary metals market. Metals which cannot be verified clean will be melted into metallurgically sound ingots. The ingots will be used to fabricate restricted use products (such as drums, boxed, shield blocks, etc.) or will be buried.

Metals shipped to MSC will be required to meet the following receipt criteria:

1. Maximum 40 ton lift off truck - container gross weight or singular component weight.
2. Metal in containers may be sized just to fit into the specific container or can be sized to meet MSC's preferred size of 2 ft long by 1.5 ft by 1.5 ft.
3. Material up to 300 mR/hr on contact is considered standard. Material exceeding 300 mR/hr, up to 5 R/hr, may also be accepted with permission and may be subject to a radiation surcharge. Customers are required to inform MSC of any material measuring

over 100 mR/hr on contact so that the appropriate ALARA controls can be implemented.

4. There is no specific smearable contamination limitation. However, it is required that the customer inform MSC of any component which is expected to be in excess of 500,000 dpm/100 cm<sup>2</sup>.
5. Unless agreed otherwise in the contract, shipments shall not exceed Class A waste descriptions. All shipments exceeding Class A must be authorized by MSC prior to shipment.
6. All shipments shall comply with DOT requirements. Containers will be subject to a full inspection upon arrival.
7. Unless agreed otherwise in the contract, the volume of non metals included in any shipment shall be limited to material (i.e., wood cribbing, wrapping) required to make shipment.
8. Unless agreed in the contract, no liquids will be accepted.
9. Resolution to all shipments not complying with the above must be complete prior to MSC accepting the shipment for processing. Non-compliant shipments, if returned, will be at the customer's expense.

### **5.26 M4 Environmental Management, Inc.**

M4 Environmental Management, Inc. (M4), is a limited partnership between Lockheed Martin Corporation and Molten Metal Technology, Inc. M4 provides the Quantum-Catalytic Extraction Process to waste brought to the facility. Developed and patented by Molten Metal Technology, this process uses molten metal to convert mixed and hazardous wastes in useful industrial products.

Four Quantum- CEP systems are either operating or are under construction at the M4 Technology Center, which also houses an analytical laboratory for real-time analysis of waste samples. Each Quantum- CEP system is referred to as an RPU (Radioactive Processing Unit). Three RPUs are operating- RPU-1, the depleted uranium hexafluoride bench-scale unit; RPU-2, two smaller Quantum- CEP units for treatability studies and to support processing operations; and RPU-3, the company's first commercial Quantum- CEP unit. RPU-4, also known as the Combo Unit, will be operational in the latter part of 1996. With a 3,000 pound metal bath, this unit will be capable of operating around the clock to process mixed waste for government and commercial customers, including contaminated soils and inorganic sludges, organic liquids and sludges, scrap metal and combustible and non-combustible debris.

M4 recently acquired Retech, a company in Ukiah, California, that designs and manufactures specialty furnaces including Plasma Arc Centrifugal Treatment (PACT).

### **5.27 Nuclear Fuel Services, Inc.**

Nuclear Fuel Services, Inc. (NFS) is a company located in Tennessee that can provide assistance to mixed waste generators. NFS possesses a RCRA Part B permit and can provide a proprietary mixture to a radioactive waste matrix containing mercury (and most other metals) for stabilization. NFS's final waste form will meet toxicity characteristic leaching procedure (TCLP) criteria.

NFS's Sludge Treatment System (STS) was built, licensed and permitted in the early 90s and successfully treated over 130,000 cubic feet of MLLW sludge. The sludges contained uranium, thorium, cadmium and other small concentrations of radionuclides. The sludges were excavated, treated to remove the hazardous components, dewatered, volume reduced and disposed at a LLW burial site. This system has successfully treated K-25 mixed waste and is available at NFS or can be relocated to another site for treatment services.

NFS designed, built, licensed, and operated a Decontamination and volume Reduction System (DVRS) which was successfully used to decommission a MOX fuel fabrication facility and a plutonium laboratory. The system is currently available for D&D at their facility in Erwin, Tennessee. A mobile unit has been designed for transportation to a particular work site.

### **5.28 Nuclear Metals, Inc.**

Nuclear Metals, Inc. (NMI) reports they can provide compaction, decontamination of contaminated metals on-site, and they operate a metal melt facility at Carolina Metals in South Carolina.<sup>7</sup>

NMI uses a high-pressure water jet technique, as well as other abrasive methods, to decontaminate metals for reuse, recycling, or release.

NMI has installed a metal facility in South Carolina to melt, cast, and process various metals exhibiting radioactive contamination.

### **5.29 Nuclear Sources and Services, Inc.**

Nuclear Sources and Services, Inc. (NSSI), located in Houston, Texas, is a company providing services to LLW and mixed waste generators in the areas of compaction, filtration, decontamination, separation, immobilization, and physical/chemical treatments of dry waste, bulk

liquids, sludges, and scintillation vials.

NSSI has the capability to perform the following functions:

- X Blending of wastes to form a fuel for use off-site
- X Consolidation of waste containers into lab packs
- X Breaking down lab packs for re-consolidation for off-site disposal or on-site processing
- X Neutralization, oxidation, reduction, and other chemical reactions or physical processing (e.g. distillation) to render wastes less hazardous or more suitable for off-site disposal or on-site processing in an authorized tank or container storage area
- X Recycling of solvents
- X Cleaning of particulate solids, empty drums, and equipment
- X Centrifugation, filtration, and ion-exchange in portable equipment within an authorized container storage area
- X Solidification or stabilization (including amalgamation) in portable equipment within an authorized container storage area
- X Shredding of containers for recovery of contents
- X Consolidation of miscellaneous hazardous wastes
- X Chemical or mechanical treatment to accomplish separation, settling, or classification in portable equipment within an authorized container area
- X Removal of hazardous constituents by absorption on solid media in portable equipment in an authorized container storage area
- X Drying of solids to render the waste more suitable for on-site processing or to meet off-site disposal criteria for release of water only
- X Operation of a mercury retort unit.

NSSI is permitted for all hazardous waste codes and all radionuclides including transuranics.

NSSI can provide storage for LLW and mixed waste and storage for decay for short half-life LLW.<sup>4</sup> NSSI is authorized to store up to 4,000 55 gallon drums and 58,000 gallons of bulk tanked liquids. NSSI has a low-pressure compactor unit that can provide volume reductions of 3-5:1.<sup>7</sup>

NSSI has recently begun operation of new process units for mixed mercury waste and animal tissue treatment.

The mercury unit is a continuous retort unit designed to distill off and recover mercury from solid sludge waste streams containing inorganic radionuclide constituents. The unit meets the BDAT requirements for wastes with mercury content above 260 mg/kg. Ash from the retort is stabilized for land disposal at existing burial sites.

The animal tissue unit uses steam and proprietary reagents to convert animal tissue and solid organic sludges into liquid streams for further treatment or disposal. Bones and other solids remaining after conversion are dried, crushed, and disposed as dry active waste.

NSSI's permits allow the operation of portable treatment units and the conduct of research and development of new waste processes at their site. This allows the company to provide a test area for new processes developed by others without the need to obtain license and permit modifications.

### **5.30 NUKEM Nuclear Technologies**

NUKEM Nuclear Technologies (NUKEM), a company operated in Columbia, South Carolina, can provide services to LLW generators in the United States including filtration, evaporation, and separation. NUKEM's headquarters in Germany provides additional support in the areas of compaction, incineration, and vitrification. NUKEM provides mobile units for filtration to generators that need assistance on-site. They provide demineralization filtration systems and cross flow reverse osmosis systems. NUKEM's mobile evaporators are capable of removing the waste from contaminated liquids resulting in a pure waste comprised of the previously suspended and dissolved solids. the "drying" process can lead to a dry granular waste form or in certain cases can be dumped as a highly concentrated slurry which subsequently dries to a salt block. The salt block has the advantage of providing an additional 30% volume reduction over the dry granular waste form. NUKEM can build to suit or can provide drying services using its mobile units with capacities of up to 1,000 gallon of feed per day.

The filtration and reverse osmosis/ultrafiltration systems immediately available through NUKEM run at a range from 5 to 50 gallons/min. NUKEM can acquire larger equipment upon request.

### **5.31 Perma-Fix Environmental Services**

Perma-Fix Environmental Services operates a fixed based facility in Gainesville, Florida oriented to process radioactive, mixed and hazardous wastes. Its predominant capability in the past has been the disposal of liquid scintillation vial waste materials. It also uses a mobile treatment service known as the "Perma-Fix process" to stabilize wastes for easier disposal options.

Perma-Fix of Florida at Gainesville has a 7.6 acre site in an industrial park. It possesses a Part B permit issued by the State of Florida Department of Environmental Protection to function as a TSDF. The hazardous waste permit predominantly provides capability for D, F. and some U code wastes. The facility also has a radioactive materials license issued by the State of Florida, Department of Health and Rehabilitative Services. The radioactive materials license not only allows for LSV waste processing, but was amended in March 1996 to allow for much broader radioisotopes and larger specific activities.<sup>4</sup> The new amendment provides capability for:

1. All LSV materials including high specific activity materials.
2. Solids and liquids containing organic, inorganic or aqueous based mixed or radioactive wastes.

Perma-Fix receives these mixed wastes, separates the components, analyzes the materials and provides technology options for the disposal of the retrospective byproducts.

The “Perma-Fix process” was originally designed and is currently used for on-site treatment of hazardous wastes basically containing “D00X” waste codes. The waste is being bound in the process to render it as non-hazardous and as radioactive only for ready disposition. This technology is currently being developed for use under the permit at the Gainesville facility.

Perma-Fix of Florida also provides R & D of mixed waste materials with unknown or difficult disposal options. The facility has a full-service support laboratory to assist in the waste management functions conducted at the facility.

### **5.32 Scientific Ecology Group, Inc.**

Scientific Ecology Group, Inc. (SEG) provides many waste treatment technologies to many different waste streams in both the low-level radioactive waste and mixed waste arenas. The following is an abbreviated list of technology categories with brief discussions on each.<sup>7</sup>

- X sizing
- X compaction
- X supercompaction
- X decontamination
- X evaporation
- X separators
- X incineration
- X vitrification
- X immobilization/stabilization
- X metal melting
- X physical/ chemical treatments including Quantum- CEP.

#### Compaction

SEG provides compacting services utilizing mobile, flat-drum compactors and their UltraCompactor®. SEG’s UltraCompactor® uses a 5,000 ton press with 10 million pounds of thrust. This compactor has the capability of handling 52 gallon and 55 gallon drums or 4ft x 4ft x 3ft boxes. It is capable of compressing motors, pumps, piping, and other metal objects to near their theoretical maximum density. The capacity of the UltraCompactor® is more than 2.5 million ft<sup>3</sup> of waste per year at a density of approximately 65 lb/ft<sup>3</sup>.

#### Decontamination Services

SEG provides a wide range of mechanical and chemical decontamination services. SEG provides

grit and sponge blasting for mechanical decontamination. They also provide acid baths for chemical decontamination. Generally, metals including lead are decontaminated for free-release, therefore, recycling resources back into the open market.

### Wet Waste Services

Rapid and Compression Dewatering systems provide for the transfer and dewatering of ion-exchange resin, activated carbon, and similar media which are generated from water purification systems at commercial facilities. These systems are designed to be used in conjunction with SEG containers and NRC topical reports document compliance with regulatory requirements of the waste form for disposal.

Water purification systems services include routine and on-demand ion-exchange systems as well as technologies such as reverse osmosis, ultrafiltration, and ultraviolet light systems to enhance water purification. Reverse osmosis is utilized to separate dissolved solids; ultrafiltration to separate suspended solids and particulates; and ultraviolet light to destroy organics.

Evaporation and drying services are provided at the Central Waste Operations complex. Typical waste streams include boric acid concentrated from PWRs and reverse osmosis/ultrafiltration reject concentrates. These wastes are containerized and shipped to Oak Ridge for drying in the porcupine dryer (resin dryer) or despatch oven (drum dryer) to achieve high VR ratios.

### Incineration

Commercial operation of SEG's first incinerator began in 1989. A second incinerator was added in 1994. These incinerators are capable of burning solid waste at the rate of 900-1600 lb/hr while achieving volume reduction ratios of greater than 100:1. Simultaneous to solid waste processing, the incinerators are also able to burn radioactive, nonhazardous waste oils at the rate of 30 gallons/hr.

Prior to processing, the waste is sorted according to the process to be used (i.e. incineration, ultracompaction, or decontamination). Sorting will minimize the burning of materials such as halogens and heavy metals which are undesirable for incineration.

At the end of the process, an evaporator is used to concentrate and solidify suspended and dissolved solids in the liquid effluents from the boiler and the scrubber. The resulting cleansed water is then recycled back to the scrubber. In this manner, liquid effluents from the incineration process are eliminated and steam from their incineration process is eliminated. The steam from the incinerator can also be used to treat the customer's aqueous waste.

SEG then compacts the waste to form a high-density, non-dispersable solid which is packaged and buried. The compaction process yields an additional 3:1 VR resulting in a VR of well over 100:1 for combustible waste.

Materials accepted by SEG for incineration include:

- X plastic
- X sludge
- X HEPA filters
- X resin
- X charcoal
- X 100% cotton cloth and 100% cotton cloth-flame resistant
- X 65% polyester/35% cotton cloth
- X high density polyethylene
- X latex
- X leather
- X nitrile or nitrile rubber
- X nylon
- X paper
- X polycarbonate
- X polyester
- X polyethylene
- X polypropylene
- X polyurethane
- X natural rubber and rubber lightly vulcanized with less than or equal to 1000 ppm sulfur
- X spun bonded polyolefin
- X transparent thermoplastic
- X ultra high molecular weight polyethylene
- X urethane
- X wood
- X corncobs.

Items that will not be accepted for incineration include:

- X explosives
- X pyrophorics
- X polyvinyl chloride
- X shock sensitive or highly reactive materials
- X hazardous wastes or materials as defined by TSCA and RCRA
- X sharps.

Figure 5-13 shows the schematic of a controlled-air incinerator.

#### Quantum Catalytic Extraction Processing

Quantum-CEP employs a bath of molten metal coupled to a catalytic processing unit (CPU) to destroy the organic components of resin and control the partitioning of metallic ions and chemical

elements into three separate physical separation phases (gas, ceramic matrix, metal). The process effectively controls the deposition of many radionuclides such as Cs-137, and chemical elements, such as sulphur, into preferred locations. This permits extremely high volume reduction of complex organic structures (400:1 for most resins), which is superior to that attained by vitrification processes.

Waste accepted by SEG for Quantum-CEP:

- X bead resins
- X powdered resins
- X metals.

Resins will be dried and injected into a molten metal bath contained in a disposable ceramic lined cubicle. The high temperature metal bath, which is 1-2 ft<sup>3</sup> in size, will instantly vaporize the organic resin and amalgam with the radioactive metallic ions captured on the resin. Since the majority of matter in resin is water, the majority of the resin material will be reduced to hydrogen and oxygen gas and water vapor. These elemental forms are collected in the gaseous region of the CPU. These gases are not radioactive and can be collected, bottled, and sold as a recyclable gas. Other elements, including sulphur, partition out in a ceramic matrix whereas most metals stay in the metal bath.

### Vitrification

SEG installed a vitrification system in its Incinerator Building in early 1994. The SEG vitrification system is capable of processing 150 pounds per hour of LLW. While the system is capable of processing all types of solid radioactive waste including resins, sludges, DAW and filters, it is intended to be primarily for vitrification of incinerator ash generated by the SEG incinerator. This sequential processing methodology (incineration then vitrification) permits the vitrification system to efficiently process a very large volume of incoming waste. With the addition of its second incinerator in 1994, SEG can now incinerate and vitrify up to 14,000,000 pounds of waste a year.

Pre-treatment wastes via incineration provide a significant volume reduction of the waste prior to feeding the resultant ash into the vitrification system. This also provides a consistent waste feed for the vitrification system so that a uniform final waste form can be produced by the vitrification system. The SEG vitrification system produces either a solid glass monolith or "glass jewels." At the present time, SEG intends to produce glass jewels, since small glass jewels are easier to reprocess than a solid glass monolith, should any rework be required. SEG guarantees the vitrified waste form will be acceptable for disposal at all future burial sites and has committed to reprocess the waste at no extra charge should the waste form not be accepted by a future burial site.

Waste accepted by SEG for vitrification:

- X incinerator ash
- X paper
- X plastic
- X wood
- X soil.

Volume reduction factors for differing waste types after vitrification:

BWR wet wastes	75:1
PWR wet wastes	45:1
filter cartridges	20:1
activated carbon	50:1
evaporator bottoms	20:1.

Immobilization/Stabilization

SEG provides a broad range of immobilization/stabilization technologies at their facility in Oak Ridge, Tennessee. These technologies and services can be provided upon demand at the request of their customer. A customer would need to contact an SEG representative to discuss their specific need and requirements.

Metal Processing

SEG’s metal processing facility is equipped with a 20 ton, 7,200 kilowatt induction furnace. This facility can process approximately 25,000,000 pounds of contaminated metals each year.

During the smelting process, the majority of the contamination is absorbed in the slag layer on top of the molten pool of metal. This contamination is removed with the slag layer. This process decontaminates the metal effectively and produces a useable product as the output.

Two avenues of potential reuse are shield blocks for use in DOE High Energy Physics programs, and nuclear waste containers and shields for use in commercial power plant applications.

SEG accepts most types of surface-contaminated metals for processing through their Metal Processing Facility including carbon steel, stainless steel, copper, brass, and aluminum. All paint, coatings, and oily films are removed by sending the metal through a pre-heater before smelting.

Steam Reforming

SEG provides steam reforming either as a mobile unit or a fixed base unit. The footprint for the unit is 8 ft x 20 ft.

Steam reforming is a newly patented waste processing technology which was originally utilized

for the processing of medical and hazardous wastes. SEG recently acquired the assets of the patent holder of this technology (Synthetica Technologies) for the use and sale of Synthetica Detoxifier Systems. This technology is often called “steam detoxification” as it “detoxifies” or renders hazardous or pathological materials “nonhazardous.” SEG has demonstrated that this technology can be used to effectively process radioactive and/or mixed wastes.

Steam reforming systems produce a final waste form similar to incinerator ash. However, the processing methodology employed is significantly different from an incinerator and the system is in fact not classified as an incinerator by the EPA. Steam reforming systems, unlike all types of incinerators, do not employ combustion in an oxygen atmosphere to reduce waste. Instead they employ a superheated steam which reduces the waste down to small size gas particles which can then be detoxified in a special reactor that is devoid of oxygen.

Organic material is reduced to a small volume of residue which is retained in the drum used to charge the waste into the system. The drum is supercompacted once all the waste in the drum is processed. Typical volume reductions of as high as 100:1 are obtained for most organic materials. Resins exhibit volume reductions of approximately 6:1. Steam reforming is ideally suited for the processing of many problematic wastes, including mixed wastes, and those exhibiting medium to high activity levels.

Waste accepted by SEG for steam reforming:

- X cartridge filters
- X sewage/sump sludges
- X EDTA/decon solutions
- X aqueous liquids
- X small generator wastes
- X hazardous wastes
- X pathological wastes
- X paints/solvents
- X charcoal filters.

### **5.33 Severson Environmental Services, Inc.**

Severson Environmental Services, Inc. (Severson), located in Munster, Indiana, can provide a unique product to immobilize LLW or mixed waste. This product or process is called Severson’s MAECTITE® process.<sup>7</sup> Unlike cement/pozzolan/silicate based Fixation/Solidification/Stabilization technologies, Severson’s process chemically bonds rather than physically binds leachable lead and RCRA materials. The products formed from the reaction are geochemically stable synthetic mineral crystals which form within the waste matrix. The product of MAECTITE is a nonhazardous material with appearance of soil, but with no volume increase

and minimal increase in mass (<10%).

Treatment in soil and solid waste with the MAECTITE process creates hard, insoluble mixed mineral forms. Heavy metals are rendered nonhazardous under the RCRA definition.

This soil-treatment process utilizes a tracked excavator to bring material to feed hoppers from staged piles of contaminated material. Conveyors in the hopper carry material through a dual shredder for sizing. The shredded material is then conveyed across a weigh-belt feeder where instantaneous and totalized mass are measured.

### **5.34 Southwest Research Institute**

Southwest Research Institute (SRI) has developed a process for stabilizing mixed waste called Metaloma™. Metaloma™ is a processing concept to transform mixed low-level hazardous waste into useful building products. The hazardous elements are immobilized through concurrent chemical and mechanical bonding developed during processing. The Metaloma™ process creates a strong ceramic material that exceeds structural strength requirements for use as a building material, and passes EPA leachability requirements so as to render the hazardous material innocuous. Radiation levels are controllable through the types and amounts of additives used for processing and the inherent shielding when the material is used in bulk. The vision is to transform the problems associated with hazardous waste materials into an asset and useful product for use in long term building applications by the waste generator, where material disposition is in control and easily accessed for long term monitoring. The vision is to find an alternative method of handling hazardous waste materials to keep them out of precious landfill sites and potentially entering the groundwater system due to unforeseen complex chemical and environmental interactions with unknown substances buried in close proximity.

In previous testing of the Metaloma™ process, mixed low-level nuclear hazardous waste material was stabilized by combination with cement, aggregate, and proprietary reagents/complexing agents. The stabilization process was enabled by use of a hydrothermal process. When cured, processed samples were tested and found to have typical crushing strengths on the order of 5,000 - 8,000 psi. It is believed that the crush strength can be varied from 3,000 - 10,000 psi through changes in processing parameters.

### **5.35 Thermo NUtech**

Thermo NUtech (TN) is a company with the unique capability of separating radioactively contaminated soil from “clean” soil. TN provides a proven nuclear assay system and is a cost-effective service that can economically reduce on-site management and containment of Cs-137, Co-60, Pu-239, Am-241, and other radionuclides from soil.

This mobile unit consists of a combination of sophisticated conveyor systems, radiation detectors, and computer controls that remove contaminated soil from a moving feed supply on a conveyor belt. Contaminated soil is diverted by segmented gates to a conveyor belt which deposits the soil in a container for disposal or further processing.

This segmented gate system includes a transportable gamma detection system with motorized conveyor belts, a variable belt speed motor controller, air actuated segmented gates, a radionuclide assay computer system and two sets of radiation detector systems applicable to radionuclides that emit low and high energy gamma rays. The mobile unit includes belt conveyors for material feed, screening, sorting, and diverting contaminated material and clean material.

### **5.36 Thomas Gray and Associates, Inc.**

Thomas Gray and Associates, Inc. (TGA) is not only a large broker in the California area, but TGA also provides supercompaction capabilities as well. TGA bought a compactor from CPC Corporation in North Carolina and converted it to a supercompactor. This box compactor has advantages over the typical supercompactor. The compactor utilizes a two cylinder hydraulic press principle. In this system, the full pressure of the two cylinders applied to the surface of a 55 gallon drum, producing a pressure of 2.3 million pounds. The compaction process occurs in a closed chamber, so if a drum contains inappropriate materials, such as liquid, the clean-up process would be simplified due to the enclosed system. The compactor is approximately 5 ft x 5 ft x 4 ft high and made of heavy gauge steel.

The compactor is stationed and operated by Environmental Management & Controls, Inc. located in Turlock, California, while TGA operates in Orange County, California.

### **5.37 US Ecology**

US Ecology (USE) provides volume reduction services for LLW.<sup>7</sup> USE located in Oak Ridge, Tennessee, has the capability of providing sizing, compaction, and decon services to certain LLW generators. USE operates a fixed supercompactor with a compressive strength of 10,000 psi.

They can handle any number of 55 gallon drums or smaller. They accept dry active waste in drums or in bulk.

If necessary, the waste may go through their baler. This baler will shred and size paper, plastics, and other DAW to the proper size before compaction.

The brokerage division of USE in Oak Ridge will provide decontamination services to any commercial customers upon request. Depending upon the situation, USE can provide any means of decon whether it be mechanical or chemical to a customer. Potential customers need to

contact US Ecology and discuss their specific contamination problem with USE representatives before an accurate assessment of which type of decontamination mechanism should be used.

### **5.38 VECTRA Waste Services, LLC.**

VECTRA Waste Services, LLC. (VECTRA), a company located in Columbia, South Carolina, can provide a variety of technologies including resin dewatering, solidification, demineralization, evaporation, and other volume reduction methodologies to generators of LLW.

The company provides resin dewatering services on a full time and demand basis to over 25 utility customers. This service is provided using a patented, NRC approved, VECTRA Drying System, which can dewater resins in 50 to 200 ft<sup>3</sup> containers in an eight hour period. The system can be used to dewater bead resins, powder, charcoal, and diatomaceous earth to less than 0.1 percent free water in carbon steel liners or HICs.

VECTRA also provides both demand and full time radwaste solidification services in container sizes from 55 gallon drums to 210 ft<sup>3</sup> containers. This company maintains procedures in the use of Envirostone™, a unique polymer, and Portland Cement.

Also provided are volume reduction and solidification services using vitrification technology through its Enviroglass™ system.

Demineralization services are provided to many utility customers on a full time or demand basis. The demineralization equipment is designed for low rates up to 150 gpm. The demineralization pressure vessels are designed to be slucible and are fabricated from stainless steel.

The ROVER- Liquid Volume Reduction System uses reverse osmosis (RO) and radwaste volume reduction (RVR) processes. Liquid waste is processed through the RO unit along effluent discharge or reuse of the bulk of the water phase. Concentrated waste streams are transferred to the RVR blender/dryer and further reduced to a dry solid. Condensed steam vapor is returned to the RO unit for additional processing when necessary.

VECTRA has supplied full-scale RO-based systems, up to 75,000 gallons/day, to treat waste streams with a variety of contaminants.

Other technologies provided by VECTRA to world-wide LLW generators include ultra-violet purification systems, remote handling equipment, cask rental, liner storage vaults, and high integrity containers.

### 5.39 Waste Reduction by Waste Reduction (WR<sup>2</sup>)

The WR<sup>2</sup>™ Process\* is a form of “reductive cremation” in which vertebrate, invertebrate, and microbial tissues are hydrolyzed for 12-18 hours at ~230-260EF with dilute aqueous alkali under pressure in a hermetically sealed stainless steel tank. The process hydrolyzes the proteins, nucleic acids, and lipids of all tissues, including hairs and feathers, thereby producing a sterile solution of the natural building blocks of tissues. The alkali itself is consumed in the process by generating the salts of the hydrolysis products. The resulting sterile aqueous solution is rapidly metabolized by the microbes used in water treatment plants. No infectious fungi, bacteria, or viruses survive this process intact because they themselves are made up of proteins and nucleic acids in combination with lipids. The only byproducts of the process are the mineral constituents (ash) of the bones of vertebrates. They are soft enough after the organic matter has been degraded to be easily ground up and recovered as calcium phosphate powder. The WR<sup>2</sup>™ Process solubilizes embalmed or fixed tissues\*\* with equal efficiency and, in addition, destroys the fixatives as well. None of the potentially hazardous chemicals used in such fixation processes can be detected after the alkaline hydrolysis process. Thus, the WR<sup>2</sup>™ Process not only compares favorably with incineration, but is free of its potential for air pollution. By contrast, all products resulting from the WR<sup>2</sup>™ Process can be truly biodegraded or recycled without stressing the environment in any way.

The WR<sup>2</sup>™ tissue hydrolysis apparatus is simple, consisting of an insulated, steam-jacketed, stainless steel tank with a clamp-on lid. The tank contains a retainer basket for bone products. Construction materials are stainless steel and Teflon® and all components are ASME pressure rated. All electrical components are built according to NEMA code. The controls are easily accessible from a control panel and the whole process is semi-automated, allowing unattended operation during most of the digestion time. Using the same seal-less pump that is used in the circulation system, a measured amount of alkali that is proportional to the amount of tissue loaded into the basket is added to the tank after the tissue has been loaded and the load has been weighed using the built-in load cells. Enough water to cover the tissues is added and the vessel sealed pressure-tight. The contents are then heated for 12-18 hours at 230-260EF while being continuously stirred, using the circulation pump. The tissue constituents rapidly dissolve during this heating time and, while in solution, are further degraded into smaller and smaller molecules. The chosen temperature, heating time, and recommended alkali-to-tissue ratios for particular types of loads, selected after extensive laboratory testing, have been found to give a sterile, non-gelling, coffee-colored, slightly alkaline, true solution with a soap-like odor. This solution can be discharged in accordance with local and federal guidelines regarding radionuclide concentrations, pH, and temperature.\*\*\*

\*US Patent 5,332,532; other US and Foreign Patents Pending

\*\*Formaldehyde- or glutaraldehyde-containing fixatives implied

\*\*\*Permitting may be required

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