Chapter 18

Waste Management and Treatment

Authored by:

Marty Brownstein, Chris Cummin and Tom Snyder

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CHAPTER 18: WASTE MANAGEMENT AND TREATMENT

18.1 Overview

D&D and remediation projects demand an integrated, life-cycle approach from planning through waste management. It can be argued (effectively) that D&D projects are just oversized waste minimization and management projects on a life-cycle basis. Choices of schedule, approach, technology, and disposal site made during planning set the floor level for D&D waste generation. Waste management cannot be a stand-alone issue; it must be integrated into planning as a pollution prevention approach. This chapter provides frameworks for screening technologies and D&D approaches during planning and outlines the available tools and options to support the plan.

This chapter addresses both legacy and D&D generated waste management, as a significant cost driver to the D&D process. It minimizes repetition of information previously presented within this handbook in describing waste stream identification (radioactive, non-radioactive, mixed, and clean wastes) based on the characterization information. Also included are regulatory drivers and stakeholder (political, worker, and citizen) involvement, as key factors in successful approach selection. The chapter identifies strategies and administrative controls for storage (RCRA wastes), handling, transportation, and disposal. It should emphasize opportunities for waste minimization through treatment technologies; optimization of D&D technologies, decontamination, recycle, and reuse.

This chapter discusses both DOE and USNRC licensed facilities compliance:

- Authorization basis dictates compliance requirements for both the on-site project operations and for any off-site processing and disposal options.
- Transportation compliance is driven by different sections of the Code of Federal Regulations (specifically 49 CFR parts 170-177) than authorization basis.

Guidance is provided for the identification and management of radioactive wastes, what is necessary to:

- Attain compliance,
- Facilitate effective and efficient implementation of the requirements, and
- Offer acceptable ways to implement the requirements.

The actual requirements have been previously identified and detailed in Chapter 5 and are summarized herein.

Also, this chapter overviews waste treatment approaches which cover the state-of-the-art treatment and minimization of wastes from nuclear facility D&D activities. Regulatory requirements (CERCLA, RCRA, USNRC, DOE and DOT etc.), identified in Chapter 5, guide treatment selection which then leads to contracting strategies to optimize disposal and transport combinations to minimize overall cost – generating the best value approach to the client's project.

The state-of-the-art waste treatment technologies discussed include solidification; thermal treatments including vitrification and incineration; and chemical destruction. The focus of technology selection is based on required operational practices, regulatory requirements, and disposal options off-site and on-site, completing the full circle in optimizing the D&D approach.

18.2 Waste Classification

Overview of Waste Classifications - Authorization Basis is the Driver

"Waste Classification" is a term relative to the authorization basis for the facility originating the waste stream in question. As shown in Table 18.2-1, terminology differs significantly depending on whether the facility is authorized under:

- NRC – Toxicity and risk of the material in terms of dose, uptake pathways, worker and public exposure, are the key classification drivers. Although isotopic composition drives activity and risk level, activity level (i.e., curies/gm) is the key issue.
- DOE – The presence of special nuclear material is the key classification element, followed by toxicity of the material, dose and exposure of workers and the public, with two key criticality issues of note:

  1. Enrichment with respect to ^{235}U – both level and grams,
  2. Presence of Pu and other actinides – with 100 nCi/g as the critical cut-off.

Our discussion here will focus on the commercial classification approach, for two reasons:

- Commercial D&D is the broadest area of impact.
- DOE applications tend to be 1) site-specific and 2) complicated by the large number of orders that may come into play.

Table 18.2-1: Contrasting NRC and DOE Approaches to Waste Classification

Authorization Basis	NRC	DOE
Application Area	Commercial Utilities	Weapons Complex and
	Universities and Processors	FUSRAP
Waste Classes	A,B,C, and GTCC	LLW, HLW, TRU, MLLW, SNM, and SNF

Table 18.2-2 sets minimum criteria that most disposal sites will require for radioactive waste – this is an area that will be addressed in more detail in Sections 18.8 where we address the WAC formally.

Table 18.2-2: Minimum Requirements for Radioactive Wastes

- **No Pyrophores**
- **No Pathogens**
- **Minimization of free liquid and corrosives – levels depend on the site WAC**
- **No Toxic Chemicals or Fumes**
- **No Explosives**
- **No Infectious or Biological Wastes**

Establishing Commercial Classifications

Commercial radioactive waste is classified *per* 10 CFR 61.55; NRC documents provide methodologies for waste classification:

- "Branch Technical Position Paper on Waste Classification", NRC 5/83.
- "Branch Technical Position Paper on Waste Form", NRC 1/91.
- "Waste Form Technical Position Rev. 1", NRC HPPOS-290
- "Final Branch Technical Position Paper on Concentration Averaging and Encapsulation", NRC 1/95.
- "LLRW Scaling Factors", NRC Information Notice 86-20.

Each of the documents should be reviewed prior to establishing waste streams and sampling protocols for waste stream analysis. Generally, the above guidance requires that the classification of waste should be accurate within a factor of 10 and the lower limit of detection for a measurement technique be no more than .01 times of the applicable concentration limit specified in 10 CFR 61. Additionally, four general methods for determining waste classification are identified as being acceptable. Any of the four methods or a combination of the methods may be used to satisfy the regulatory requirement for classification of waste. The four methods include:

- Materials Accountability - This method is generally applicable to licensees who only receive and use a limited number of radionuclides in known concentrations or activities. This method amounts to a balance of activity.
- Classification by Source - This method is similar to the materials accountability with the exception that if a waste stream is not exposed to specific radionuclides, then accountability of those nuclides is not required.
- Gross Radioactivity Measurements - This method is generally applicable to reactors generating a spectrum of radionuclides and method requires that:

    1. Gross radioactivity measurements are correlated on a consistent basis with the distribution of radionuclides within a waste stream.
    2. Radionuclides are initially determined and periodically verified.
    3. The gross radioactivity measurement method must also take into account waste package and detector geometries, shielding and attenuation effects, the effective gamma energies and the number of photons per decay.

- Measurement of Specific Nuclides/Scaling Factors - This method is generally applicable to reactors that generate a spectrum of radionuclides including hard to detect radionuclides, such as pure beta or alpha emitters. In this method, scaling factors for individual radionuclides are established based on direct measurement of representative samples. Scaling Factors are the ratio of hard-to-detect nuclides to gamma emitting nuclides. The scaling factors are then applied to a subsequent analysis ~~and~~ of gamma emitting nuclides from the waste.

Care must be exercised in defining waste streams to ensure that the waste stream will remain relatively constant. Waste streams that do not remain constant include liquid waste streams than are affected by processing technologies and the chemical characteristics of the radionuclides, specifically:

- Cs-137 and Sr-90 are generally soluble radionuclides generally removed from water with the use of demineralizers.
- Co-60 is generally an insoluble radionuclide that is removed from water by filtration.
- As a result of the chemical characteristics of the radionuclides, it may not be appropriate to scale Sr-90 to Co-60.

Typically, fission products (Cs-137, Sr-90, etc.) are scaled to other fission products and activation/corrosion products are scales to other activation/corrosion products (Co-60, Mn-54).

Details of Commercial Radioactive Waste Classifications

Commercial radioactive wastes are classified as Class A, Class B, and Class C, based upon the radio-toxicity with:

- Class C being more toxic than Class B, and
- Class A being the least radiotoxic.

When determining Waste Class evaluations, consideration must be given to:
1. Concentration of long-lived radionuclides,
2. Concentration of shorter-lived radionuclides for which choices of institutional controls, waste forms, and disposal methods may be effected.

These criteria are discussed below with reference to the Barnwell Waste Acceptance Criteria (WAC). The Barnwell waste classification discussion, however, is a good reference point and would, regarding general issues, apply equally well to U. S. Ecology or Envirocare of Utah – noting that the specifics for the three sites' WAC's will vary. In addition, each site has more restrictive criteria than prescribed by Federal Regulations (e.g. Barnwell requires stability for Class A waste that exceeds 1 µCi/cc of > 5 year half life nuclides.

Class A waste must meet the minimum requirements for all physical form and characteristics l wastes as shown in Table 18.2-2. Class A wastes are those for which the concentrations of the selected nuclides in Table 18.2-3 are less than 10% of the level cited. Class A wastes will also meet the isotopic concentrations of Table 18.2-4, column 1.

Table 18.2-3

Radionuclide	Concentration Ci/M^3
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.08
Alpha emitting transuranic nuclides with half life > 5 years	100[1]
Pu-241	3,500[1]
Cm-242	20,000[1]

[1]Units are in nanocuries/gram

Class B waste must also meet the minimum Class A requirements, will exceed the levels of Table 18.2-3, but will have isotopic activities between columns 1 and 2 in Table 18.2-4. Class C waste must also meet the minimum requirements, will exceed 10% of the activity levels cited in Table 18.2-3 and will have isotopic activities that lie between columns 2 and 3 in Table 18.3-4. In accordance with DOT regulations, the Unity Equation (sum of fractions) must be performed. The unity equation is used for the determination of the permissible activity in a package for a mixture of radionuclides. The reference for performance of the calculation is found in the DOT regulations, 49 CFR 173.433 (b) (3).

Table 18.2-4

Radionuclide	Concentration Ci/M^3		
	Column 1	Column 2	Column 3
Total of all nuclides with >5 years half life	700	(1)	(1)
H-3	40	(1)	(1)
Co-60	700	(1)	(1)
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7000
Sr-90	0.04	150	7000
Cs-137	1.0	44	4600

1. There are no limits for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentration for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table 2 determine the waste to be Class C independent of these nuclides.

NOTE: **IF RADIOACTIVE WASTE DOES NOT CONTAIN ANY NUCLIDES LISTED IN TABLE 1 OR 2, IT IS CLASS A.**

Stabilization

Stabilization addresses a level of structural stability and has little to do with waste classification – although specific classifications may trigger additional controls on both waste form and packaging, both per the WAC and per NRC regulations. Normally, stabilization ensures that the waste:

- does not degrade structurally prior to 300 years and
- will not affect overall stability of the site through slumping, collapse or other failure of the disposal trench and thereby lead to water infiltration.

This issue is as much a concern at DOE's Nevada Test Site (NTS) disposal facility as it is at the commercial disposal sites. Stabilization is also a factor in limiting exposure to an inadvertent intruder, since it provides a recognizable and non-dispersible waste. Some examples of structural stability requirements are:

- Maintain 500-psi compressive strength.
- Maintain exposure to a minimum of 10^8 Rads and still maintain 500-psi strength.
- Maintain exposure to culture growths and maintain 500-psi strength.
- Maintain 500-psi strength after submerging in water for 90 days and testing for leaching, again.

Commercially, stability is typically provided by High Integrity Containers (HIC's) or an approved solidification binder. Prior to 1996, the NRC certified processes for stabilization when documented testing of waste forms ~~and~~ met the above criteria. Since 1996, the States approve waste forms. Waste forms may be tested by the DOE INEEL for subsequent state review and approval.

High Level Radioactive Waste- Greater Than Class C (GTCC)

Radioactive waste that exceed the concentration limits of Class C waste are designated Greater Than Class C (GTCC) wastes.

- GTCC wastes are generally not acceptable for disposal in near surface disposal facilities.
- No facility in the United States is available for the ultimate disposal of GTCC wastes.
- GTCC waste must be disposed of in a geological repository which to date has not been licensed.
- Currently, GTCC waste is generally stored at the licensee's site awaiting availability of a geological repository.
- Major sources of GTCC waste at commercial nuclear facilities include:
  - Activated steel associated with reactor internals,
  - Filter media, filters and resin, used to process water at facilities, and
  - Radioactive sources used for instrument calibration and reactor start up, such as Pu/Be, Am/Be neutron sources.

Stainless steel is used in commercial reactors in the active core region and at shutdown has dose rates ranging to a few thousands of Rem/hour. Generally, an activation analysis is performed to identify concentration of radionuclides based on steel type with associated elemental fractions and neutron flux in the active core region. For type 304 stainless steel, nickel 63 is generally the GTCC limiting radionuclide.

Water processing filter media, including filter cartridges and resin, is used to remove impurities from liquids to maintain quality and clarity. The potential exists to concentrate radionuclides at levels that exceed Class C limits. For reactor sites with a history of failed fuel, the transuranic concentration limits may be exceeded on cartridge type filters and the cesium or strontium limits may be exceed on resins. In addition, C14 concentration limits may be exceeded on sub micron filters.

Radioactive sources, including Pu/Be, Am/Be sources are used as neutron start up sources or for instrument calibration. These sources generally have sufficient transuranic content to preclude disposal after encapsulation. Cesium 137 and strontium 90 sources can generally be encapsulated for disposal, if allowed by the receiving disposal site.

Radioactive and Hazardous Waste Mixtures (Mixed Wastes)

Mixed wastes are hazardous wastes as defined by the United States Environmental Protection Agency that are radioactively contaminated. The radioactive portion of the waste may be either Class A, Class B, Class C or Greater Than Class C. The hazardous portion of the waste may either be a characteristic or a listed hazardous waste as defined in 40 CFR 261(RCRA) and 40 CFR 761(TSCA). Characteristics of Hazardous Waste include:

- ignitability,
- corrosivity,
- reactivity, and
- toxicity.

Listed wastes are wastes from non-specific sources or discarded commercial products. Mixed wastes can exist at a facility due to design and construction of the facility or can be created due to handling and use of materials at the facility. Definition and examples of sources of each of the Characteristics of Hazardous Wastes is listed below:

- **CHARACTERISTIC OF IGNITABILITY (Quoted from 40 CFR 261 in part)**
  Definition: A solid waste exhibits the characteristic of ignitability if a representative sample of waste has any of the following properties:

1. It is a liquid, other than an aqueous solution containing less than 24% alcohol by volume and has a flash point less than 60°degrees C, as determined by a Pensky-Martens Closed Cup Tester, using the test method specified in ASTM Standard D-93-79 or D-93-80, or a Setaflash Closed Cup Tester, using the test method specified in ASTM Standard D3278-78.
2. It is not a liquid and is capable under standard temperature and pressure, of causing fire through friction, absorption of moisture or spontaneous chemical changes and when ignited, burns so vigorously and persistently that it creates a hazard.
3. It is an ignitable compressed gas as defined in 49 CFR 173.300 and as determined by the test methods described in that regulation or equivalent test methods.

Potential sources of mixed waste exhibiting the characteristic of ignitability include:

1. Contaminated alcohol
2. Contaminated cylinders of acetylene,
3. Uranium /thorium turnings.
4. Uranyl nitrate

- **CHARACTERISTIC OF CORROSIVITY (Quoted from 40 CFR 261 in part)**
  Definition: A solid waste exhibits the characteristic of corrosivity if a representative sample of the waste has either of the following properties:

  1. It is aqueous and has a pH of less than or equal to 2 or greater than or equal to 12.5, as determined by a pH meter using Method 9040 in "Test Methods for Evaluating Solid Waste, Physical /Chemical Methods".
  2. It is a liquid and corrodes steel at a rate greater than 6.35 mm per year at a test temperature of 55 degrees C as determined by the test method specified in NACE Standard TM-01-69.

Potential sources of wastes with the Characteristic of Corrosivity include:

1. Wet Cell batteries from emergency lighting,
2. Acids and bases from Radiochemistry laboratories,
3. Acids and bases from water treatment facilities,
4. Undiluted cleaning compounds.

- **CHARACTERISTIC OF REACTIVITY (Quoted from 40 CFR 261 in part)**
  Definition: A solid waste exhibits the characteristic of reactivity if a representative sample of the waste has any of the following properties:

  1. It is normally unstable and readily undergoes violent change without detonating.
  2. It reacts violently with water.
  3. It forms potentially explosive mixtures with water.
  4. When mixed with water, it generates toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment.
  5. It is a cyanide or sulfide bearing waste which, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors or fumes in quantity sufficient to present a danger to human health or the environment.
  6. It is capable of detonation or explosive reaction if it is subjected to a strong initiating source or if heated under confinement.

7. It is capable of detonation or explosive decomposition or reaction at standard temperature and pressure.
8. It is defined as an explosive by 49 CFR.

Potential sources for wastes with the Characteristic of Reactivity include:

1. Sodium at certain reactors,
2. Compressed gases,
3. Chemistry laboratory chemicals.

- **TOXIC CHARACTERISTIC (Quoted from 40 CFR 261 in part)**
Definition: A solid waste exhibits the characteristic of toxicity if, using the Toxicity Characteristic Leaching Procedure, test Method 1311 in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," , the extract from a representative sample of the waste contains any of the contaminants listed in Table 18.2-5 at the concentration equal to or greater than the respective value given in that table. Where the waste contains less than 0.5 percent filterable solids, the waste itself, after filtering using the methodology outlined in Method 1311, is considered to be the extract.

Table 18.2-5
Maximum Concentration of Contaminants for the Toxicity Characteristic

Contaminant	Limit mg/l	Contaminant	Limit mg/l
Arsenic	5	Hexachlorobutadiene	.5
Barium	100	Hexachloroethane	3
Benzene	.5	Lead	5
Cadmium	1	Lindane	.4
Carbon Tetrachloride	.5	Mercury	.2
Chlordane	.03	Methoxychlor	10
Chlorobenzene	100	Methyl Ethyl Ketone	200
Chloroform	6	Nitrobenzene	2
Chromium	5	Pentrachlorophenol	100
o-Cresol	200	Pyridine	5
m-Cresol	200	Selenium	1
p-Cresol	200	Silver	5
Cresol	200	Tetrachloroethylene	.7
2,4-D	10	Toxaphene	.5
1,4-Dichlorobenzene	7.5	Trichloroethylene	.5
1,2-Dichloroethane	.5	2,4,5-Trichlorophenol	400
1,1-Dichloroethylene	.7	2,4,6-Trichlorophenol	2
2,4-Dinitrotoluene	.13	2,4,5-TP (Silvex)	1
Endrin	.02	Vinyl Chloride	.2
Heptachlor and its epoxide	.008		
Hexachlorobenzene	.13		

Potential sources of waste exhibiting the Toxicity Characteristic include:

- Mercury contained in thermostats, mercury pressure switches on plant systems and phone switch panels, thermometers, light bulbs, manometers and Nessler's Reagent.
- Lead sheet, shot, blankets or bricks used for shielding, and as a component of paint.
- Cadmium in neutron shielding, and as a component of paint and lubricants.

- Solvents (halogenated and non-halogenated) canned spray paint, oil based paints, dye penetrant test kits, asbestos test kits, maintenance shops and chemistry labs.
- Chromium in lubricants for motors and in corrosion inhibitors.

Transuranic Wastes, a DOE Classification

Wastes with transuranic radionuclides are generated at nuclear facilities from the activation of uranium in the reactor core. Most transuranic radionuclides have relatively short half-lives which result in rapid elimination from normal waste streams. The transuranic radionuclides that are normally present relative to the classification of waste include Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, Cm-242, Cm-243, Cm-244, Cm-245, Cm-246. These radionuclides may be released from fuel during operations which results in transuranic contamination of the plant liquids, piping, and structures. Transuranic wastes are a major concern for fuel processing facilities, which in the United States is limited to the Department of Energy facilities. DOE specifically sets the concentration limit for "TRU" waste as those with actinide concentrations > 100 nCi/g.

Spent Nuclear Fuel

Spent nuclear fuel falls under the category of GTCC wastes and produces a significant heat load due to decay of the radioactive materials in the fuel. Currently, no facility exists for the disposal of spent fuel in the United States, but the Department of Energy is involved in the siting of a geological repository in Yucca Mountain, Nevada. As an interim process, many reactor facilities are storing spent fuel on site in either the fuel pools or in on site spent fuel storage casks.

18.3 Drivers

Two key driver's pair waste management technology with waste stream characteristics to ensure regulatory compliance at minimum cost:

- Regulatory Compliance Framework:
  - NRC and DOE maintain separate authorization bases.
  - Both authorization bases are compatible on the whole - even though they may appear to be in conflict in specific instances.
- Economics – the "best value" for waste management and disposal.

The regulatory compliance framework (including the disposal sites available and the appropriate WAC) is determined by the authorization basis of the facility in question:

- NRC (either the Federal Agency directly or Agreement State authorization) drives nuclear regulatory compliance outside the Federal weapons complex, including:

  - Commercial Utilities, such as Big Rock Point, Maine Yankee, Connecticut Yankee, TVA Stations, and others.
  - Commercial processors such as Westinghouse Nuclear Fuels Division (Columbia SC, Ogden UT, Blairsville PA), GE Nuclear (Wilmington NC, San Jose CA), Framatome (Lynchburg, VA), and others.
  - University reactors, such as University of Missouri, Georgia Tech, University of Virginia, University of Michigan and others.

Table 18.6-3 describes the commercial disposal sites (historically) that have addressed waste management under this authorization basis.

- Department of Energy Authorization applies only to Federal Weapons Complex and FUSRAP Facilities such as those at Fernald, OH, Rocky Flats, CO, Hanford, WA, and others.

  - Note 1: FUSRAP is now managed through the USACE.
  - Note 2: Selected DOE projects such as the Advanced Mixed Waste Treatment Project (AMWTP) in Idaho have considered adopting NRC authorization basis driven by two factors:

    1. NRC authorization is more direct with fewer directives to guide compliance.
    2. The NRC process is a determinant exercise compared to the relatively open-ended approach to DOE authorization.

  Table 18.6-4 describes Federal disposal cells available to address waste management under this authorization basis; many DOE sites (e.g., Fernald, Y-12, Hanford and others) have their own disposal cells which are mandated for use during site D&D projects.

As shown in Section 18.2, waste classifications differ between the two authorization bases, as will disposal WAC; some disposal options cover both clients:

- Envirocare of Utah takes both government (DOE/DoD) and commercial wastes from all states, but is currently limited to Class A (LLW) waste forms; permit applications have been filed to expand the authorization to Class B and C wastes.
- WCS at Andrews, Texas, currently takes NORM and FUSRAP materials from both the Federal and commercial sectors, as well as RCRA/TSCA wastes for disposal. WCS also has an expansive rad permit for processing and storage (but not disposal) of radioactive mixed waste (LLMW).
- Commercial facilities, such as the Barnwell Site and the Hanford site, accept commercial Class A, B, and C wastes. The Barnwell facility will soon restrict quantities of waste from states outside the Atlantic Compact States of Connecticut, New Jersey, and South Carolina. The Hanford site restricts waste from outside the Rocky Mountain and northwest compact.

Once the regulatory compliance framework is set, cost becomes the primary driver: low-cost pairing of waste stream and approach is <u>the</u> goal. Project and site waste managers nominally cite "cost-benefit analyses" in selecting among options. However, most often, this normally results in a simplified version of the full cost-benefit analysis regimen – i.e., a trade-off study to minimize cost. Following the framework of Lave and Lave [(1)], we address the requirements of a full cost-benefit analysis <u>and</u> when to apply it. We will also show why radwaste trade-off studies often offer the same level of rigor in reaching a solution with (seemingly) less work.

Regulatory Frameworks for Compliance

<u>*DOE Regulated Facilities*</u>

Three separate agencies have regulatory purview over waste management and project operations on Federal facilities:

- US DOT governs shipping and transportation.

- US EPA addresses the regulation, worker, public and environmental protection from hazardous materials (principally through RCRA, TSCA, SARA, CWA, CAA, and CERCLA legislation).
- DOE Orders and Directives drive the operational and waste management compliance.

Our discussion here will focus only on the operational/waste management issues – DOT and EPA impacts are summarized in Section 18.3.1.2, since DOT, EPA and NRC requirements are found in a common body under the Code of Federal Regulations (CFR).

DOE Order 435.1 (which replaces 5820.2A of 26 September 1988) is the key driver for DOE waste management operations and compliance:

"...The objective of this order is to ensure that all Department of Energy (DOE) radioactive waste is managed in a manner that is protective of worker and public health and safety, and the environment."

The order applies to management of several classes of waste:

- High level (HLW), Transuranic (TRU), low level (LLW), and the radioactive component of mixed (RMW) wastes that are generated on DOE sites.
- Accelerator-produced rad-wastes.
- Byproduct materials that are managed at DOE sites (e.g., the DUF_6 inventories under DOE stewardship at Paducah and Portsmouth).

Exemptions to these categories, including spent fuel, materials that are overlapped by NRC purview, non-DOE byproducts, and others, as identified by the order.

While O 435.1 is less than five pages (with attachments), detailed compliance with the order is guided by two supporting documents:

- DOE M435.1-1: Radioactive Waste Management Manual, and
- DOE G 435.1-1: Implementation Guide for Use with DOE M 435.1-1,

each providing several hundred pages of documentation. We refer the reader to the DOE's homepage for the full documentation.

DOE M 435.1-1 covers the waste management and design/operating requirements for a wide range of projects and materials. The following list of supporting orders is only a road map directing the reader where to go for compliance requirements on Federal projects – also indicating why the NRC authorization, where applicable, is viewed as being more direct and streamlined. The list includes all issues that will be mandated for addressing D&D or waste management on a Federal site:

Closure Process	DOE P 450.3
Safety Management System	DOE P 450.4
Directives System Manual	DOE M 251.1-1A
Performance Indicators and Analysis of Operations	DOE O 210.1

Classified Waste: Safeguards and Security Interests	DOE 5632.1C
Control and Accountability of Nuclear Materials	DOE 5633.3B
Conduct of Operations	DOE 5480.19
Criticality Safety	DOE O 420.1
Emergency Management	DOE O 151.1
Environmental and Occurrence Reporting	DOE O 231.1 and O 231.1A
Environmental Monitoring	DOE 5400.1 and 5400.5
Hazard Analysis Documentation And Authorization Basis	DOE-STD-1027-92, DOE-EM-STD-5502-94, DOE O 425.1A , DOE O 5480.21, DOE 5480.22 and 5480.23.
Life-Cycle Asset Management	DOE O 430.1A and DOE 4330.4B
Mixed Waste	RCRA (also see CERCLA and SARA requirements)
Packaging and Transportation	DOE O460.1A and DOE O 460.2
Quality Assurance Program	10 CFR 830.12 and DOE O 414.1
Rad Protection	10 CRF Part 835 and DOE 5400.5
Records Management	DOE O 200.1 and O 414.1
Release of Waste-containing Residuals	DOE 5400.5
Safeguards and Security	DOE O 470.1
Safety Management System	DOE P 450.4, P 450.5, 48 CFR Chapter 9, and DOE M 411.1-1.
Site Evaluation and Facility Design	DOE O 420.1 and DOE O 430.1 A.
Training and Qualification	DOE O 360.1 and DOE 5480.20A
Waste Minimization and Pollution Prevention	Executive Orders 12856 and 13101, and DOE 5400.1
Worker Protection	DOE O 440.1A

The information for each of these areas is detailed for each waste stream (HLW, TRU, RMW, LLW) in separate chapters of the manual, including:

- Waste stream definition – in DOE terms, e.g., "TRU Waste" streams with actinide concentrations greater than 100 nanocuries per gram of waste is a DOE classification. While it is the trigger point for WIPP disposal in DOE, it carries no meaning in the commercial world, where spent fuel is currently stored on site.
- Waste certification and characterization requirements.
- Facility design and operation requirements.
- Packaging, transportation, disposal, and all other key issues involved in the life cycle approach to DOE waste management.

For each DOE waste stream the key point to be stressed is life cycle planning through ultimate disposition.

USNRC Regulated Facilities

Commercial sector projects must comply with regulation from three agencies:

- The United States Nuclear Regulatory Commission (NRC) and Agreement States issue regulations regarding the possession, use, transfer and disposal of licensed radioactive materials.
- The Department of Transportation (DOT) issues regulations regarding the packaging and shipment of hazardous materials in commerce, which radioactive materials are considered to be during transport.
- The Environmental Protection Agency (EPA) issues regulations for collection, storage, treatment and disposal of hazardous materials used in industry.

A detailed analysis of the regulations will not be attempted, rather this section will identify the major regulations associated with use, transfer and disposal of licensed radioactive materials.

10 CFR 20-STANDARDS FOR PROTECTION AGAINST RADIATION

10 CFR 20 Subpart K-Waste Disposal, provides regulations concerning the transfer and disposal of licensed radioactive material. In summary, licensed material must be transferred to an authorized licensed recipient. In the case of waste intended for ultimate disposal at a licensed low-level land disposal facility, the use of NRC forms 540, 541 and 542 are required to manifest the waste. Additionally, a tracking method must be established to ensure timely acknowledgement of receipt of the waste. This section also provides alternative disposal methods.

10 CFR 61-LICENSING REQUIREMENTS FOR LAND DISPOSAL OF RADIOACTIVE WASTE

10 CFR 61 provides regulatory guidance on the licensing and operation of a near surface land disposal facility. This regulation affects generators of waste in that it requires classification of the waste as Class A, Class B or Class C based on the radionuclides and activity of the waste. Minimum standards for waste form are also established.

10 CFR 71-PACKAGING AND SHIPMENT OF RADIOACTIVE MATERIAL

10 CFR 71 provides regulatory guidance on packaging, preparation for shipment and transportation of licensed material. The major affect of this regulation is to provide procedures and standards for packaging and shipping of fissile material and for shipping licensed material in excess of a Type A quantity of material (e.g., Type B Casks).

49 CFR TRANSPORTATION-SUBCHAPTER C-HAZARDOUS MATERIALS REGULATIONS

These regulations address the transportation of hazardous materials in commerce. Eight parts of the regulations are applicable to transportation of radioactive materials and are summarized below:

49 CFR 171 provides general information regarding shipment of hazardous materials including definitions and actions relative to hazardous materials incidents.

49 CFR 172 provides regulations relating to proper shipping name, hazardous substance identification, shipping paper requirements, package marking requirements, package labeling requirements, placarding requirements, emergency response information requirements and Hazmat worker training requirements.

49 CFR 173 provides regulations for shippers on the specific requirements for shipments and packaging. Subparts A, B and H are applicable to radioactive materials.

49 CFR 174-Carriage by Rail- provides regulations for carriers on the requirements for shipments of hazardous materials by rail. Included is specific Hazmat employee training requirements. Subpart K is specifically applicable to radioactive materials.

49 CFR 175-Carriage by Aircraft-provides regulations for carriers on the requirements for shipment of hazardous material by aircraft.

49 CFR 176-Carriage by Vessel-provides regulations for carriers on the requirements for shipment of hazardous material by boat.

49 CFR 177- Carriage by Public Highway-provides regulations for carriers on the requirements for shipment of hazardous material on public highways.

49 CFR 178-Specifications for Packaging-provides design basis packaging specifications for the manufacture and marking of packaging.

40 CFR SUBCHAPTER I- SOLID WASTES-provides regulations regarding the identification and management of hazardous waste. Four parts of the regulations are related to mixed wastes and hazardous wastes as discussed below.

40 CFR 260 provides definitions of terms, general standards and an overview of regulations.

40 CFR 261 provides standards for the identification of hazardous wastes.

40 CFR 262 provides standards applicable to generators of hazardous wastes.

40 CFR 263 provides standards applicable to transporters of hazardous wastes.

40 CFR 268 provides land disposal restrictions and treatment.

40 CFR Part 761-POLYCHLORINATED BIPHENYLS (PCB'S) MANUFACTURING, PROCESSING, DISTRIBUTIN IN COMMERCE AND USE PROHIBITIONS-provides regulatory guidance for handling and disposal of PCB's.

In addition to federal regulatory requirements, state regulatory requirements may also apply, specifically in cases where disposal sites and/or processing facilities are licensed by agreement States. The specific disposal and processing facility licenses should be reviewed when using these facilities, consult the appropriate facility licenses.

Environmental Requirement Summary

Waste management, regardless of authorization basis or site, must comply with a range of regulations that go beyond the bounds of radioactive waste only. The key issues include:

- Level concentration of activity:
    1. Class A, B, C or GTCC for commercial;
    2. LLW, HLW, SNM/SNF, or TRU for Federal;
    3. Remote or contact handled (RH or CH) for both.

- Non-rad hazards and constraints:

    1. Resource Conservation and Recovery Act (RCRA);
    2. Toxic Substance Control Act (TSCA);
    3. Superfund Act and Reauthorization Amendments of 1986 (SARA);
    4. Clean Air and Clean Water Acts (CAA and CWA);
    5. Occupational Safety and Health Act (OSHA);
    6. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 – commonly known as Superfund.

- Any necessary permits for discharge, including NESHAPS, NPDES, and NEPA filings that may be required for the project.

Each adds both time and cost to the schedule and budget baselines for any D&D or remediation project – all requirements must be identified in advance, not only as part of a project bid, but as part of the bid decision itself.

Cost-Benefit Analysis – a Technology Screening Approach

Lave and Lave [1] address frameworks for selecting risk reduction options (i.e., technology screening) in servicing the public sector; several have been identified depending on the agency with regulatory purview over the compliance area, and on the potential impact to the public:

- **No Risk Frameworks** – as approached by legislation such as the Food and Drug Act or the Clean Air Act, drive selection to reduce the risk of exposure to zero.
- **Technology-based Frameworks** – as approached by the Clean Water Act and OSHA, drive the selection of remedy technology based on the best technology available or the best available within engineering judgement.
- **Risk-Risk Frameworks** – as approached by the Food and Drug Act and the Department of agriculture, it balances the risks of use against the risks of non-use.

Rarely are these frameworks invoked for radioactive waste management. Instead, a fourth approach, the Cost-Benefit Analysis[1], does allow for identification and quantification of factors that trade-off costs incurred against the benefits of the treatment – with quantification the key issue. In its most rigorous form, the cost-benefit analysis (CBA) encompasses ten steps. While exercising the full CBA regimen is often time consuming and expensive[1], Lave and Lave also noted that an accurate problem definition (step 1) often results in direct resolution. In the case of radioactive waste management, this is the norm:

- Accurate definition of the problem abbreviates the CBA to a **trade-off study** addressing steps 1 through 5 **with the number of options restricted** to the few already permitted and found to be in compliance with both the project authorization basis and the disposal site WAC.
- Many of the issues addressed by steps 6 though 10 were resolved (in advance of the project) during the original public comment periods for permitting and authorization basis for disposal site candidates or for the original site permits.
- Only a very large, first-of-its-kind project risks having to run the full CBA.

Therefore, comparison of alternatives and near term costs for D&D projects becomes a very manageable problem, often over a window of ten years project life or less. These ten steps, as will be discussed in Section 18.8, guide process and technology screening approaches to some extent for every project:

1. ***Define the problem*** – the set of conditions, (feed and waste characterization), materials to be treated, (classification issues are targeted here as well as hazardous mixed wastes), treatment alternatives (the technologies from characterization and processing to containers and transportation), and potential goals (WAC compliance and cost). Lave and Lave note that proper definition may render the decision directly, with little further analysis once the full set of options and drivers are known [(1)]. For example, once one has determined that the main waste from a DOE project is "TRU" waste, then packaging, WAC, and disposal site alternatives are determined and driven by access to WIPP.
2. ***Set goals and objectives in advance*** – before any analysis and resolution are attempted, including not only the objectives for the project but also:
   - the criteria for success and
   - the agendas of as many stakeholders (explicit or hidden) as possible.

   Otherwise, an apparent resolution to the problem or approach to the project only triggers a new set of debates evolves in its place regarding the meaning of the solution [(1)]. Note that, as has been found to be the case in DOE projects, different stakeholders (industry, Civilian Advisory Boards, Citizen Groups such as FRESH or SOCM, DOE, and others) have different objectives – all should be tabled right up front to derive a meaningful solution.
3. ***Identify all reasonable means to attain the objectives*** – the key is to offer all "reasonable" approaches without being too restrictive to be meaningful. For radioactive waste management projects, the number of acceptable alternatives will normally be limited to well under five (often under three).
4. ***Analyze the benefits of the alternatives*** – in terms of the objectives of the overall program and requirements for waste disposal. D&D or remediation program approaches (such as a leaching approach that is heavily based on application of chelants) that result in wastes with no direct route for disposal are of no utility to anyone.
5. ***Analyze the costs*** – often the toughest step, because quantifying cost (as in the value of a human life resulting from an order of magnitude reduction in the risk of cancer) may start more arguments than it solves. However, in the case of radioactive waste management, quantification normally comes down to a selection from among predetermined options (e.g., waste forms and disposal sites) for which such dialogue has been settled. Secondly, a firm analysis of cost, supported by pro forma analyses, is standard procedure for most corporate bid decisions (not only the go/no-go decision, but also which projects to select on the basis of the highest return among several alternatives).
6. ***Specify the perspective*** – which may vary among the various stakeholders (see #2 above).
7. ***Perform all cost evaluations in terms of Net Present Value*** – discount all future costs and benefits to current dollars.

8. ***Analyze uncertainties*** – particularly from steps 4, 5, and 7 where assumptions will have been made regarding costs, appropriate discount rates for the risks involved, and the like.
9. ***Address the ethical situation of the solution*** –such as social or environmental justice, particularly for large, problem-oriented procurements such as:
   - DOE's MOX and DUF_6 projects,
   - Whether Oak Ridge's ETTP is brown-fielded for an industrial park,
   - Whether a commercial utility sitè is green-fielded or brown-fielded,
   - Who "wins" and who "loses" in terms of the prevailing of their point of view.
10. ***Interpret the results*** – particularly in light of steps 1, 2, 3, and 9.

The key point from the ten steps is that most of these steps are exercised (at least in abbreviated fashion) by most companies through their project management approach and marketing programs. Many of these are issues that must be addressed in project bid decisions, in project permitting, or in developing the project approach and costing (which is always in the form of a pro forma that estimates multi-year projects in terms of their Net Present Value and Rate of Return. The key issues are to discount all costs at the appropriate risk-rated discount factor for the project and to capture all cost elements in the project Work Breakdown Structure (WBS).

Disposal Options – Compliance/Risk Management

There are five main disposal options available, driven by the authorization basis for the generating site:

Commercial Wastes:

The Barnwell Site (Barnwell, SC) operated by Duratek, EoU (Clive, UT), WCS (Andrews, TX – primarily for hazardous and certain 11e.(2) and NORM wastes), U. S. Ecology Hanford Facility (Richland, WA) are the main sites:

- Each facility has site-specific licenses and waste acceptance criteria.
- Each facility has dedicated inspectors responsible for the receipt, inspection and approval of waste arriving at the facility. Typically, every aspect of a shipment arriving at the facility is inspected including condition of the containers relative to damage and labeling, and completion and accuracy of the shipping documentation, manifests and waste profiles.
- Additionally, each facility has made provisions to randomly inspect the contents of containers to ensure that the waste acceptance criteria have been met. Failure to meet waste acceptance criteria may result in rejection and return of the load, notification of regulators of violations, exclusion from the burial site and/or fines.

Envirocare of Utah is the only site receiving waste from all domestic licensees. Specific requirements of that site include limitations as to the specific Class A waste activity of waste NORM, NARM, 11e.(2), and hazardous only materials with no Class B or Clàss C waste allowed.

	The Barnwell Waste Management Facility, part of the Atlantic Compact, currently accepts waste from any licensee. Waste volumes received from other compact regions will decrease annually until only waste from the Atlantic Compact is accepted. Class A, Class B and Class C wastes are acceptable for disposal at Barnwell.
	U S Ecology Hanford Facility accepts waste from the Northwest and Rocky Mountain Compacts. The Hanford Facility accepts Class A, Class B and Class C wastes for disposal. Norm and exempt materials from any generator are also accepted.
DOE Low-Level Wastes:	NTS and Hanford are the main defense-related disposal sites; EoU and WCS are alternatives. EoU: 11e.(2), LLW, NORM, MLLW; WCS: 11e.(2)/NORM wastes; both for hazardous materials under RCRA or TSCA purview. Many sites, including Hanford (ERDF), Oak Ridge (Y-12 Landfill and EMMWF), Fernald and SRS either have or plan to have disposal cells on-site for the bulk of D&D wastes. For example, Bechtel Jacobs will maximize use of direct disposal at the Y-12 Landfill and EMMWF cell for ETTP D&D.
DOE TRU Waste:	Defined in DOE authorization as any waste stream containing >100 nano curies/gram of transuranic materials, TRU materials will all target WIPP disposal.
Commercial Class B&C:	Only Barnwell and U. S. Ecology offer disposal options at this time for Class B and C wastes from commercial applications.
Spent Fuel:	Although not an issue for D&D, no commercial reactor can proceed with decommissioning until the spent fuel has been removed from the reactor pressure vessel and placed in the spent fuel pool or dry storage system. At present, there is no alternative for the spent fuel, the object of an on-going legal action between the utilities and DOE.

Each site will have its own WAC for compliance – normally available off the web directly, and discussed in Section 18.8. Appendix C shows the compliance process for meeting the WAC at both EoU and NTS.

The greatest impediments to commercial waste management in support of the utility D&D programs, at this time, are:

- The absence of a Spent Fuel disposal option.
- The failure of the compact system to establish the required disposal sites across the country – particularly in light of the formation of the Atlantic Compact and the anticipated restricted access to the Barnwell site.

The former will ultimately be addressed through the recently let DOE contract to Bechtel for the Yucca Mountain repository; the latter offers two mitigation's:

- The planned expansion of EoU to accept Class B and C wastes.
- The potential development of the WCS site.

Risks and Risk Mitigation

Risks and risk mitigation are the critical issue for waste disposal and can be classified into several categories:

1. Transportation risks incurred in meeting all packaging, container, and transportation requirements of 49 CFR parts 171, 172, 173, 174, and 177 or 10 CFR 71. Key issues arise during transportation, and packaging:

   - Release of licensed material to unrestricted and uncontrolled areas,
   - Improper classification of wastes,
   - Improper packaging and labeling of containers,
   - Accidental release of licensed material in transit.

   The development, implementation and maintenance of a rigorous radiation protection and waste management program at the licensees' site address risk mitigation for these items. The consequences of failure to maintain an adequate program include citations from regulatory agencies, civil penalties, lawsuits and negative public relations. Risk mitigation for accidental release of licensed material in transit is addressed by screening licensed carriers based on safety record:

   - Routine audits of carrier and equipment should be completed and documented to ensure the carrier is continuing to comply with regulations.
   - Each shipment should be inspected prior to release to ensure that required safety equipment is being maintained.

     Note also that the transportation mode itself introduces both risk and restrictions inherent in the selection of the disposal site, for example:

   - Safety statistics show a heavy safety weighting in favor of rail over truck, but only truck is available for NTS – there is also a significant cost impact.
   - Barges may be the preferred way of addressing large components but EoU cannot be reached by barge so a rail alternative may be needed.
   - Certain waste forms may need to be overpacked prior to shipping.
   - The shipper, in signing the manifest accepts much of the liability for the integrity of the container/package and associated regulatory compliance for the shipment.

2. Disposal site selection risks becomes a risk of both cost and nuclide acceptability per the WAC both in terms of grams/activity and in terms of allowable isotopes. For hazardous materials, cradle-to-grave-liability applies – which may include the risk that a user may be cited as a principle responsible party in disposal site Super Fund action.

3. Disposition operations risks incurred in meeting site WAC for particulate, particle size distribution (NTS, WIPP, and EoU – to a lesser extent), off-gassing and thermal load (WIPP), the presence of organics, and waste form leaching performance may all be mandated. The key to compliance is in four areas:

- Waste Certification Program – and the needed QA/QC to support it, as well as waste form characterization and documentation to comply with the disposal site programs – particularly important for WIPP and EoU (through its finger printing and waste form profiles).
- Characterization of the waste stream(s) prior to processing and shipment – particularly difficult on many DOE sites where fixed price or fixed unit price bids are required, but insufficient characterization is available to determine the needs for stabilization or containers.
- Costing basis – volume reduction still offers some benefit, but its value is largely driven by the cost of disposal (and note that even Barnwell's pricing structure is partially based on mass, although improving density offers a price benefit).
- Container selection – with the package often defining the final form of the waste.
- Debris issues – where shredded, heterogeneous metals may offer significant waste form sampling challenges, but also where proper application of the Debris Rule may significantly simplify the management of D&D debris.

The requirement of EoU and NTS to establish waste profiles, and potentially to supply finger print samples for wastes as determined by the WAC, provides useful guidance for all sites

4. Regulation change risks are too difficult to predict in advance but are capable of causing a major swing in the disposal cost and availability. The basic rule is that disposal of waste should never be delayed: it will never get easier and will probably never be cheaper.

5. Financial or physical risks resulting from failure of waste processors, waste brokers, and/or disposal facility:

- Mitigation of risk associated with financial failure of a waste processor or waste broker is addressed through the QA program, by qualifying processors based on bonding and ability to complete the contracted task - this may require a deeper audit than is normally required for inclusion on an approved suppliers list.
- An indication that a company is having financial problems may be identified by the amount of waste accepted but not disposed of in a timely fashion.
- Mitigation of risk associated with the failure of a disposal site is addressed by screening sites based on safety and compliance record. Additionally, the design and operation of the facility should be reviewed to ensure adequate controls, accountability and maintenance of disposal cells.

18.4 Waste Management Strategies and Controls

Waste management strategies and controls vary by the type of facility being decommissioned. The strategies and controls that remain constant regardless of the facility include:

- A plan detailing the radiological and chemical characteristics of the site and the items to be disposed of should be developed. This detail is needed for cost estimation and demolition planning.
- A plan detailing the waste processing or disposal facilities to be used should be developed. This detail is needed for cost estimation and packaging planning.
- A plan detailing which waste streams will be consigned to each facility should be developed. This detail is needed for cost estimation, demolition planning and packaging planning.
- A transportation plan should be developed which identifies licensed and approved transport companies. This should include planning for over sized components such as reactor vessels and concrete segments.
- During demolition the spread of radioactive contamination should be minimized.

- During demolition hazardous materials should be segregated from radioactive materials, if possible.
- During demolition fluids should be segregated from solid materials.
- On site material-handling requirements should be identified.

Treatment, Handling and Storage of Wastes

Most facilities contain a variety of materials, which may be radioactive, including but not limited to:

- Miscellaneous chemicals, such as caustics, acids, grease and paints,
- Fluids such as water, sludge, oil, solvents and antifreeze.
- Asbestos in insulation, floor tiles and wall panels,
- PCB's in paint, transformers and lighting,
- Mercury in switches, lighting and thermostats,
- Lead for shielding,
- Steel in piping and structures,
- Aluminum in conduit and cabinets
- Concrete structures,
- Copper or brass in piping, wiring and motors, and
- Wood in structures and cabinets.

On-Site Treatment

The availability and cost of waste disposal and the size and capabilities of the facility being decommissioned can dictate on site treatment options. For example, if the facility is equipped with compaction equipment and disposal space is available and the cost is acceptable, compaction of materials for disposal may be an option. Typical on site treatment options include:

- Chemical decontamination of systems,
- Compaction of waste,
- Neutralization of caustics,
- Drying of sludge,
- Filtration and release of water,
- Filtration and release of gases,
- Decontamination and release of materials,
- Survey and free release of materials, and
- Sizing and sorting of materials based on activity for disposal.

Each of the treatment options has costs, risks and benefits associated with it. Costs include labor, equipment and space requirements. Risks include injury to workers, radiation exposure to workers, contamination of facilities, non-conforming waste at disposal facilities or negative press if radioactive materials are released. The major benefit is potentially reduced cost for the D&D effort.

On-Site Material Handling

Decisions on material handling need to be made before the demolition process starts. Major decisions that are required include:

- Expected disposition of the material, such as will it be processed on site, processed off site or sent directly to disposal.
- Physical dimensions of material removed. Sizes of components must be acceptable for transportation off site. Additionally, the component size must be acceptable to the receiving facility, able to be handled by individuals removing the components and fit the selected container.
- Weight of the material removed. The weight of the components should be acceptable for transportation off site. Additionally, the weight must not exceed the capacity of on site handling equipment such as cranes, rigging or forklifts and must be acceptable to the receiving facility.
- Package loading should be accomplished by individuals sufficiently trained and aware of waste packaging requirements. This may be accomplished by pre job briefings, general employee training, or direct observance by appropriate personnel.
- Package loading should occur inside of buildings, if possible. Packages loaded in outside areas should be closed, when loading stops. This is to prevent moisture from entering the packaging.

During demolition, the efficient use of on site labor requires that materials be handled the least number of times possible. Additionally, the waste must be packaged to efficiently use space and be acceptable for the receiving facility. Packaging for the waste stream being removed should be available as close to the work area as possible. A generally acceptable sequence for removal of components and equipment from an area is as follows:

- Hazardous materials or hazardous substances, such as mercury, lead, PCB and asbestos are removed prior to general demolition. This prevents subsequent contamination of the waste with the materials and in the case of asbestos removal reduces protective clothing and monitoring requirements for subsequent work.
- The higher dose rate components are removed. This reduces total worker doses and should reduce worker control requirements.
- Components that interfere with access are removed. This improves worker efficiency.
- The area is cleared of internal components or contamination.
- The structure is demolished.

After a package is loaded, the contents and exterior of the package should be inspected. The contents should not be able to shift and should not contain free standing liquid. The exterior of the package should not be damaged. Required gaskets and closures should be installed.

Waste Storage

Most facilities have limited waste storage capacity. The capacity is limited by the physical size of the facility and the radioactive materials license activity limits. Waste storage on site can be either long or interim term storage. Long term storage for a D&D site is generally limited to items such as spent fuel or greater than Class C wastes. Interim storage of low level waste is often required to allow efficient utilization of transport vehicle capacity.

The Nuclear Regulatory Commission has issued guidance for waste storage in the following documents.

- NRC INFORMATION NOTICE 89-13, "Alternate Waste Management Procedures in Case of Denial of Access to Low Level Waste Disposal Sites."
- NRC GENERIC LETTER 81-38, "Storage of Low Level Waste at Power Reactor Sites."

- HPPOS 239, "Clarification of NRC GL 81-38."
- NRC GENERIC LETTER 85-14, "Commercial Storage at Power Reactor Sites of LLW not Generated by the Utility".
- NRC Letter, Temporary On Site Storage of LLW."
- NRC INFORMATION NOTICE 90-09, "Extended Interim Storage of LLW."

Each of the documents should be reviewed for applicability to the specific situation involved in the D&D process. The overall theme of the guidance is that waste storage should not negatively impact the environment or personnel safety and that storage is not an acceptable alternative to disposal.

Transportation and Disposal

Regulations concerning the transportation of radioactive materials inside the United States are included in 49 CFR, 10 CFR 71, 10 CFR 20 and in some cases individual state laws. The general intent of the regulations is to ensure that radioactive material does not leak in transit, that the hazards associated with the material are properly documented and that information is provided to the carrier and the consignee, and that the consignee is authorized and able to receive the material. The driving force in selection of a mode of transport is safety, the availability of the mode of transportation, the availability of infrastructure to support the transport mode selected and cost.

Truck Transport

Most facilities have road access to major highways as a result most radioactive waste is shipped by trucks. Legal truck weight and width dimensions are 80,000 pounds and no wider than 102". Over dimensional loads are allowed for transport, but the load must be a single item and not devisable without significant effort or alteration from the intended purpose. Over dimensional loads are usually permitted through each state and may require the use of escorts. Very heavy loads may be transported by truck, but may have speed limits during transport and routing to avoid bridges or other interference. The transport company selected should be evaluated to ensure a good safety record, adequate training of drivers in Hazmat regulations, acceptable equipment and appropriate EPA and DOT permits for the transportation of hazardous goods.

Rail Transport

Rail transport is often available at reactor sites. When available, rail is a useful transport method for large components or for bulk shipments requiring transportation for long distances. Load limits with respect to weight and size are limited by the rail company servicing the facility. Weight limitations may be imposed due to the condition of the track, bridges, rail car configuration and interchange points. Load size limitations are generally imposed for tunnels and bridges. Standard gondola styled cars are generally limited to approximately 220,000 pounds of weight and have internal dimensions of approximately 8' H X 9'6" W X 49'L. Flat cars are limited based on design of the car and the limitations imposed by the rail service provider.

Vessel Transport

Vessel transport is limited to facilities with navigable waterways near the facility and is usually associated with extremely large or heavy components, such as reactor vessels and steam generators. Vessel selection is based on needed capacity, depth of waterways and facility design.

Disposal

Commercial Low Level Radioactive waste can currently be disposed of at three different facilities in the United States. These facilities include:
Envirocare of Utah, Clive, Utah
Barnwell Waste Management Facility, Barnwell, South Carolina and
U S Ecology Hanford Site, Hanford, Washington

Each facility has a site specific waste acceptance criteria and radioactive materials license. Envirocare of Utah is currently limited to Class A waste. Barnwell and Hanford are licensed to receive low level waste up to and including Class C wastes. Included in each facilities waste acceptance criteria are limitations as to size and activity of waste that can be received.

Government waste disposal sites are located at the Nevada Test Site, Hanford Reservation, Oak Ridge, Savanna River and WIPP. Each disposal site has waste acceptance criteria.

Regardless of the site the waste is destined for, the individual shipping waste to a disposal site is responsible for knowing the waste acceptance criteria and complying with the conditions established in the criteria.

Non radioactive waste may be disposed of at a local industrial landfill or may be recycled as allowed by recycling companies. Most industrial landfills have waste acceptance and profiling requirements for waste disposal.

Waste Minimization

The goal of waste minimization is to reduce the cost of waste disposal and to prevent the generation of waste classed as Greater Than Class C waste. The major methods to accomplish these goals include:

- Prevention of materials from entering areas,
- Prevention of contamination of hazardous materials existing in areas,
- Dense packaging of materials for disposal,
- Decontamination and unconditional release of materials,
- Decontamination and disposal of materials at LLW facilities, and
- Transfer of equipment and materials to other licensed facilities for use.

Prevention of Materials From Entering Areas

The most cost effective method of waste minimization is the prevention of contamination of materials. This effort includes the removal of packing material prior to entry into controlled areas, use of reusable protective clothing in controlled areas, elimination of equipment modifications and use of contaminated tools and tool rooms. On an average, for every dollar of material brought into a controlled area, it costs a dollar to get rid of the material as waste.

Prevention of Contamination of Hazardous Materials Existing In Areas

Many items in facilities contain hazardous materials including mercury, contained in vials for pressure switches, thermometers and manometers, acids, lithium, lead and cadmium in dry and wet celled batteries, PCB's in lighting ballasts and transformers, and lead sheeting or bricks. The best method for dealing with this type of material is to remove the items before they become contaminated with radioactive material, i.e., becomes a mixed waste. Mixed wastes are generally 10 to 100 times more expensive to process and dispose of as compared to radioactive waste.

Dense Packaging of Materials Sent for Disposal

Generally, waste disposal pricing is based on the volume of material to be disposed of at the facility. Some facilities charge for disposal by the pound, based on waste density, with a surcharge for low weight containers.

Decontamination and Unconditional Release of Materials

This process involves the removal of radioactive contamination from materials and/or the survey of materials for free release. This process is fairly labor intensive yet has the capability to reduce or eliminate a large volume of materials going for processing or disposal. An important part of the process is the selection of materials for the survey and release process and regulatory criteria/approval of the process. Acceptable materials will have all areas accessible for survey and be easy to decontaminate. The risk associated with this method is the unintentional release of low levels of licensed materials.

Decontamination and Disposal of Materials at Low Level Waste Facilities

This method generally involves the segregation of higher activity material from components with the disposal of discrete higher activity material at one disposal facility and the disposal of lower activity material at a lower cost disposal facility.

Transfer of Equipment or Materials to Other Licensed Facilities for Re-Use.

This process is usually involved with multiple use items such as electric motors, crane parts, scaffolding, tools, shielding, ventilation equipment, protective clothing, respirators and fire protection equipment. In this case, the material is not waste to the receiving facility.

18.5 Waste Stream Characterization

As noted in Section 18.2, waste classifications differ depending on the authorization basis for the generating site. Many of the same methodologies identified in Section 18.2 apply to waste stream characterization as for determining classification, with a key exception. Two different issues than waste classification drive characterization needs:

- **Pre-D&D Characterization** is driven by the need of potential subcontractors to develop accurate estimates of costs and waste volumes to be generated by their proposed approach to a project.
- **Waste Stream Characterization** is driven by disposal site WAC compliance requirements.

Federal Waste Characterization (primarily DOE)

Table 18.5-1 outlines pre-D&D characterization data available for the key waste forms across the DOE complex, based on DOE's most recent documentation[2]. DOE's main characterization is based on material (i.e., LLW, MLLW, SNF) and function (ER, EM,…). However, detailed characterization, defining composition and including both the basic composition of the waste matrix and of the hazardous and radioactive contaminants, is not available for the bulk of the generation or legacy waste. This includes, for example, the status of historical disposal cells in DOE, no longer in use, but which may be leaking and require remediation such as SWSA 5 at Oak Ridge. For such applications, the original characterization requirements do not necessarily support the current level of compliance required by DOE of its own facilities. Many of the restoration, D&D, and clean-up projects mandate both site and legacy waste characterization as the first step in the scope of work; however, note also that waste management tasks must be costed for the scope in the absence of such critical information. Site knowledge, through consultants with experience at the site, is a key hedge, but this will continue to be a major source of risk in bidding Federal work.

Regarding the DoD waste, the USACE is the best starting point to address waste characterization projections. While DoD will have nuclear and mixed materials to address in D&D, the nuclear load in the Defense Department is dwarfed by the DOE stewardship. Much Defense waste will be debris and hazardous materials from base closing and realignment programs. Each DoD site must perform its own characterization of materials that go back decades in origin, well before the RCRA/TSCA/SARA/CAA/CWA regulatory frameworks were instituted for tracking, reporting and disposal of materials. The Chemical Weapons Program inventory should be regarded as a different level of program inventory and risk beyond basic D&D.

Table 18.5-1: Federal Waste Summary - Doe Waste Inventory Summary[2]

DOE Field Office	Waste Categories						
	TRU	Mixed Low-Level	Low-Level Waste	High-Level Waste	Special Nuclear Material	Spent Nuclear Fuel	ER Wastes Mixed, Low Level and TRU Media.
	(M^3)	(M^3)	(M^3)	(M^3)	(M^3)	(M^3)	(M^3)
Oak Ridge							
Legacy	2,300	41,000	1,000,000	na	Classified	<1MTHM	31,000,000
Generation: D&D + Ops.	3,500	31,000,000	52,000,000	na	Classified	na	.
Richland							
Legacy	16,000	8,600	180	220,000	Na	3000MTHM	16,600,000
Generation: D&D + Ops.	8,000	64,000	64,000	0	Na	na	
Nevada							
Legacy	670	15	368 to 190,000	na	Na	na	3,080,000
Generation: D&D + Ops.	5	<1	0	na	Na	na	
Savannah River							
Legacy	11,000	3,500	26,000	130,000	Classified	20MTHM	185,000,000
Generation: D&D + Ops.	10,000	11,000	2,000,000	16,000	Classified	na	
Chicago							
Legacy	80	140	570	na	Na	na	20,710,000
Generation: D&D + Ops.	5	23	1,300	na	Na	na	
Rocky Flats							
Legacy	1,500	17,000	7,100	na	Classified	na	790,000
Generation: D&D + Ops.	7,000	62,000	58,000	na	Classified	na	
Albuquerque							
Legacy	8,600	815	880	na	Na	na	50,100,000
Generation: D&D + Ops.	12,000	2,900	590,000	na	Na	na	
Carlsbad							
Legacy	80	140	570	na	Na	na	20,710,000
Generation: D&D + Ops.	5	23	1,300	na	Na	na	
Idaho							
Legacy	65,000	850 to3200	9400 to 22000	10,000	Classified	240MTHM	na
Generation: D&D + Ops.	3,700	7,300	100,000	11,000	Classified	na	
Oakland							
Legacy	300	470	570	na	Classified	<1MTHM	20,710,000
Generation: D&D + Ops.	880	13,000	1,300	na	Classified	na	
Ohio							
Legacy	770	220	16,000	2,200	<7 Kg	11	48,002,670
Generation: D&D + Ops.	24	38	1,300	0	0	0	

Civilian Facilities

Reactors

Reactors generate a broad spectrum of radionuclides that can include fission products, activation products and transuranic radionuclides of varying concentrations. Generally, waste streams can be broken down into the following large categories:

- Surface-contaminated items, such as piping, electrical components, and Dry Active Waste (DAW).
- Activated items, generally steel (carbon and stainless), concrete and lead.
- Water processing streams, such as filters, resin and sludge.

Surface-contaminated items are those items that become contaminated either internally or externally due to exposure to radioactive materials. Often the contamination is a result of leakage of fluids and subsequent plate out of radionuclides on the material. The distribution of radionuclides for this waste stream remains relatively constant unless an event such as significant fuel failure changes the distribution. The radionuclide distribution is generally determined by taking and analyzing representative samples from the typical waste stream.

Activated materials are those items, which have been exposed to a neutron flux. The radioactivity associated with this material is incorporated into the structure of the material.

Activated steel may have very high specific activities with dose rates that may exceed 1000 Rem/hr. Each type of steel whether carbon steel, 304 SS, 321 SS, rebar, stellite or zircalloy steels have different chemical make ups and impurities. The difference in chemical impurities will result in different concentrations of radionuclides in each different type of steel. Due to the high specific activity, direct sampling and analysis of activated steel may not be appropriate or ALARA. The use of a properly documented activation analysis may be the only option isotope identification and quantification for activated metals.

The quantity and depth of activated concrete depends on the reactors neutron leakage rate. The activated band of a concrete in a bioshield seldom exceeds four feet in depth from the reactor vessel wall. Signature radionuclides associated with activated concrete include Eu-152, Eu-154 and Eu-155.

Lead becomes activated due to use gamma shielding for neutron detectors adjacent to the reactor vessel and in access plugs to the reactor vessel. The specific activity of activated lead is relatively low and can be sampled to determine the radionuclide distributions. Generally, lead is encased in steel, which may become very radioactive.

Commercial Operations, Universities and Hospitals

The materials accountability or the classifications by source methodologies are expected to be used to establish waste classification by commercial operations, universities and hospitals. The type and function of most licenses issued to these facilities drive this expectation. Generally, the license issued to these facilities is specific to the type and quantity of radioactive material authorized to be on the facility and the material sent is usually discrete quantities that will need to be accounted for by either decay or shipment.

Waste Profiles

As a WAC-driven issue, waste profiling is disposal site-specific as will be shown in Section 18.8. Most disposal sites require a profile of the waste to be disposed of at the facility. The profiling requirements are generally specific to the disposal site and comply with the form expected by the site. General information expected in a profile include:

- A physical description of the waste material type, such as demolition debris, soil, rubble, concrete, steel, etc.

- A general description of the waste material, such as color, odor, liquid, solid, sludge, etc.
- A classification as a hazardous waste, such as identified in 40 CFR 261.
- Identification of containing PCB or Asbestos materials.
- A listing of radionuclides and possibly concentrations of radionuclides.

Additional requirements for disposal sites may include specific analysis by a certified lab.

18.6 Technology Selection

In order to select a process technology, a Technical Process and Treatment Plan should be prepared. This should include a chemical and physical evaluation of the waste streams and an evaluation and selection of preferred treatment options vs. direct disposal. If on-site treatment is favored, a process flow diagram, and a facility conceptual design should be prepared. The following paragraphs will detail the approach usually performed to develop this information - note that the best approach is one based on a life cycle approach to the entire project.

Evaluation of Waste Options: Treatment vs. Disposal

The waste streams must be reviewed for the treatment process option evaluations. The characterization data collected or assumed provides the basis. The primary purpose of this activity is to aid process engineering in evaluating the treatment options. As an initial evaluation, data must be reviewed and the waste streams categorized into four groups: inorganic sludge; organic; metal, and other. Obviously, the quantity of each waste stream will heavily weigh towards technology selection.

Table 18.6-1 Waste Streams and Example Treatment Methods

Overall Waste Stream Category	Example of Treatment Approach	Secondary Waste
Inorganic Sludge	Open Package & Remove Contents	Waste Package
	Size Reduce/Shred	Liquids
	Dry, if needed	
	Stabilize (Grout, Poly)	
	Package, Cure	
Organic	Open Package & Remove Contents	Waste Package
	Sort/Size Reduce	Scrubber Solution
	Incinerate (or Alternate Organic Destruction)	Filters
	Stabilize Ash (Epoxy, Vitrify)	
	Package, Cure	
Metal	Open Package & Remove Contents	Waste Package
	Sort/Size Reduce	Decon Solution
	Decon Surface (Chem./Mech. Decon)	Slag
	Melting, Smelting	Filters
	Casting, Reuse, Packages	
Other Miscellaneous specialized, usually small waste streams	Various per waste stream	Various

Evaluation of Treatment Options

This activity evaluates potential methods of processing and treating the various waste streams. It includes development of evaluation criteria for the options, evaluation of treatment methods against the criteria and selection of the preferred option(s).

As the initial activity for the evaluation of treatment options, the criteria for evaluating the options must be developed. As part of the optimization (or optioneering) process, a functional analysis is required to identify the functional requirements and constraints for the process systems. Based on the functional analysis, objective and subjective criteria can be generated to evaluate the technologies. Objective criteria typically will include categories such as: equipment and operating costs, status of development (maturity), size, complexity, throughput capability, volume reduction factor(s), number of waste streams applicable for processing, effluents, secondary waste generation, schedule constraints, waste form performance, permits needed, and ownership (patents). Subjective criteria include categories such as licensability, regulatory, public and DOE acceptance, and ability to finance.

Public acceptance should be judged based on previous stakeholder consultations if known, or at a minimum estimated:

- EPA accepted Best Demonstrated Available Technology (BDAT) treatment methods will be included in the evaluation criteria. For processes which have not received EPA review and acceptance, the need for EPA acceptance should be factored into the evaluation of these processes.
- Some criteria may involve a pass-fail condition, which must be passed to be considered an acceptable option. For example, if the process has only been theorized, but has not been tested on any scale (from treatability on up), it would fail the maturity criterion.
- Waste form must be an important requirement along with the best overall volume reduction factors, which ensure that cost-benefit requirements are met.

Acceptable ranges of responses for objective criteria must be assigned where possible or known and weighting factors applied to the range. One important factor to be determined is the cost-effectiveness of disposal cost avoidance, that is, how much volume reduction or cleaning for release is cost-effective.

Treatment Options

The optimal treatment processes must be determined through an options evaluation and selection process sometimes called "optioneering". The potential processing option(s) for each waste stream will be ranked in accordance with the evaluation criteria. A treatment process which will process more than one waste stream should be given preference over a single purpose process. All waste streams should have at least one potential treatment option. Based on the cost effectiveness of the treatment options and the relative ranking, a preferred set of treatment options must be identified for the entire group of waste streams. A priority will be given to proven, commercial processes. A backup, non-commercial technology may be carried as a further option if there is significant advantages to the new technology. A non-proven technology should only be selected if there is no other suitable alternative.

A list of objective and subjective evaluation criteria should be developed based on the anticipated functions and attributes for typical systems and facilities for processing the expected types of wastes. Each individual evaluation criteria is given:

- A weight which can be between 5% and 15%, depending on the importance of the individual criteria to the project.

- A range of raw scores reflecting the potential merits of the alternative:

Best	5
Above Average	4
Average	3
Below Average	2
Worst	1

The total score for each treatment process is then calculated for each technology by multiplying the raw score and the weights as shown on Table 18.6-2.

Table 18.6-2 Evaluation Criteria Weighting

Criteria	Weight	Raw Score	Total Score
1. Cost			
a. Equipment	5%	(1-5)	5% times (1-5)
b. Operating Services	2%	(1-5)	
c. Operating Labor	3%	(1-5)	
d. Operating Consumables	2%	(1-5)	
e. Development	3%	(1-5)	
2. Schedule	10%	(1-5)	
3. Equipment		(1-5)	
a. Complexity	5%	(1-5)	
b. Maintainability	5%	(1-5)	
c. Reliability	3%	(1-5)	
d. Operability	2%	(1-5)	
4. Hazardous processes	4%	(1-5)	
5. Volume reduction	8%	(1-5)	
6. Secondary wastes	4%	(1-5)	
7. Number of systems	6%	(1-5)	
8. Demonstrated technology	8%	(1-5)	
9. Regulatory acceptance	10%	(1-5)	
10. Public Acceptance	10%	(1-5)	
11. Process flexibility	5%	(1-5)	
12. Throughput	5%	(1-5)	
TOTAL	**100%**		

The following are the evaluation criteria, which are recommended for the selection of treatment options:

Costs:

Equipment – Relative cost for this evaluation will be limited to the capital cost for the equipment; there will be no consideration for performance testing or installation costs. <u>Weight 5%</u>

Operating Services – Relative cost is limited to utilities (power, water, air, etc.) required to operate the equipment. <u>Weight 2%</u>

Operating Labor – Relative cost is the manpower required to operate the equipment. <u>Weight 3%</u>

Operating Consumables – Relative costs are for the materials necessary to support the equipment operation, such as containers and process chemicals or additives, but not utilities. If routine and frequent replacement of parts is necessary, such as furnace firebrick or equipment liners, these parts would be considered consumables for this evaluation. Weight 2%

Development – If the preferred process is laboratory or pilot scale, a relative cost will be defined to upgrade the technology to a full scale system (including demonstration testing evaluation and implementation). Weight 3%

Schedule – The ability to purchase equipment, manufacture, deliver, install, commission, inactive test, and active test within the schedule needed for the overall facility plan will be considered. Any development time needed will be included in the overall schedule for delivery. If this duration fails to meet the already established schedule objectives, the system will score low. Weight 10%

Equipment:

Complexity – Equipment that requires elaborate control and monitoring with careful control of material input will rank lower than processing equipment that has a higher tolerance of material input variance, is simpler to control, and is a more robust process. Weight 5%

Maintainability – Low maintenance equipment or equipment that can be maintained in situ with minimal impact on processing throughput will be ranked higher than equipment requiring long periods of shutdown, or complex maintenance operations requiring the fabrication of temporary confinement barriers to effect the repair of equipment and/or its replacement. Weight 5%

Reliability – Reliability is directly proportional to the quantity of moving parts required to operate the equipment. The less number of moving parts within the waste zone will result in a higher rank. A higher specification of seals, bearings, motors, and pumps will reduce the probability of equipment malfunction. The justification in terms of cost is insignificant to the processing impacts. Proven technology will therefore be ranked higher. Weight 3%

Operability – This is directly proportional to the level of qualified staff required to operate the processing equipment. Operability is closely tied to produce quality and product acceptance. Equipment that is relatively simple to operate will rank higher than more complex equipment. Weight 2%

Hazardous Processes – Processes that are potentially hazardous to the operator or personnel within the building will be ranked lower. Equipment must be capable of meeting all OSHA and associated regulatory requirements or it will not be considered further. Weight 4%

Volume Reduction – Volume reduction may result in an overall cost savings, with significant reduction in waste containers and a better utilization of available storage grounds. A high volume reduction will receive a higher score. Weight 8%

Secondary Wastes – Secondary waste will be generated by most of the treatment processes under consideration. The lowest generator of secondary waste will receive the highest score. The level of effort and costs to treat secondary wastes will also factor in the scoring. Effluents, such as decontamination materials will also be considered as secondary wastes and they too will require processing. Weight 4%

Number of Process Systems – Any process system capable of processing more than one waste stream will attract a higher score. Weight 6%

Demonstrated Technology – Evaluation of the current status of available process configuration technology will be evaluated in relation to the existing system size, either lab, pilot or full scale. A higher score will be awarded to the process technology with full scale experience at the projected or required throughput. Weight 8%

Regulatory Acceptance – Assessment of technology or equipment and the final waste form resulting from that process will consider the ability to meet or exceed with the Federal and State regulatory requirements, and disposal requirements. If the process will not meet requirements it will be excluded from further consideration. Weight 10%

Public Acceptance – Assessment of technology or equipment will consider the ability to meet with public expectations. Process equipment for each waste stream or group of waste streams will be evaluated. Weight 5%

Process Flexibility – Advantage will be gained if the process technology can adapt to changing waste characteristics. The process, with tightly tolerant constraints, will score less. Weight 5%

Throughput – The ability of the equipment or technology to process at desired or higher processing rates will be considered with a higher score to equipment which has a higher relative throughput for a nominal size, that is the flexibility to process at higher rates rather than at a minimum rate for a given size of equipment. Equipment must meet minimum process throughput requirements or it will not be considered further.
Weight 5%

Conceptual Systems Design

Once the overall processes are selected, a process block flow diagram for the project should be prepared, which includes each waste stream identified and its corresponding treatment process. After the process block flow diagram is prepared, a process description should be written which describes each step of the process and accumulates the information from the selected options evaluation. For each process, the effluents and secondary wastes will be identified and quantified. For example, for an incinerator facility, scrubber solution and filter media are expected secondary waste streams which will require processing and disposal. Proposed processing methods, such as liquid waste treatment (evaporation, ion exchange, etc.) for these secondary wastes must be selected and the resulting end products specified.

The primary equipment necessary for the selected processing system(s) must be identified. The size of the equipment for the selected throughput should be estimated. The approximate costs for the equipment identified, both capital and operating costs, based on information from similar systems or vendor information. Costs at this stage will be about + or – 50%. Alternatives for a larger central facility must be identified.

The first step of the conceptual design will be to establish the general design criteria (conceptual design stage) for the facility. The facility functions will be identified along with design requirements. The results of the process system functional analysis which is performed during the process evaluation should be utilized. Applicable codes and standards for design of equipment should be estimated and included.

General Arrangement sketches should be prepared at the earliest stages. The overall approach for the preparation of the treatment facility involves generating a series of facility design sketches that utilize the process treatment system design requirements to form the functional basis of the facility.

These facility design sketches should depict location or area layout, process arrangement, utilities, shipping and receiving, sampling and testing, confinement features, process support areas, elevations and typical cross-sections and will implement the input from all members of the design team. This activity begins by making simple sketches of material flow moving through the facility incorporating the size information for basic equipment and areas necessary for operation, control, shielding, shipping and receiving, and material handling. Once a simplified sketch looks like it incorporates all the basic features, a more complete arrangement sketch should be prepared.

Next Process Flow Diagrams must be prepared for each major system to be included in the facility, both process systems and service systems and a written description of the facility must be prepared. The facility description should describe the major features, systems, equipment, material handling, operations, and maintenance. Construction features should be identified along with staffing requirements and shift plans. Facility service utility systems, such as HVAC, service water, power, communications, drains, and service and instrument air, must also be identified and described.

Transportation Options

Based on size, weight and cost, radioactive materials may be shipped by air, truck, rail, ship or barge. In some instances, a combination of methods are used. There are about 100 million U.S shipments of hazardous materials annually, about two million of which involve radioactive materials like radio-pharmaceuticals or radioactive compounds for medical research. Only a small fraction of these shipments contain low-level waste. Since 1972, there have been four transportation accidents that led to the release of radioactive material, like a package opening. In all cases, the releases were small and the released materials were quickly repackaged. No injuries or deaths have ever been caused by a release from low-level radioactive waste in a transportation accident. Most low-level waste is shipped to disposal facilities by ground transportation, regulated by DOT and the NRC. The NRC requires that radioactive materials be packaged for shipment to protect the public in case of an accident. The kind of packaging required depends on the amounts and types of radioactive elements in the waste.

Disposal Options and WAC's (5)

The following tables detail commercial and government disposal sites, as well as, possible disposal sites.

Table 18.6-3
Commercial Disposal Sites

	Maxey Flats, KY	West Valley, NY	Sheffield, IL	Barnwell, SC	Beatty, NV	Richland, WA
Date Opened and Closed	1962-1977	1963-1975	1967-1979	1971-Present	1962-Present	1965-Present
Operator	US Ecology	Nuclear Fuel	US Ecology	Chem-Nuclear	US Ecology	US Ecology
Licensing Authority	State	State	State & NRC	State & NRC	State	State & NRC
Total Facility Area	280 acres	3345 acres	320 acres	300 acres	80 acres w/400 acre buffer zone	1000 acres
Burial Site Area	25 acres	12 acres	20 acres	47 acres	47 acres	100 acres
Mean Annual Precipitation	1050 mm	1040 mm	900 mm	1200 mm	100 mm	172 mm
Surface Material	Clay, Siltstone	Till, Gravel, Silty Clay	Silt, Sand	Sand, Clay	Sand, Gravel	Silt, Sand, Gravel Zones
Interstitial Permeability	Low	Low	Low	Low	Moderate	Low
Bedrock Material	Shalt, Siltsone, Sandstone	Shale, Siltstone	Shale, Siltstone	Sedimentary Sands	Clay, Shale	Basaltic lavas
Depth To Groundwater	Unknown	31-38 M	6-15 M	10-20 M	100 M	Unknown
Depth to Regional Aquifer	85 M	>60 M	>50 M	200 M	Unknown	110 M
Capacity for LLRW				975,000 M^3	140,000 M^3	1,494,000 M^3
Amount LLRW Buried	140,000 M^3	66,837 M^3	90,500 M^3	On-going	Closed	On-going
Activity Buried	Unknown	736,000 curies	Unknown	On-going	Closed	On-going
Problems Faced	Fractured sandstone allowed tritium leaks, caps fell, poor drainage of site	Tritium leakage, water accum.	Erosion, trench subsidence, tritium escape, gas releases	Avoided Problems by not accepting liquids, mixed waste, or high TRU	Compact disputes	

Table 18.6-4
Government Disposal Sites

	Fernald (OHIO)	Hanford (WA)	Idaho Nat'l Engineering Laboratory	Los Almos National Laboratory (NM)
Date Opened and Closed	1951-1989	1943-Present	1949-Present	1943-Present
Site Purpose	Manufacture over 500 million lbs of high-purity uranium for nuclear weapons	Production and purification of plutonium	Nuclear Reactor Testing	Application of science & technology for weapons development, energy supply & conservation programs
Total Facility Area	1,050 acres		570,000 acres	
Burial Site Area	72 acres	1,500 acres LLRW	144 acres	64 acres (Area G)
Types of Waste	Uranium, radium, radon, solvents, asbestos, PCB's, heavy metals	LLRW, tritium, chromium, nitrates, cobalt, cesium, and mixed wastes	LLRW, MLRW, mixed waste before 1984, TRU storage	LLW, asbestos LLW, and mixed waste
Amt Buried	Over 2.3 million m^3		210,000 m^3 of LLRW in Subsurface Disposal Area (88 acres)	96,000 m^3
Site Capacity		Between 3.9 and 21 million m^3	250,000 m^3	400,000 m^3

	Nevada Test Site	Oak Ridge Nat'l Lab (TN)	Rocky Flats (CO)	Savannah River Site (SC)
Date Opened and Closed	1951-Present	1969-Present	1952-1989 (weapons production), 1989-present (environmental goals)	1950-Present
Site Purpose	Nuclear Testing facility	Research & Development for plutonium production	Prod. of nuclear weapons till 1989	Site remediation, and processing nuclear materials
Total Facility Area	864,000 acres	35,252 acres	7,000 acres	192,000 acres
Burial Site Area	50 acres (Area 3 Radioactive Waste Management Site allotted 732 acres)	68 acres (Area 6 used since 1969)		195 acres (E area) Original 76 acre site (1953-1972) filled
Waste Types	Debris from testing and DOE LLW	LLW, MLLW	LLW, MLLW, VOC, solvents	LLW, Tritium, ILW
Amt Buried	600,000 m^3			

Table 18.6-5
Recent and Possible Future Disposal Sites

	Waste Isolation Pilot Plant (WIPP) (NM)	Ward Valley (CA)	Hudspeth County Site (TX)
Location	25 miles east of Carlsbad, NM	22 miles west of Needles, CA	80 miles east of El Paso, TX
Operator	Government	US Ecology	
Purpose	Geologic repository for transuranic (TRU) disposal resulting from production of nuclear weapons for past 50 years.	Alternative LLRW Disposal Site	Alternative LLRW Disposal Site, Unaligned compact disposal site
Capacity	176,000 m^3 (850,000 55-gal drums) of Contact Handled TRU. 7,100 m^3 of Remote Handled TRU.	Unknown	Unknown
Why Chosen	Deep caves	Arid conditions, deep groundwater and geologic stability	Arid, deep groundwater, no industry
Began	1982	1992	1991
Problems	Retrievable system abandoned	Blocked by Clinton Administration, will not transfer site land from Feds to State.	Economic impact considered unjust during final site review. May not open at all, $60 million in development lost

	Envirocare (UT)	Yucca Mountain (UT)
Location	Clive, Utah	
Operator	Envirocare	
Purpose	Type A LLRW Disposal	High Level Radioactive Waste Repository
Capacity		
Why Chosen		
Began		
Problems		

18.7 Technology Alternatives

As previously discussed, selection of treatment should be preceded by a detailed review of the physical and chemical characteristics of potential input waste and determination of the waste form characteristics required to meet the disposal site WAC. Such waste could arise from various sources during operation, decommissioning and decontamination. A brief discussion of each waste source relative to a treatment plan selection is present below and is essential for establishing a cost-effective treatment plan.

To determine processing needs, the waste must be described and evaluated. Typically the composition of the waste varies widely from one source to another, but, from a Land Disposal Restrictions (LDR) processing standpoint, the various streams may be grouped into several major treatment categories as presented below, based on common characteristics of the groupings:

- **Organic (combustible) waste.** Examples are organic sludge, resins, PVC and other plastics, wood, paper, and cloth – always candidates for volume reduction, but such volume reduction can concentrate RCRA metals, resulting in a mixed secondary waste.

- **Inorganic (noncombustible) waste.** Examples are inorganic sludge, ceramics, firebrick, cement, glass and glass filter media, desiccants, dirt, and salts – only the sludges offer opportunities for volume reduction, but all will require some level of stabilization to meet disposal site WAC.
- **Metal waste.** Examples are carbon steel, stainless steel, aluminum, copper, and other miscellaneous metals – opportunities for recycle and decontamination exist, but the greatest opportunity is often to manage the stream as a debris waste.
- **Lead waste.** Examples are lead brick, lead shielding, lead blankets, and lead rubber gloves – always a candidate for either recycle or macro-encapsulation.
- **Special waste.** Special waste is asbestos, bulk mercury, graphite, and other material which exist in small quantities and that will require special treatment.

Once this is accomplished, one can evaluate technology alternatives with respect to cost and compliance as the focus for final selection. A typical overview of waste treatment process options versus waste streams is shown on Table 18.7-1.

Table 18.7-1. Waste Treatment Options

	Thermal Treatment				Oxidation/ Reduction			Chemical Process			Solidification/ Stabilization				Mechanical Process				Debris/ Containers		
WASTE STREAMS	STEAM REFORMING	INCINERATION	PLASMA	MELTING	WETOX	SILVER II	CATALYTIC EXTRACTION	CHEMICAL DECON	CACITOX	CONCENTRATION	GLASS VITRIFICATION	CEMENT ENCAPSULATION	POLYETHYLENE	POLYMER	ULTRA COMPACTION	SIZE REDUCTION	SHREDDING	DECON	HIC's	STRONG TIGHT	CASKS
Organic (combustible) Waste																					
Organic Sludge																					
Resins																					
PVC and other Plastics																					
Wood, Paper, and Cloth																					
Inorganic (noncombustible) Waste																					
Inorganic Sludge																					
Ceramics, Firebrick, and Cement																					
Glass & Glass Filter Media																					
Desiccants and Dirt																					
Salts																					
Metal Waste																					
Carbon Steel and Stainless Steel																					
Aluminum, Copper and other Miscellaneous Metals																					
Lead Waste																					
Lead Brick, Shielding, and Lead Blankets																					
Lead Rubber Gloves																					
Special Waste																					
Asbestos																					
Bulk Mercury																					
Graphite																					
Other Miscellaneous Sources																					

Waste Form Technologies

Waste forms must comply with regulations for disposal either through the container itself (HIC) or through a process to either solidify or encapsulate the waste contained within a non-compliant container. In many, if not all cases, the waste is pretreated prior to generating the final waste form. This may take place by chemical or mechanical decontamination or separation. These processes are discussed in greater detail in Sections 18.7.4 and 18.7.5.

<u>Containers</u> [(4)]

Low-level waste is shipped in containers/packages designed to meet stringent NRC and DOT standards. The majority of low-level waste forms contain sufficiently low levels of radioactivity to be shipped in Industrial Package (IP-1) (strong tight) containers. These take the form of boxes or cylindrical liners. In most cases these containers contain low enough amounts of radioactivity that they can be transported in enclosed trailers or on flatbed trailers with no additional shielding.

As the radioactivity of the waste increases, so do the package requirements – necessitating DOT Type A or Type B containers:

- It should be noted that Type A and B shipping packages bear no relation to NRC Class A, B and C waste.
- Type A packages must be able to withstand ordinary transportation conditions.
- Wastes containing high levels of radioactivity are shipped in Type B packages, which must be able to withstand accident conditions. Type B Casks must demonstrate that shipments can survive a 30-foot fall onto a flat, unyielding surface; a 40-inch drop onto a six-inch steel spike; a 30-minute exposure to a fire of 1,475 degrees F; and submersion in 50 feet of water for eight hours.

Burial site requirements and the amount of radioactivity in the waste often dictate solidification or the use of a HIC. HICs generally take the form of right circular cylinders:

- Are designed for a life expectancy of 300 years.
- Undergo a series of rigorous tests to be certified.

The NRC has approved HIC made of Fermium, stainless steel polyethylene composite and polymer impregnated cement. Several states have approved HIC made of polyethylene but these must be placed in concrete overpacks to compensate for the lack of structural stability offered by poly.

A key exception to the proceeding definitions is the case of HICs certified by Federal disposal sites to meet site-specific criteria. For example, the Hanford site has qualified rectangular concrete vaults as HICs for waste forms disposed at their site. These containers are normally "strong-tight" or Type A packages used for storage or transport

Because of the radioactivity in the waste inside the HIC, they are usually transported inside lead shielded shipping casks. These casks are certified to DOT Type A or Type B requirements.

NOTE: All polyethylene high integrity containers must have less than 365/days of sunlight (ultraviolet) exposure to be qualified as a high integrity container. Anything greater than 365/days would be considered a strong tight package.

Solidification vs. Stabilization (1) (2) (3) (4)

Solidification refers to a range of processes in which additives are added (in predetermined ratio and may even be monitored through a process control program) to a given batch of low-level radioactive or mixed radioactive and hazardous waste. The waste is then converted to a single, solid form. Prior to solidification, the waste can take a variety of forms: liquid, slurry (liquid plus suspended solids), sludge (wet solids), or dry solid particles. However, solidification does not mean the waste has been stabilized.

Stabilization requires that the waste form to be structurally stable under the effects of disposal condition such as overburden pressure, the presence of moisture, irradiation and microbial action. Stabilization may come from the waste form itself, from a mixing process, which actually converts the waste form such as solidification, or from the container that provides the stability after disposal such as a HIC. However, in the event of binder addition, such as grouting, application of a process control program (or PCP) regimen as part of the operation is absolutely critical to ensure the performance of the final waste form against either disposal site WAC or LDR restrictions. The NRC is not qualifying new waste forms as of 1996. INEEL is currently conducting waste forms tests for disposal site States review and approval by

Solidification is accomplished by mixing the waste with a solidification agent or binder. The binder forms a monolithic solid by reacting chemically with the waste, by forming microscopic cells that encapsulate the waste by coating and binding the individual particles of waste together or by encapsulation of the waste. The primary reason for solidifying waste in the U.S. has been to satisfy regulatory requirements.

Regulatory requirements in the U.S., such as plant technical specifications, Department of Transportation requirements, and disposal site licensing requirements encourage solidification with stringent conditions placed upon waste packages containing liquids. The regulations have their roots in concern for public health and safety. Solidification of waste for transportation and burial is regarded as being part of the public protection which underlies most regulations; that is, the burial site (by its location, design, and management) provides barriers inhibiting the release of radioactivity to the environment.

Each of the regulatory requirements in the U.S. addresses a different phase of the radioactive waste disposal cycle, i.e., in –plant processing, transport from plant to disposal site, and disposal. These regulations may differ in detail and not be in full agreement, for example:

- Sorbent materials may suffice for waste processing to support transportation, but may not be acceptable to satisfy burial site WAC.
- Certain types of waste packages may meet transportation requirements, but not those of a particular burial site.
- Limitations on allowable total radioactivity in a package may be different for transportation than for burial.

It is the responsibility of the generator of radioactive waste to assure compliance with all of the applicable regulations.

Solidification is used as a means of binding liquid in radwaste. This is why media that cannot be effectively dewatered and other liquid waste streams are solidified. In a strict sense, this is considered micro-encapsulation – the classical meaning of solidification. Macro encapsulation, such as cement encapsulation, is used to stabilize objects like cartridge filters.

Stabilization is also used to ensure that:

- Isotopes will not exceed their individual leach index limits of the waste form.
- The waste form or container will withstand the weight of soil and equipment **after** being buried in the trench.
- The waste form or container by itself will pose a recognizable hazard to an inadvertent intruder.

Examples of waste that must be SOLIDIFIED are:
Wastes which cannot be dewatered to 0.5% free standing liquid for a steel container and 1.0% for a high integrity container, liquid waste streams, and pyrophoric wastes (such as uranium metal).

Examples of what must be STABILIZED or placed within a HIC include:
Class A waste containing isotopes with a half-life > 5 years with a concentration > 1 uCi/cc, Class B and Class C wastes, and some waste containing chelating agents.

The following is a brief list of definition of terms commonly used in discussions relevant to this subject.

Absorption: Liquid enters the volume of the absorbing medium by either physical or chemical means, such as capillary or hydration.

Adsorption: Liquid adheres to the surface of the adsorbing medium.

Binder: See Solidification Agent.

Buffer Zone: A portion of the disposal site that is controlled by the licensee and lies under and between disposal trenches and the site boundary.

Container: The primary containment receptacle in which the wastes are contained.

Chelating Agent: Araine polycarboxylic acid (e.g. EDTA, DPTA), hydroxyl- carboxylic acids, and polyearboxylic acids (e.g. citric acid, carbolic acid and gluconic acid). Used as decontamination fluids.

Custodial Agency: An agency of the government designated to act on behalf of the government owner of a disposal site.

Dewatered: Liquid or slurry wastes that have had excess water removed.

Disposal: The isolation of radioactive wastes from the biosphere inhabited by man and containing his food chains by emplacement in a land disposal facility.

Encapsulation: To cover and surround an object with solidification agent.

Engineered Barrier: A man-made structure or device that is intended to improve the land disposal facility's ability to meet specific performance objectives. The barrier is required for Class C waste and the effective life span of this intruder barrier should be 500 years. At the Barnwell

Facility requires an Engineered Barrier (concrete overpack) is required for both Class B and C wastes.

Free Liquid: Uncombined liquid not bound by the solid matrix of the solid waste mass.

Homogeneous: Of uniform composition; the waste is uniformly distributed throughout the package.

Immobilize: To treat the radioactive wastes in such a manner as to eliminate the characteristics of fluidity, dispersability, or freedom of movement within the packaging.

Inadvertent Intruder: A person who might occupy a disposal site after closure and engage in normal activities such as agriculture and dwelling construction.

Institutional Controls: The control of access to a burial site for 100 years after site closure. This permits the disposal of Class A and Class B wastes.

Intruder Barrier: A sufficient depth to cover over the waste, or an engineered barrier that inhibits contact with the waste, and helps ensure that annual radiation exposure to an inadvertent intruder will be less than 25 millirems.

Land Disposal Facility: The land, buildings, and equipment, which is intended to be used for the disposal of radioactive wastes in the subsurface of the land.

Near Surface Disposal: A land disposal facility in which radioactive waste is disposed of in or within the upper 30 meters of the earth's surface.

Packaging: Container plus waste combined to assure compliance with applicable requirements.

Render Non-Hazardous: To immobilize by a method that ensures hazardous constituents are not leachable beyond acceptable limits and consistent with the US EPA requirements.

Site Closure and Stabilization: Those actions that are taken upon completion of operations that prepare the disposal site for custodial care and that assures that the disposal site will remain stable and will not need ongoing active maintenance.

Slurry Wastes: Liquid radioactive wastes of high insoluble content (greater than 0.1% solid by weight).

Solidification: The process by which waste is blended with a solidification medium to form a free standing monolith with incidental free standing liquid. Burial sites require that wastes treated by solidification be processed in accordance with a process control program using a media approved by their particular site.

Solidification Agent: Material which when mixed in prescribed proportions with waste can form a freestanding monolith with no free liquid.

Solidify: To immobilize by a method, which converts the liquid, slurry, or powder to a solid. The immobilized substance shall be monolithic with a definite volume and shape, bounded by a stable surface of distinct outline on all sides (free standing).

Stabilization: The process by which waste is given structural stability to maintain its physical dimensions and its form under the expected disposal conditions such as weight of overburden and compaction equipment, the presence of moisture and microbial action, and internal factor such as radiation effects and chemical changes. Structural stability can be provided by the waste form itself (stainless steel, control rod blade, etc.), processing the waste form, or placing the waste in a disposal container or structure that provides stability after disposal (high integrity container).

Stabilize: To immobilize by a method that ensures the waste form will pass the test requirements stated in the U.S. NRC Branch Technical Position on Waste Form.

Table 18.7-2 details the present regulatory compliance 10 CFR Part 61 waste form requirements Class B&C waste.

Table 18.7-2 [1,2,3]
PART 61 REGULATORY REQUIREMENTS

Criteria	Old Requirements	Current Requirements
Compressive strength	60 psi	500 psi
After thermal cycling	60 psi	500 psi
After irradiation	60 psi	500 psi
After biodegradation test	60 psi	500 psi
After immersion test	60 psi	500 psi* **
Free Liquids	<0.5%, pH 4.0 to 11.0	<0.5%, pH>9
Leach testing	L>6, 90 days	L>6, 5 days
Full-scale correlation	Simulated waste	Simulated waste, then compressive test

* If post immersion is <75% of original strength, immersion test must be performed for longer immersion periods (120, 150, 180 days).

** For bead resin, chelates, filter sludge, and floor drain wastes, seven-day immersion is followed by seven days of drying, then examined and compressive strength test run.

Table 18.7-3 is a subjective list of commonly used solidification waste form properties.

Table 18.7-3 [1,2,3]
WASTE FORM PROPERTIES

Property	Portland Cement	Asphalt	Polymer	Polyethylene	Glass
Product density, lb/ft^3	90-125	62-90	69-81	70-86	150-175
Water-binding strength	High	N/A	Moderate-High	High	N/A
Free-standing water	Occasionally	Never	Seldom	High	None
Compressive strength, psi	500	N/A	750	1000	5000
Mechanical stability	High	Moderate	Moderate-High	Moderate-High	High
Flammability	None	Moderate	Low-Moderate	Low	None
Leachability	Moderate	Low-Moderate	Moderate	Low	Low
Corrosivity to mild steel	Protective	Non-Corrosive	Non-Corrosive	Non-Corrosive	Non-Corrosive

Macro Encapsulation

Macro Encapsulation is used to stabilize a waste into an acceptable waste form. Waste that is considered to be debris, as defined by the EPA or RCRA, may be macro encapsulated by surrounding the waste with a neat solidification media to ensure that the waste form disposal criteria is met. Traditionally, macro encapsulation of a radioactive object, like cartridge filters, may be entombed in a binder, Cement, or polymer is used to encapsulate filters.

Thermal Treatment

- **Incineration**

Organic wastes are generally suitable for incineration, unless there is a significant chloride content, such as with polyvinyl chloride materials, which:

- Generates excessive amounts of acid gas – as a minimum, increasing maintenance requirements, and at the maximum increasing the constraints and materials cost of the capital equipment.
- Produces excessive salt product secondary wastes from chloride neutralization – complicating stabilization requirements.

There are a number of potential incineration processes, which can be considered for organic wastes; however, the two design types with extensive radioactive waste processing experience are rotary kilns and controlled air units. A typical controlled-air incineration system, such as that deployed at the Duratek Oak Ridge facility includes waste sorting, feed material preparation, a gas-fired incinerator unit which meets or exceeds the time-temperature relationships necessary for the destruction of the wastes, ash handling and stabilization, and off-gas treatment. Typically, volume reductions of 200 to 1 are obtained utilizing an incinerator. A separate or integrated oil burning system may be used to process contaminated oils and oily wastes, depending on the quantity and quality of material. The oil burning system is a simple system very similar to a home oil-fired furnace with a burner and ignition system. Solid and water separation systems can be employed to improve the quality of the oil.

Basic descriptions for each incinerator technology with experience in radioactive or hazardous waste applications are as follows:

Vertical Hearth Incinerator

Vertical Hearth Incineration is a batch process accomplished in two stages. In the first stage, the waste is thermally treated by pyrolysis, then combusted in the second stage. Waste is introduced at the top of the unit and falls on the waste ash pile at the bottom of the pyrolisis chamber. The ash is held in the top pyrolisis chamber by swivel arms and released to the thermal treatment chamber as determined by process monitoring. In the combustion chamber, the pyrolysis products are then combusted under controlled air supply at about 900°C.

Horizontal Fixed Hearth Incinerator

In a horizontal hearth incinerator solid waste is fed to the primary chamber and burned at roughly 50 to 80% of the stoichiometric air requirement (starved air condition). This pyrolyzes the waste, thus emitting a volatile fraction with the required heat supplied by partial combustion and oxidation of the fixed carbon.

The resultant smoke and prolific products, consisting primarily of volatile hydrocarbons and carbon monoxide along with some combustion products, pass to the secondary chamber. Ash is typically moved across the primary chamber hearth by augers, hydraulic rams, or moving grates toward an ash chute, where the ash is collected in a container. Excess air is provided in the secondary chamber to assure complete combustion. Liquid waste can be incinerated in either the primary or secondary chambers.

Fluidized Bed Incinerator

A fluidized bed incinerator is a vertical refractory-lined vessel containing a bed of an inert granular material. The bed is "fluidized" by passing air for combustion through a perforated plate at the bottom of the vessel. Size-reduced solid waste, sludges, and liquids are fed to the hot bed, where the high thermal mass and turbulent mixing action of the bed material rapidly transfers heat to the waste. Auxiliary fuel is often used to maintain bed temperature. A secondary chamber may be required to ensure complete combustion for organic hazardous wastes. Limestone is usually added to the bed to provide capability for in-bed acid gas scrubbing capability. A variation of fluidized bed technology is a circulating bed system, where higher air velocities cause high carryover rates. The carryover material is recovered with cyclones and returned to the system.

Rotary Kiln Incinerator

The rotary kiln incinerator is a cylindrical refractory shell mounted on a slight incline. Kiln rotation moves the waste through the kiln and enhances waste mixing. Rotary kilns normally require a secondary combustion chamber to assure complete destruction of hazardous organic constituents. The primary chamber functions to pyrolyze or combust solid waste to gases, which are completely combusted in the secondary chamber. Both primary and secondary chambers are generally supplied with auxiliary fuel systems.

- **Steam Reforming**

Steam Reforming is ideally suited for processing the toughest organic wastes, including RCRA/TSCA and PCB wastes exhibiting high activity levels and medical wastes. Steam Reforming vaporizes and destroys organics in either liquid or solid form, leaving behind a dry, non-hazardous, mineral-like solid residue. Steam Reforming chemistry is performed in a steam-laden, oxygen-deficient environment to convert hazardous organic and biochemical compounds to CO, H_2, CO_2, and H_2O. The two-step process first employs an evaporation phase, which breaks down and vaporizes the organics and water from the waste. Several evaporator designs can be used, including in drum processing or a heated-screw auger unit. Waste solids in the evaporator are not exposed to the high temperatures where most hazardous metals and radionuclides will volatize from the residue. The volatized gases exit the evaporator and pass through a high temperature filter, which removes any entrained particles. The particulate-free gas exiting the filter is then mixed with superheated steam and passed through a high-temperature reformer, where the organic vapors are fully destroyed.

Since the process chemistry does not form the secondary pollutants and dioxins/furans associated with combustion, Steam Reforming is not classified as an incinerator by the U.S. Environmental Protection Agency (USEPA) and is easily licensed for on-site or fixed-base operations. Steam Reforming has also been successfully used to process "Greater Than Class C" radioactive fuel pool filters to destroy hydrogen bearing materials rendering the processed wastes suitable for long-term dry-storage.

- **Plasma-Driven Reactor**

The process uses plasma, a high temperature (> 5,000 °C), ionized, conductive gas created within the plasma torch by the interaction of a gas with an electric arc. This interaction disassociates the gas into electrons and ions, which enables the gas to become both thermally and electrically conductive. The conductive property of the ionized gas in the arc region provides a means to transfer energy from the arc to the incoming process gas and in turn, to the process or furnace. This state is called plasma and will exist in the immediate confines of the arc within the torch. By the time the gas exits the torch, it will have largely recombined into its neutral (non-ionized) state. However the gas will still maintain its superheated properties.

Plasma systems offer a means of achieving the high temperatures required for the safe destruction of many toxic and hazardous wastes, including PCBs, dioxin, DDT, furans, halogenated hydrocarbons, and RCRA wastes which, untreated, pose serious problems to the environment and to the public.

- **Metal Melting**

Melting is used to process metal materials or assemblies which have been internally contaminated. The metal is melted in a furnace and the contamination, which is usually an oily film or oxide layer, rises to the surface and is stripped away in slag. Various admixtures can be used to strip out radionuclides impurities as well. The end product can be formed into useful products or recycled for use in radioactive service. The process activities includes size reduction, melting in a furnace, slag removal, pouring into molds, and off-gas treatment. This is a proven technology presently operation at the Duratek and MSC Oak Ridge facilities.

Other Oxidation/Reduction Processes (Non-Thermal Treatment)

A variety of treatment processes are being developed to handle organics and other waste streams without using a combustion process. Few of these processes are yet developed to a commercial stage, at this time. In some, considerable work is being done and commercial systems may be forthcoming in the near future. Some specific waste streams may be more suitable for alternative processes than using incineration.

- **WETOX**

The wet oxidation process (WETOX) operates under aqueous conditions and involves the reaction of the organic containing waste with hydrogen peroxide in the presence of a catalyst at 100°C and atmospheric pressure. It is capable of treating a wide range of radioactive and toxic organic wastes with organic concentrations ranging from 20% concentration down to effluent streams containing several hundred ppm. Examples of wastes include ion exchange resins, organic decontamination effluents (EDTA, citrate, oxalate, etc.), nitro and chlorophenols, tributyl phosphate, pyridine and PCB's (after pre-treatment).

- **Supercritical Water Oxidation**

Supercritical water oxidation is a process which will break down organic molecules to stable products such as CO_2 and H_2O. Above its critical point the solvent properties of water are reversed; organic liquids and gases become miscible while inorganic salts become insoluble. In addition, at such temperatures and pressures all organic material becomes unstable. By introducing oxygen (as air) complete oxidation of the organic species is achieved. Oxidation takes place through a series of related oxidation and hydrolysis reactions at temperature in the range 175-300° and pressures of 300-3000 psig. The reaction rate can also be enhanced by the use of appropriate catalysts. The process is very versatile with regards to the range of compounds it is able to treat, with virtually complete destruction of even the most intractable materials such as plastics and rubbers. While this process has been used extensively for municipal and sewage sludge, it has not been applied commercially to radioactive wastes.

- **Chemical Hydrolysis**

Hydrolysis refers to reactions involving solvation with water which can take place either in an acid or alkali medium. For the substituted organics compounds, a well known reaction is the base hydrolysis (involving nucleophilic attach with OH-ions). An example of this chemical process applied to radioactive waste is for the treatment of spent PUREX reprocessing solvent containing tri-butyl phosphate and kerosene.

- **Silver II**

Silver II is a proprietary electrochemical process (US Patents 4,874,485 and 4,925,643) demonstrated at the pilot scale for the efficient oxidation of a wide variety of solid and liquid organics to carbon dioxide, water and inorganic acids. The oxidation is carried out in a nitric acid electrolyte in a divided cell. The carbon in the organic waste leaves the anolyte as carbon dioxide plus a small amount of CO. The water from the hydrogen in the organics appears in the catholyte, and is removed from the catholyte by evaporation. By altering some of the system's internal operating parameters, the organic feed to the anolyte can be varied over the range 100% organics down to a few percent aqueous solution or suspension without affecting overall operation. The process is well suited for treatment of mixed and hazardous wastes as it is a low-temperature/low pressure, wet process and the chemistry can be easily stopped by switching off the current to the cell(s). The electrolyte is nitric acid, which is an ideal medium for the treatment of alpha-emitters like Pu. Most metals and metal oxides are soluble in nitric acid and remain in solution as soluble nitrates, as does most of the activity associated with the waste.

- **Microbial Degradation**

Microbial degradation processes have been developed at the pilot scale for treatment of biodegradable waste and for removal of surface contamination of non-biodegradable waste. Treatment of biodegradable wastes can be done using an anaerobic reactor involving three discrete groups of microbes in a multistage process consisting of hydrolysis of waste to small chain intermediates followed by acetogenesis to organic acids and finally methanogenesis to carbon dioxide and methane (a possible energy source). Such a reactor could be inoculated with sewage sludge and would require the addition of nutrients such as nitrogen, phosphate, minerals, vitamins and cofactors.

Treatment of non-biodegradable waste, for example, glass and concrete involves the removal of the contaminated surface layer. This could be achieved, for example, by the use of Thiobacilli which produce sulfuric acid as a bi-product of their metabolism. This would lead to solubilization of α nuclides which would have to be dealt with separately. This could be achieved by biotechnological processes involving absorption to microbial biomass or the use of sulfate reducing bacteria to precipitate the nuclides as insoluble sulfides.

Chemical Processing

Chemical Decontamination

Chemical decontamination is used for processing metal wastes to remove surface contamination. The process involves successive stages of decontamination in process liquors, which are subsequently treated by – ion exchange precipitation, neutralization and other methods. The metal materials, including equipment, pipe, etc., are first reduced in size and opened so that all surfaces are exposed. The materials are placed in a suitable basket which allows surfaces to be exposed to the process chemicals. The basket is moved by a lifting device and placed successively into the various process baths this removes the surface contamination.

The material in the basket may need to be rearranged and reprocessed to ensure that the process liquor has contacted all surfaces. The material is then surveyed to ensure that the contamination has been removed and that it meets release criteria. These processes have significant commercial maturity and are considered today a primary method for processing metallic waste streams.

CACITOX Process for Heavy Metal Removal by Chemical Dissolution

The BNFL patented CACITOX process can be used to dissolve a contaminant from solid waste and transform it into a soluble species that can be readily removed from solution or to transform already dissolved species into a form that allows them to be separated from other dissolved species.

The CACITOX reagent is a three component mixture, comprising low concentrations of carbonate, oxidants and complexing agents such as carboxylic acids. CACITOX functions by converting the insoluble or absorbed contaminant into soluble complexes; the presence of the oxidant assists in dissolving certain metals which are often found in their less soluble forms. The reagent is used at low concentrations, near neutral pH, and ambient temperature. Pilot tests have been performed to demonstrate the removal of a number of other materials from waste feeds, such as Plutonium, chromium, nickel, zinc, arsenic, copper, strontium, cadmium, cesium, lead and thorium.

Separation Technologies

Separation technologies allow for minimization of the hazardous/radioactive species. Concentration of the hazardous/radioactive species in a sludge is an important step in the waste management process. It reduces the volume, and therefore, cost of the waste which requires special treatment/handling and allows subsequent process steps to act purely on the species of concern rather than on the bulk of non-hazardous waste. Some of the applicable processes include: filtration (including ultra filtration), ion exchange, electrochemistry, drying, evaporation and distillation for slurry (liquid) waste streams for slid waste volume reduction, soil washing, electrochemical processing, solvent extraction, and other processes are effective.

Water Processing

- **Filtration**

Filtration is the removal of suspended residue from water by passage through a filter medium. The filter medium can be layers of fine granular material such as rock, garnet, sand and anthracite or a bag constructed of fabric with a known pore size or cartridges made of similar material. Some "membrane" cartridge filters can filter to as low as 500 Angstroms. Bag filters exhibit pore size as low as 10,000

Angstroms while granular filters exhibit an effective pore size as low as 50,000 Angstroms. Common problems with all types of filters involves formation of an impermeable "smutsdecker" on the surface of the filter with prevents passage of water through the medium. Operational pressures for the various media range from a few inches of water too as much as 300 psi. While the uniformity coefficient and mean grain size of granular media controls the effective filter pore size, the pore size of bag and cartridge filters is usually a manufactured component. Membrane and standard cartridge filters that exhibit an extremely concentrated distribution of pore sizes about the rating of the filter are deemed "absolute" filter while those that exhibit a wider range of pores in the media are deemed "nominal". Granular filters are usually backwashed at 15 to 22.5 GPM/ft2 to clean the material. After many backwashing events, the granular material will lose its angular configuration and must be replaced. Some cartridge filters can also be backwashed. Turbidity below 1 NTU is possible with all of the above filters.

- **Ultra-filtration and Nano-filtration**

Though the thought is not technically correct, it is convenient to think of a Reverse Osmosis, Nanofiltration (NF) or Ultrafiltration (UF) membrane as simply a membrane filter with extremely small holes in the membrane. UF and NF are simply membrane separation systems that operate at lower pressure than RO systems and higher pressure than suspended solids filtration systems. NF is applicable for separation of dissolved and particulate material of 8 to 75 Angstroms in size while UF systems remove material in the 40 to 1200 Angstroms size. NF can be used to precondition the wastewater for subsequent RO treatment by removal of multivalent cations at 60 to 180 psi operational pressure ranges. UF systems, operated at 30 to 80 psi, can be used to precondition wastewater for subsequent treatment by NF or RO units by removal of large chain molecules such as oil, surfactants and powdered carbon slurries. UF and NF membranes are subject to the same scaling, fouling and organic bonding problems as RO membranes, but to a lesser extent.

- **Demineralization/Ion Exchange**

Ion exchange (IX) is the replacement of an ionized cation or anion in wastewater by a more active ion upon passage of liquid through a column of bead or powdered IX material. While many specialized systems are available, in the nuclear field, the most common cationic exchange is a hydrogen ion while the most common anion exchange is a hydroxide ion. In some applications, sodium or chloride ions may be the exchanged ion. In order to provide detention times sufficient to allow the kinetics of the exchange process to function, IX columns must be designed volumetric flows within the proper Gal./ft^3 range. In order to minimize short-circuiting of flows through the beds, applied flows must be maintained within the proper Gal./ft^2 range. In most cases, IX is applicable for treatment of liquids with dilute to medium ionic strength; however, some applications are valid in solutions of high ionic strength. Feed to IX columns must be pretreated by filtration to remove suspended material in order to avoid rapid rise of head losses through the columns. IX systems function due to concentration and chemical activity driving forces to achieve an equilibrium in which the extreme majority of ions in a wastewater are exchanged for a more acceptable ion from the IX medium. Hence the kinetics of the process are driven by chemical and physical parameters in a manner similar to a chemical equilibrium.

- **Reverse Osmosis**

Reverse Osmosis (RO) systems use pressure to separate dissolved salts from water by forcing water to pass through a semi-permeable membrane. In the simplest form, a semi-permeable membrane separates a solution of high salt concentration from an area of low salt concentration but allows the passage of water through the membrane. Pressure is applied on one side of the membrane. The applied pressure is sufficient to overcome the ionic bond of the salts with water molecules and cause the water to pass through the membrane leaving the salts near the surface of the membrane. Hence RO is a candidate treatment process to separate dissolved solids in the 1 to 12 angstrom size range from water. RO systems employ a multitude of membrane types, 60 to 1200 psi operational pressures and operate at temperatures below 65°C to treat relatively chemically inert solutions. The RO systems may be composed of hollow fiber membranes, spiral wound membranes or plate and frame membranes depending upon the water quality, capital available for purchase of a wastewater treatment system and the degree of volume reduction required. The operation of RO systems will be negatively impacted by presence of excessive scale forming salts, any bacterial growths, oxidizers, extremes of pH, extremes of pH, oil, silica and most organic materials.

- **Evaporation and Distillation**

Evaporation is employed when the object is to reduce the residue remaining for disposal to the maximum extent possible. The process may be combined with a condensation of evaporated water and reuse of the water. In that case the process is called distillation. Evaporation can remove interstitial water from between solids particles, water bound to the surface of the solids and, given enough heat, even remove waters of hydration from solids. In most applications, only the first two type of water are removed. There are multitudes of evaporation processes available. The more common types are thin film evaporators, multiple effect vacuum units and drum dryers. All evaporators lose heat transfer efficiency due to build-up of dried solids with low heat transmission potential on the heated surfaces of the evaporator. It is not uncommon to initiate operation with an overall heat transfer efficiency of 85%, but after a few weeks of operation, observe heat transfer efficiency of 60% or less. Evaporation rate is directly proportional to the area of the liquid exposed to the gas phase in the evaporator – or the surface renewal rate in a mixed evaporator. Hence, an unmixed drum dryer is the slowest of the evaporation systems. All evaporators employ heat and/or vacuum to elevate the wastewater temperature to the boiling point or lower the vapor pressure at which boiling will occur. The most efficient method of evaporation involves use of a heat exchanger to condense the evaporator gas phase and exchange the heat to the wastewater feed. Thus the evaporation process is a distillation process in this case.

The use of raw wastewater as a heat exchange medium requires pretreatment to avoid fouling of the heat exchanger. Thin film evaporators involving spraying of a film of liquid on a heated rotating cylinder. Upon evaporation of the liquid, a scrapper blade removes the dried material from the cylinder. Hence a dry residue can be produced from this type of evaporator. A multiple effect, vacuum assisted evaporator employs several stages, each under vacuum, to achieve evaporation of the water from wastewater. Only a drum dryer and thin film evaporator are capable of production of a totally dry residue. With other evaporators, it is rarely possible to achieve total dissolved solids above 25% using this type of evaporator due to solubility restrictions.

- **Solids Separation**

Solids separation involves gravity segregation of suspended solids from wastewater to form a slurry of 1% to 5% dry solids content. These processes may involve chemical coagulation and flocculation of micro-solids into large particles that will settle from the water in hours rather than days or weeks. A typical settling rate for metal hydroxide solids is 8 ft/hr while a solid produced with lime will settle at up to 12 ft/hr. The keys to design of successful solids separation devices are to not overload the solids flux capacity of the component, maintain surface overflow rates below 325 GPD/ft^2 of clarification area, avoid surges in flow or solids content of the wastewater and remove the settled solids slurry before bacterial action generates sufficient gas to float the solids to the surface. Hence oils, light solids or fine solids are not good candidates for solids separation unless chemically coagulated, flocculated and polymerized into large particles. Typically, a gravity solids separation device will produce a settled solids slurry that is about 1% dry solids and an overflow that is near 30 mg/l TSS. However, one separation device attaches micro-air bubbles to the solids particles to float them to the surface – in a manner similar to a unattended straw is floated upwards in a soft drink. The solids-enriched layer at the top typically exhibits 5% dry solids content (and oils) while the clarified bottom discharge layer will exhibit 100 mg/l TSS or less. DAF treatment should never be used for treatment of wastes over 90°F due to losses of air solubility at the higher temperatures.

- **Sludge Dewatering**

Sludge dewatering is usually composed of two steps. The first step is to increase the solids content of the wastewater to 2% dry solids or higher and then dewater the resulting sludge slurry to a dry solid with 12% to 60% dry solids content. If a flow with less than 1% TSS from a clarifier underflow or raw wastewater is to be dewatered, it is common to employ a sludge decant tank. A decant tank is actually a clarifier with an extremely low surface overflow rate, hence, the solids will compact to as high as 4% dry solids – with certain sludge types even condensing to 10% dry solids or more. Sludge decant facilities always feed a mechanical sludge dewatering device. These devices as sand beds, centrifuge, rolling paper filters, vacuum filters, or sludge press. All of these processes either multiply the gravity effect or employ mechanical straining of solids particles from the water with or without pressure in addition to atmospheric pressure. All of the dewatering processes dictate that sludge slurries that have been chemically and physically conditioned in a proper manner be received by the dewatering device.

- **Activated Carbon, Ultraviolet Light/Hydrogen Peroxide Oxidation**

Activated carbon is pure carbon that has been subjected to specialized manufacturing processes to cause the dense particles of carbon to expand. The expanded particle can best be viewed as a sponge or steel wood pad in which the pathways inside the carbon particle exhibit surface areas many thousands of times greater than the surface are of the exterior of the particle. Activated carbon has an almost unique property of attraction of non-polar organic molecules and rejection of almost all ionized species, organic or otherwise. Since the attraction to the surface of the carbon varies with respect to each organic species known, the isotherm for each organic species and each type of carbon is different. Generally, the short chain aliphatic molecules are not candidates for carbon adsorption while the higher molecular weight aliphatic molecules and organic molecules with ring structures are the best candidates for activated carbon treatment. The most common design error involves failure to consider surface and volumetric flow rate considerations in a manner similar to those required by ion exchange systems. Activated carbon can be obtained in the powdered form (PAC) or granular form (GAC). While the same isotherm will apply to a given PAC or GAC for a specific organic, the final equilibrium concentration of organic remaining in the wastewater is always higher using PAC than when using GAC. GAC, like ion exchange resins or zeolite, can also be regenerated upon exhaustion. In the nuclear field, neither medium is normally regenerated. For those organic molecules that have poor adsorption isotherms using activated carbon, the process of ultraviolet light and hydrogen peroxide will break those organic molecules into carbon dioxide, water and other components. This is accomplished with peroxide doses that are usually triple the chemical oxygen demand of the wastewater and with considerable expenditure of electrical energy. UV/peroxide is subject to negative interference due to iron and suspended or colored material in the wastewater that may absorb or disburse ultraviolet light. UV is also subject to bacterial inhibition due to slime growths if not properly maintained and idled.

- **pH Adjustment, Coagulation, Flocculation and Polymerization**

Suspended solids and some dissolved solids can be removed at 99% or higher efficiencies using coagulation, flocculation and/or polymer addition in conjunction with pH control to the isoelectric point of the component to be removed from the wastewater. Coagulation is the addition of a chemical to wastewater that results in the conversion of dissolved components to micro-solids. In order to coagulate a dissolved solids component, the pH of the wastewater must first be adjusted to the isoelectric point via addition of acid, base and/or a coagulation agent. The isoelectric point is the pH at which a dissolved component exhibits minimum solubility. Flocculation is the building of those micro-solids into larger clumps of solids known as floc particles. Polymerization is the further building of floc particles into larger clumps. Typical problems with these processes involve inadequate detention times for complete chemical reactions, selection of an incorrect isoelectric point, faulty calibration of pH controllers and fouling of sensor surfaces due to coating of sludge and oil on the sensing surfaces that inhibit quick exchange of water across the sensor barrier.

Solids – Volume Reduction

- **Soil Washing**

The Soil Washing process is based upon commonly available mineral treatment processes. Soil washing is one of the few techniques that can treat soils contaminated with organics, heavy metals, radionuclides and combinations of contaminants.

Soil Washing is a means of partitioning the contaminants in contaminated soil such that a large portion of the inlet soil is cleaned and discharged with contamination levels below a specified limit, while the extracted contaminants are concentrated in the remaining, smaller portion of the soil for disposal. It does this through a combination of particle separation by size and/or density and by chemical extraction using a number of "soaps" or extraction solutions to clean the particles themselves. The system is modified to fit the needs of the particular site by changing the extraction solutions and particle separations. Feed rates of 1/2 ton to 1000 tons per hour are dependent on extraction chemistry, required retention time, and equipment size. The almost infinite combinations of site soil characteristics and contaminating chemical waste forms make the use of a treatability study mandatory, but the flexibility inherent in the Soil Washing Process allows a wide degree of latitude in its application.

- **Solvent Extraction**

Solvent extraction is a separation technique that can be applied to different types of mixture: (1) a mixture composed of two or more solids; (2) a mixture composed of a solid and a liquid; (3) a mixture of two or more liquids. One or more components of the mixture are removed (extracted) by exposing the mixture to the action of the solvent in which the component to be removed is soluble.

- **Mining/Leaching Technology**

Mining/Leaching Technology can be applied either to mined material or insitu to recovered minerals from the ground. Extraction is performed by percolation of an appropriate solvent through the solids or ground. This technique is used to remove contamination from soils and is applied in heap leaching, soil washing, in-situ pumping of a solvent into the ground, etc. Leaching of uranium ore is accomplished by leaching it with either a strongly acidic or strongly alkaline solution (leachate). The uranium can then be recovered from the leachate using either solvent extraction or ion exchange processes.

Mechanical Processes for Size Reduction

Large components will need to be size reduced for processing. Boxes will need to be opened, and some of the contents size reduced. A variety of techniques, such as cutting, burning, and component disassembly can be used. Possible systems include simple, hand-held equipment, remotely-operated equipment, and robot-operated equipment.

Shredding is used to break up material for further processing and to provide a material of the proper size for handling and processing. Some materials may be encapsulated directly, after shredding, if this is the most cost-effective method of handling the waste. Typically, two stages of shredding are used, a first stage, hydraulically-powered heavy industrial shredder using low RPM counter rotating sets of teeth which tear the material apart. The second stage shredder with appropriate grid to ensure a relative uniform output of material.

Compaction [5] to reduce the volume of Low Level Radioactive Waste (LLRW) has been utilized for many years within the nuclear power industry. The earlier compactors used a hydraulic ram to compress paper, rags, cardboard and plastics in a drum. These compactors are called low force systems, with a capacity of up to about 50 tons. Other relatively low force systems, such as box compactors, shredder compactors, and screw compactors were also utilized, each having advantages and disadvantages.

As disposal costs increased and the quantity of metal, concrete, wood and other materials became a higher percentage of LLRW that was non-compactable with the low force systems, super-compactors capable of exerting a force of 1000 tons and higher were developed. The first super-compactor, a 1500-ton system, became operational in the Netherlands in 1978. Today, over 50 radioactive waste super-compactors have operated in many countries having a nuclear power program.

Basically, a super-compactor is a large hydraulic press that crushes a drum or other receptacle containing essentially all types of solid waste. The container is held in a mold during the compaction stroke of the super-compactor, which sizes the container's outer dimensions. The compressed drum is then stripped from the mold and the process is repeated. Two or more crushed LLW containers (pellets) are then sealed inside an overpack container for storage and ultimate disposal.

A compactor system may be mobile or stationary in concept; supplied as a basic system; manually controlled, with a minimum of auxiliary equipment; to an elaborate computer-controlled system, which: selects drums to be processed, measures weight and radiation levels, compresses the drums, places the crushed drums in overpack containers, seals the overpacks, and records the overpack content, weight and radiation level via a microprocessor-based inventory control system.

Most of the super-compactor installations in the world are 1500 ton or 2000 ton units handling beta-gamma LLRW with a radiation level less that 200 mr/hr are mobile. There are presently two stationary units, one in England (BNFL) and one in Tennessee (Duratek) that are 5000 ton units that will handle drums and boxes up to 109 cm X 91 cm X 122 cm high. These units were designed, procured, and commissioned by Duratek (formerly SEG).

Typical volume reduction capability of super-compaction is shown in Table 18.7-4. Please note that these are only examples, the content of each drum may vary substantially, hence, results may differ.

Compaction is used to pre-compact waste material in to drums prior to ultra compaction. It can also be used to compress used drums and boxes for loading into a larger container for grouting or direct disposal.

Ultra Compaction is used to process paper, plastic, asbestos, metals, dirt, and filters. These can be compacted up to the theoretical ultimate density of the material. A variety of items, such as motors, pumps, pipes, valves, and conduits, which are often too large to place into drums, can be sectioned and/or placed whole into 4x3x3-foot boxes and significantly reduced in size using the compactor.

Table 18.7-4 Typical Volume Reduction Factors for Super-Compaction

Material Description (kg/m³)	Initial Density (kg/m³)	Final Density	VR Factor
Rags, Paper	261	1242	4.8
Newspapers, Magazines	200	1006	5.0
Plastic Sheets (Wadded)	126	1200	9.5
Hardwood	376	1142	3.0
Scrap Metal	781	3312	4.2
Small Electric Motors	968	3680	3.8
Concrete Paving Blocks	800	1296	1.62
Glass	378	1558	4.1

In most cases, a container of waste will have more than one waste type (e.g. x% plastic, y% paper, z% metal). The achievable final density for each container and the resulting VR factor will depend on the specific mixture in the container.

Mechanical Decontamination

A variety of mechanical decontamination methods are available to clean surfaces of metals and other hard materials.

Methods include grit blasting, dry ice or CO_2 blasting, grinding, sonic baths, and high pressure water blasting. A variety of techniques may be needed to handle different components or materials.

Solidification or Stabilization

- **Glass Vitrification**

A vitrification system for low-level wastes can be used to stabilize incinerator fly ash, incinerator boiler ash, incinerator bottom ash, and other wastes, such as furnace slag and asbestos. To limit off-gas volumes, the melter should most efficiently use electric joule heat as the energy source, although heat-up initially or after shut down period can be accomplished using a gas (propane or natural) burner. The melter would need to be capable of adequately mixing the waste with any necessary additives to generate a homogenous vitrified waste form capable of passing the TCLP test and 10 CFR 61 requirements for a Class A low-level radioactive waste form.

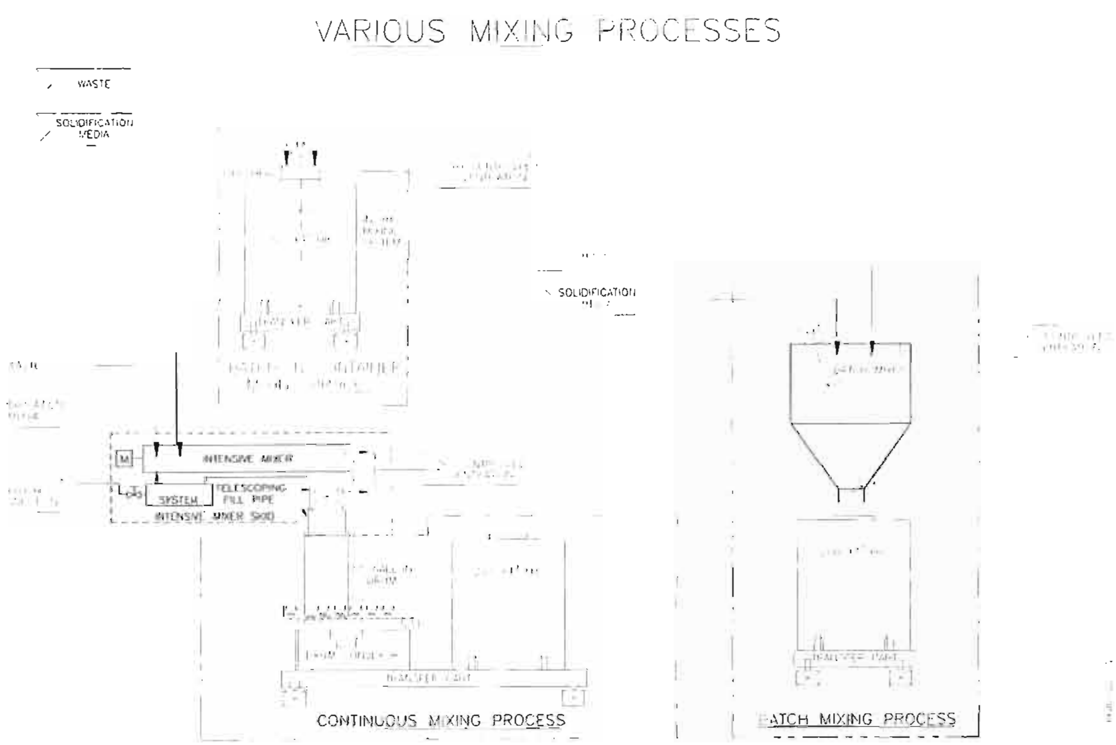
Glass melters use modern glass science to convert a liquid mixed waste into stable glass. The glass produced is leach resistant (typically passing the TCLP for nickel and other components), stable (glass maintains its mechanical integrity for thousands of years), and economical (large volume reduction). The hazards associated with this technology are minimal and the process has been demonstrated as a safe and reliable method of treating radioactive and hazardous wastes. The operation of vitrification has been performed safely for more than 20 years. Glasses of various compositions have received considerable attention for the solidification of high level wastes. The capital and operating costs of glass systems have largely precluded their application to LLW. However, glass systems applicable to LLW have been developed and used successfully for both low level and mixed waste solidification. Briefly, glasses are materials with a high melting point, generally inorganic oxides that, upon cooling, solidify, forming an (typically) amorphous structure with little long-range order. Waste solids are generally incorporated into the glass structure as oxides produced during the high temperature processing conditions (1200°C) of the process. The amount of waste oxides that can be incorporated in glass is limited, particularly if a single-phase glass is desired. However, because of the processing conditions, a large volume reduction is achieved, particularly for combustible wastes.

- **Cement-based Grout**

Portland Cement with mixtures of blast furnace slag or pulverized fly ash, in specific qualified formulations can be used to stabilize specific waste forms. The process consists of taking the waste feed stream, size adjusting by shredding, mixing the grout and waste material, allowing the mixture to cure, and sealing the drum. Various techniques are used to ensure proper mixing of the waste and grout. Cement-based grouts are a suitable waste form for most waste streams.
Various mixing systems are used for cement solidification. These systems (Reference Figure 18.7-1) can be broken down as follows:

In-Container Mixing Processes	In-Line Mixing Processes
• **Rolling**	• High shear kneading and screw auger
• **Rotary Paddles**	• High speed, high shear, low pressure batch mixer
- Insert and Remove	
- Disposable	
• **Tumbling**	• Positive displacement pumps
• **Static Mixers**	• Screw augers

Figure 18.7-2



- **Polyethylene Encapsulation**

Wastes not suitable for grout encapsulation due to high soluble salts (e.g. ammonium sulfate) can be encapsulated in polyethylene. Polyethylene is used to physically capture the wastes in a stabilized matrix in order to prevent radioactive or hazardous materials being released into the environment after disposal. Operationally, particulates and dried sludges will be mixed with polyethylene in a polyethylene/waste extruder. New polyethylene can be stored as pellets. The extruder melts the polyethylene, mixes the polyethylene and waste, and drives off residual waste and volatile compounds. The product is loaded into waste drums and cured.

- **Epoxy-based Solidification Media**

An epoxy-based solidification media immobilizes heavy metals in RCRA hazardous mixed waste (incinerator fly ash). It allows a 3:1 volume reduction of incinerator fly ash using waste loadings of 40% and densities of 80 lbs/ft^3, and renders the solidified ash non-toxic per the Toxic Characteristic Leaching Procedure (TCLP). This waste form is acceptable for disposal at the commercial nuclear low-level waste disposal sites. This waste from can also be used to solidify ion exchange bead resin, and aqueous solutions.

Technology Suppliers

Treatment Technology may be furnished by an off-site vendor who has a facility specifically set up with various or a single treatment process or technology for processing waste. Alternatively, some vendors furnish on-site treatment technologies, in most cases, using mobile or transportable system. Table 18.7.5 provides a listing of treatment technologies for both on-site and off-site services.

Table 18.7-5
Technology Suppliers

	ON-SITE TECHNOLOGY (MOBILE)		OFF-SITE TECHNOLOGY (FIXED BASE FACILITIES)	
Technology	**Vendor**	**Description/ Capacity**	**Vendor**	**Description/ Capacity**
Solidification/Stabilization	Duratek ATG Nukem	Small containers, 55 gallon drums thru 215 cu ft liners	Duratek (TN, SC) ATG Envirocare USE (TN)	Small containers, 55 gallon drums thru 215 cu ft liners
Water Treatment (IX,RO,UF,Evaporation)	Duratek ATG DTS Nukem			
Mechanical Decon	Duratek Siemens Nukem		Alaron (PA) Duratek/Siemens (TN) MSC(TN) USE (TN) RACE(TN)	
Chemical Decon	Duratek Siemens Framatome		Duratek/Siemens (TN) USE (TN) Alaron (PA)	
Thermal Treatment Vitrifier Incinerator Steam Reforming Catalytic Pyrolisis Plasma Metal Melting	 N/A N/A Duratek N/A N/A N/A	 2000 lbs/day-of Organics	 ATG(WA) Duratek (TN) Duratek (TN) Studsvik Startech(CT) Duratek (TN), MSC (TN)	 1600 lbs/hr/ininerator 2000 lbs/day-of Organics 50,000cu ft/yr 88,000 lbs/day
Sort, Segregate & Packaging	Duratek USE ATG Philotechnics	As requested by client need	Duratek (TN) ATG (TN,WA) USE RACE MSC	50 Drums/day
Compaction Low Force Compactors Super Compactors Ultra Compactors	 Duratek, CPC, ATG Duratek, USE, ATG, BNFL	 50-1000t 135 1500t	 Duratek (TN),USE Duratek (TN) Duratek (TN)/BNFL (England)	 50-1000t 1500t 5000t
Containers HIC's Strong Tight Type A	 Duratek, Nukem, ATG, Philotechnics Duratek, Nukem, ATG, CPC, Philotechnics Duratek, Nukem, ATG, CPC, Philotechnics			Reference Appendix B
Casks	Duratek Nukem ATG NAC Transnuclear			Reference Appendix A

18.8 Screening and Selection

As an overview, much of the discussion on life-cycle costing and process selection will parallel the issues identified by Lave's Cost-Benefit approach [6] discussed in Section 18.3.2 – so the framework provides guidance for all aspects of project planning, costing and execution.

Waste Form Requirements

One of the goals that must be identified and set in advance, as we define the project, (Steps 1 through 4 of Lave's framework) is the end-disposition requirements of the waste – this impacts decisions from approach choices that impact waste volume, to stabilization, container, and transportation requirements. The disposal site WAC will dictate waste form requirements. Section 18.2 summarized the minimum requirements to be expected of the WAC, but here we provide a more detailed look at the specifics of compliance, with particular focus in Table 18.8-1 on three sites: EoU, NTS, and Barnwell to bound the range of expectations for both Federal and commercial wastes. WIPP WAC is not discussed here for two reasons: 1) WIPP's WAC applies only to a select class of DOE wastes, and 2) a discussion of the WIPP WAC could require an entire section itself.

Although there are similarities between disposal sites, each site's WAC is unique and must be addressed specifically as shown by the requirements shown in Table 18.8-1. Note that although the authorization basis for a site and project is closely related to disposal options and, therefore, to waste form requirements, CERCLA sites offer a deviation from this norm. When addressing D&D, remediation or clean-up on a CERCLA site, the licensing of processing technologies and systems may be significantly simpler with regard to RCRA or TSCA permitting because of the CERCLA finding. However, the acceptance criteria for waste forms shipped off site do not change – the WAC for the selected site must still be met. Note that the individual WAC and the sites' approaches to the WAC vary so strongly that we are only able to force-fit some level of commonality in the WAC across the three sites included.

Table 18.8-1: Relative Comparison of the Various Site WAC

Sources: EoU WAC as of 30 September 1999; available off the web. NTS WAC Revision 3, as of December 2000; available off the web. Barnwell WAC Revision 3, as of August 2000.

Issue	EoU	NTS	Barnwell
QA Plan	None specified, *per se*	QA Plan must be approved by the Bechtel Nevada RWAP Manager, including review of personnel, site visit audits, and surveillance as part of the program.	None cited *per* se in the site WAC summary
Stream Characterization and profiling	Generator must complete a detailed characterization of the stream; forms are available on line.	Generator must submit a waste form, characterization data, and referenced procedures in the NTS format.	Not discussed.
Pre-shipment sampling	Must be sent after the profile is approved. EoU does not use SW-846 or similar protocols. The sample is for waste stream finger print only.	Requires split samples.	Not addressed.
Notice to Ship	Must be obtained from an EoU Technical Services Representative, and must be accompanied by EoU's Uniform Low-Level Radioactive Waste Manifest (which conforms to NRC requirements).	Not required as such; manifest must still be addressed.	Only manifest is required.

Note: Waste Acceptance Criteria are shown in Appendix C.

Life Cycle Design/Life Cycle Economics – Key Impact Issues

The current trend in DOE's proposal evaluation is a three-fold emphasis on cost:

- Best Value.
- Life Cycle Costs.

- The third aspect is the shift to fixed price or fixed unit price procurements – all geared to shifting economic and operating risks to the subcontractor.

In commercial space, corporations may do the homework to provide adequate detail to their subcontractors (to project their own cost and to limit their own risk; however, in Federal space, the same level of detail may not even be feasible. When one considers the lack of detailed characterization data available for many of the remediation or D&D projects on Federal sites, as cited in Section 18.5, the risk of fixed price contracting on life-cycle costs balloons.

Commercial utilities have the same objective for procurement as DOE: to evaluate project alternatives (and bids) based on net present value (the same criteria used in financial evaluations to evaluate investment alternatives) for the complete project life cycle. This coincides with the same project management regimen that subcontractors should use in their development of work breakdown structures, project costing, and bid decisions, i.e.:

- Will the return on the project be acceptable if we take it on? (For a multi-year project, the cost proposal is a significant portion of the *pro forma* required for the evaluation.)
- In choosing between two mutually exclusive bid opportunities, which one should we bid – what is the lost opportunity cost of the other bid? (Again, based on the project *pro forma*, this requires determining which of two projects offer the higher rate of return and net present value.)
- Have we captured all WBS scope elements and their associated costs – particularly in a firm fixed price bid?

Certain issues immediately surface when we address costing on a life cycle basis; note that these same issues also track Steps 3 through 7 of Lave's Cost-Benefit Analysis [(1)]:

1. Particularly for hazardous projects, are all the residual liabilities for the disposed waste recognized and captured?
   - Hazardous remediation or D&D invokes cradle-to-grave liability and the risk that any disposal site used may become the next Super Fund restoration site (with the shippers all becoming potential Principal Responsible Parties (PRP's)).
   - Will the "derived from rule" mandate that the equipment and miscellaneous (secondary) waste streams now be treated as hazardous or mixed?
2. What is the proper discount or hurdle rate to be reflected in the net present value calculation? Strictly speaking the discount rate for the calculation is one which must reflect the risk of the project, not the cost of capital to the bidder. Key issues to be resolved here include:

   - Does the return match the level of risk?
   - Among various alternatives, does the return justify the project?

   The key issue here is to identify the level of risk involved in the project and then to assign the calculation the same discount rate that the market would expect of a venture of similar risk.
3. Equipment acquisition vs. rental is a key decision:

   - This issue triggers issues such as expensing equipment (will it be expended on the project) *vs.* amortization (will it have application on other similar projects).
   - For short-term or one-of-a-kind projects, rental may make more sense.
   - If the equipment will be so contaminated by the project that it must be disposed of, it must clearly be expensed.

4. When using proof-of-process demonstration data to improve life-cycle cost projections, close attention must be paid to three issues:

   - Were all the operations for the project captured in the proof-of-process or just key operations for selected equipment? The most glaring risks from such demonstrations are that:
     A) Unless the demonstration is an integrated demonstration, it will miss key dependencies between operations that can impact operating (and capital) cost projections – particularly in the area of availability.
     B) They normally under-estimate secondary waste generation while overestimating both labor and utilities.
     C) They must use actual, valid feed streams, directly at the site, with full benefit of site history knowledge and without aging effects on the feed chemistry that come from off-site shipments. (Surrogates are of little value other than mechanical shake-down of equipment)
   - What is the final scale up from the demonstration to the full-scale process? If the demonstration is within a factor of five of the full operating scale, the final leap of faith is probably valid – particularly for operations such as ion exchange, or filtration that are well-documented:
     A) For scaling factors over five (and certainly those over ten) another pilot demonstration may be required. The greatest risk lies in the design of unit operations where mass/heat transfer and chemical reaction may compete to determine the rate-limiting step. For large scale-up factors, greatest risk to the capital and operating cost projections is that the rate-limiting step has shifted, and the system is not capable of meeting its performance projections.
     B) While much of the history around DOE's Pit 9 project at INEEL has been negative, there was a very positive spin on the original procurement. The initial RFP required a pilot scale process demonstration, but required the demonstration of "full scale" equipment on pilot scale quantities of the actual waste – a strong step in the direction of reducing scale-up risks for both costing and operation.
   - Was the demonstration conducted on a CERCLA site? If so, its information will fall short on two cost issues that may represent no-go results for proceeding:
     A) The demonstration will provide no read on the issues and success probability surrounding RCRA or TSCA permitting – they are not addressed for specific operations on a CERCLA site.
     B) Waste disposal and secondary waste generation will not get the proper attention, because they may simply be absorbed into the overall project.

Stakeholder Impacts

Stakeholders, another of the critical elements (Steps 1, 2, 7, 8, 9, and 10) of Lave's Cost-Benefit Analysis [1], are one of the most significant impacts to life cycle planning and costing. Their impact, potentially resulting in a no-go decision on a project, is several-fold:

- Stakeholder attitudes may determine which alternatives are acceptable and which are not – with direct impact to the permitting cost and to the operating and capital costs of the project. The best example in recent history is the AMWTP incinerator. The stakeholders of Idaho, Wyoming, Utah and others (many unanticipated) have put an entire project on hold based on their refusal to accept an incineration alternative that was only offered by one of the AMWTP bidders. Groups such as those in Idaho, FRESH at Fernald, Ohio, SOCM in East Tennessee, and others will be vocal contributors; their preferences and reactions must be anticipated in developing a workable solution for everyone. Many of their comments can drive to a better solution. SEG was able to achieve a RCRA-B permit for West End Treatment Facility (WETF) mixed waste vitrification at Y-12 in six months, but only with the support of the affected stakeholders in the project – cutting cost and accelerating the project.

- Project schedules impact both deliverables and cost, and are often led by a permitting phase. Slippage in permit cost or timetable will be on critical path for the project – day for day, dollar for dollar, and in some cases days for day, and dollars for dollar. An adverse reaction for the stakeholder means a prolonged comment period and possibly failure, for the permit application.
- Work force transition issues on DOE projects represent another set of stakeholders that impact project bid structure. Clearly the cost and liability associated with the project is impacted by the work force available or mandated.

Criticality and Safety Issues

Uncertainties and risks (Lave's Step 8) for the screening and selection must address criticality and safety issues – in current days, corporate safety records are critical to even being allowed to bid Federal projects and the hurdles for compliance are high. As noted in section 18.3 a number of Federal orders address safety for DOE projects from facility design and operation to field projects. The project budget and schedule base lines must address the impact of the orders and the requirements for key analyses for:

- Criticality – normally more prevalent for DOE contracts.
- Preliminary and Final Safety Analysis Reports – largely for DOE contracts.
- Safety planning and readiness reviews – across the board, on all projects.

Failure to address these issues in planning or execution can result in a contract being terminated for cause as the worst case, and in significant negative variances in cost and schedule baseline as the least case.

Materials Handling and Transportation Risks

All materials handling and transportation approaches and equipment must be selected to be consistent with the governing regulatory frameworks for the project:

- Project health and safety plan must be designed, with regard to procedures, personal protective equipment, and training, to address all materials handling risks.
- All designs and operating procedures must be driven by ALARA.
- Facility designs must address the containment and potential emissions of radioactive and hazardous materials – often several levels of containment will be required to contain materials such as Plutonium.
- Equipment selection must address the issues of performance, but must also address the follow-on issues of:

    1. Maintenance – including man-Rem exposure during maintenance, requirements for contact vs. remote maintenance, and overall availability, the need for redundant units, and the impacts to capital and operating cost.
    2. Corrosion – proper selection of materials for acidic or caustic environments can increase capital cost to the project, and may also increase the secondary waste costs regarding relining refractory materials or decontaminating units.
    3. Thermal properties of the contaminants and the potential for entrainment, volatilization, and hideout – particularly important issues for alpha containment on Federal sites.

- Hazardous materials reporting as required for RCRA, TSCA, and SARA reporting and compliance must be planned into the project.
- Final waste form and packaging must ensure compliance with the disposal site WAC and with 49 CFR Parts 171, 172, 173, 174, and 177.

Economic Models

Based on the Lave analysis framework, on DOE contracting/procurement practices, and on best financial analysis practices the best economic model is that of life-cycle cost with the project returns evaluated on the basis of net present value. The discount rate for the calculation should be addressed based on the return rate required for the risk level of the project, not the cost of capital for the corporation.

Disposal Options: WAC vs. Characterization

Table 18.8-1 shows an overview the level of characterization that is required – clearly there are similarities across the sites; clearly the characterization and QA requirements for complying with each WAC are site-specific.

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