Chapter 5

Current and Emerging LLW Minimization and Treatment Techniques

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INTRODUCTION

The management of low-level radioactive waste (LLW), including mixed LLW, has three main steps: waste minimization, treatment, and disposal. Waste minimization and treatment techniques are reviewed here, while disposal technologies are discussed in chapter 6.

We define waste minimization as in-plant practices that reduce, avoid, or eliminate the generation of harmful waste so as to reduce risks to human health and the environment. Waste minimization, therefore, is applied to the pre-generation of waste. Treatment, in contrast, is applied to the post-generation of waste, but before the waste is disposed. Treatment is defined in the Resource Conservation and Recovery Act (RCRA)[1], Section 1004, to mean

> . . . any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste nonhazardous, safer to transport, store, or dispose of; or amenable for recovery, amenable for storage, or reduced in volume.

We broaden this definition to include techniques that facilitate the overall management of LLW, but may not be defined as treatment by the Environmental Protection Agency (EPA). These techniques include waste decontamination, storing radioactive material for decay, compaction, shredding, incineration, and waste stabilization.

Since 1980, escalating LLW disposal costs (see ch. 6) have forced the increased use of waste minimization and treatment techniques. In the future, these techniques will likely continue to play a significant role until disposal costs stabilize.

The problem of managing *mixed* LLW—waste that contains both radioactive and hazardous constituents-has also increased the use of waste minimization and treatment techniques. Since no disposal option has been available for this waste since 1985, mixed LLW generators continue to look for techniques to avoid generating the waste. When the waste's initial generation cannot be avoided, these generators use techniques to treat the waste so that it is *either* solely radioactive or solely hazardous. The generator can then ship the waste to either a LLW disposal site or a hazardous waste landfill. Furthermore, under EPA regulations, a mixed LLW generator is required to treat the hazardous constituent in the waste so that a specified treatment standard is followed. However, the facility necessary to meet these standards is often inaccessible or nonexistent.[2] Once EPA has fully developed and begins to enforce these standards, waste generators will pressure industry to build the necessary facilities to meet the standards, and the use of waste minimization and treatment techniques will further increase.

From a reducing risk standpoint, waste minimization and treatment techniques are often more critical for mixed LLW than for nonmixed LLW. The hazardous constituents (e.g., organic chemicals) in mixed LLW are often more likely to migrate in a disposal site than are the radionuclides. Furthermore, while radionuclides decay over a set time period, hazardous constituents may not degrade significantly. As a result, EPA requires that a certain treatment standard be met for a particular hazardous constituent before it is disposed.

With respect to waste minimization, substitution techniques can eliminate or drastically reduce the amount of radioactive material used, and in-plant processes can be modified to reduce the quantity of waste generated. Waste treatment techniques are used to make LLW that is generated, including mixed LLW, safer for storage, shipment, and disposal. Generators also frequently use treatment techniques to reduce their handling, shipping, storage, and disposal costs.

[1] Public Law 94-580, Oct. 21, 1976.

i? Furthermore, EPA has yet to develop treatment standards for some mixed LLW, as is discussed below in the section on "~~s of Mixed LLW for Which No Waste Minimization or Treatment Techniques Are Currently Available."

Table 5-1--Summary of *Mixed* LLW Generation Practices

	GENERATOR COMMUNITY							
	Industrial facilities					Medical/academic institutions		Nuclear power plants
TYPE OF MIXED LLW	Pharmaceutical manufacturing	Biotechnology manufacturing	Other manufacturing	Spent fuel storage	Waste processor	Medical/clinical & research	University nonmedical research	
Liquid scintillation cocktails or fluids	**Substitute onmentally benign fluids** store for decay Declare BRC Revise procedures Long-term storage	**Store for decay**	**Substitute environmentally benign fluids** **Store for decay** Declare BRC	NA	**Liquid released as waste**	**Substitute** environmentally benign fluids **Store for decay** Declare BRC	**Substitute** environmentally benign fluids **Store for decay** Revise procedures Long-term storage	**Reclaim solvent and incinerate** **Substitute environmentally benign fluids** **Manage as radioactive waste** Long-term storage
Organic chemicals	Substitute nonhazardous materials Revise procedures Store for decay Long-term storage	Justify use Store for decay	Substitute environmentally benign fluids Store for decay improve inventory practices Long-term storage	NA	NA	NA	Education Notification prior to use Justify use Long-term storage	Recycle Substitute other materials Manage as radioactive waste Long-term storage
Trash with organic	NA	store for decay	M	NA	NA	NA	M	NA
Lead	Use nonlead containers Long-term storage	Decontaminate	Long-term storage	NA	Decontaminate Use coated lead	Use non lead containers Minimize use of containers Long-term storage	Use nonlead containers Minimize use of containers Long-term storage	Decontaminate (onsite or at waste processor) Long-term storage
Lead decontamination solutions	NA	NA	NA	NA	**Solidify**	NA	NA	NA
Waste Oil	NA	NA	Solidification	NA	Filtration solidification incineration	NA	Long-term storage	Filtration Solidification Incineration
Trash with oil	NA	NA	NA	NA	NA	NA	NA	Manage as radioactive waste
Chlorofluorocarbon (CFC) solvent	NA	NA	NA	NA	NA	NA	NA	Manage as radioactive waste Recycle solvent Long-term storage
CFC concentrates	NA	NA	NA	NA	*Long-term* storage	NA	NA	Manage as radioactive waste Delist Long-term storage
Aqueous corrosive liquids	NA	NA	NA	Long-term storage	NA	NA	NA	NA
Chromate waste	NA	NA	NA	NA	NA	NA	NA	Manage as radioactive waste
Cadmium waste	NA	NA	NA	NA	NA	NA	NA	Delist by solidification Manage as radioactive waste

NA = Not applicable.

SOURCE: Rogers & Associates Engineering Corp., “Management Practices and Disposal Concepts For Low-Level Radioactive Mixed Waste,” RAE-8830-1, contractor report prepared for the Office of Technology Assessment, March 1989, p. 2-17

Table 5-1 lists all minimization and treatment techniques currently in use for all 12 known types of mixed LLW, which are discussed in chapter 4. This table compliments table 4-3 which lists the practice(s) responsible for generating these mixed LLW types. Where the phrase ''long-term storage' appears on table 5-1, either a minimization and/or treatment technique used at another facility needs to be transferred or such a technique is currently unavailable. Examples of such cases are made in the following sections.

Most of the minimization and treatment techniques discussed are applicable to nonmixed radioactive LLW as well as mixed LLW. However, more examples of techniques relating to mixed LLW have been chosen to illustrate current problems associated with managing mixed LLW and to provide some possible solutions. Furthermore, mixed LLW examples can encourage technical and information transfer between generating communities—something that is not fully occurring today.

WASTE MINIMIZATION TECHNIQUES

Material Substitution

Generators use material substitution to avoid or reduce their use of radioactive material and, in turn, their generation of LLW and mixed LLW. Material substitution is used extensively on scintillation vials, which are used in a wide variety of industrial and medical research procedures. These vials are glass or plastic and often contain an organic chemical solution (e.g., toluene or xylene, both listed as hazardous under RCRA) and a radioactive tracer (e.g., carbon-1 4, tritium, and to a lesser degree sulfur-35, phosphorus-32, and iodine-125). The waste scintillation liquid is a mixed LLW if:

1. the liquid is RCRA-hazardous, and
2. the radionuclides are other than tritium or carbon-1 4, or
3. if the amount of tritium or carbon-14 is greater than the NRC limit of 0.05 microcuries per gram of scintillation liquid (10 CFR Part 20.303-20.306).

Scintillation liquids are the largest contributor to the overall volume of mixed LLW generated in the United States, By substituting a nonradioactive tracer (e.g., enzymes and fluorescent labels) for the radioactive tracer. a generator not only eliminates producing a radioactive waste but also a mixed LLW. In such cases, the liquid waste is defined only as a hazardous waste. Procedures using this substitution technique often lead to equivalent or superior results (32, 10).

A waste generator can also choose to substitute its RCRA-listed hazardous scintillation liquid with a non-RCRA listed liquid--often referred to as an ''environmentally benign' or biodegradable scintillation liquid (20). As organic-based compounds, these environmentally benign liquids are composed of large organic molecules that are nonhazardous. Once released into the environment, microbial and bacterial activity can destroy these compounds without production of hazardous constituents (20).

At some facilities, environmentally benign scintillation vials are now required for all new research at some facilities. If a generator does not want to use them, the burden is on the generator to justify why a RCRA-hazardous fluid is essential for the procedure. There are cases where this justification can be made. For example, it may not be scientifically prudent to switch vials in the middle of a long-term experiment. Some generators also claim that the environmentally benign liquids are not completely interchangeable with the toluene and xylene liquids (25). In some cases, equipment or procedures need to be changed to use the environmentally benign liquids, In other cases, the environmentally benign liquids may be incompatible with other materials or processes used in the experiment or study. A major reason why some generators want to avoid switching to environmentally benign liquids is that they are simply accustomed to using the toluene and xylene liquids and do not want to learn new procedures (20). Finally, one facility reported that they were not confident that the environmental] y benign vials were in fact benign (20).

In cases where environmentally benign vials are appropriate. there are great advantages. The liquid waste would be regulated as only radioactive if it passed the EPA hazardous characteristic tests. A mixed LLW stream, therefore, would be avoided.

Finally, in some cases it may be possible to use both substitution techniques-a nonradioactive tracer and an environmentally benign scintillation liquid—

resulting in neither a mixed LLW nor a radioactive waste. Generators, in turn, could either send the waste to an incinerator or, if permitted by their license and local permits, release the material to sanitary sewer systems.

Another example of a material substitution that eliminates a mixed LLW stream is in the corrosion inhibitor used in nuclear power plants' cooling systems. A hexavalent chromate, which is RCRA-listed as hazardous, has often been used to stop pipes from corroding. Several plants have replaced this type of chromate with a nonhazardous chemical[3] and thus are no longer generating a mixed LLW (20).

Dry cleaning of contaminated clothing can also generate mixed LLW. Waste generators (e.g., nuclear utilities) will dry clean some of their protective clothing (e.g., coveralls) that is slightly radioactive so that it can be re-used. Chlorofluorocarbon (CFC) solvents, often referred to as freon, are used in dry cleaning because of their decreasing capability and are RCRA-listed as a hazardous waste. When the cleaning solution has to be changed, a mixed LLW is produced in the form of sludge and used filters. Several utilities have switched to a water-based laundry service so that hazardous chemicals are eliminated and only nonmixed LLW is produced (20).

Good Housekeeping Practices

Especially for biomedical and medical research institutions, it is possible to reduce the quantities of radioactive material used by improving the scheduling of practices that use radioactive material, reducing excess purchases of radioactive material, and coordinating purchases through a clearinghouse. Education of organic chemical users, for example, has helped sensitize them to avoid generating of mixed LLW. Organic chemicals are often used to clean radioactively contaminated equipment, but users are encouraged to consider alternative cleanup methods.

Good housekeeping practices can also improve technical procedures so that liquid wastes and solid wastes are minimized. With respect to liquid wastes, generators use a variety of techniques to minimize their production and to concentrate them when they are produced. Nuclear utilities, for example, have made small improvements that have resulted in large reductions in the quantity and type of liquid wastes generated. These improvements include:

- minimizing the use of chemicals that increase the quantity of radioactive corrosion products in the liquid cooling system, and
- identifying and stopping leaks in the cooling system so that the amount of contaminated material generated is further reduced (20).

For solid wastes, LLW generators use techniques to ensure that material that does not have to be exposed to radioactivity remains uncontaminated. Contaminated lead is a good example of a solid waste that generators are trying to eliminate, primarily because it is a mixed LLW. Pharmaceutical companies, for example, store neutron-activated stainless steel tubes, which are used to manufacture pharmaceuticals, in underwater storage pools (20). These companies add lead to the aluminum storage cans to ensure that the cans will not be buoyant. The inside of the cans can become contaminated with various radioisotopes. To avoid generating this mixed LLW, companies are replacing the lead with high-density, nonhazardous material (e.g., steel).

Lead is also used in manufacturing shielded isotope shipping containers. These containers typically have a cavity inside for holding a bottle. At times the radioisotope in the bottle can spill and contaminate the lead container. This mixed LLW can be avoided by either using a container that is not made of lead or by placing the bottle in a plastic bag before it is inserted into the lead container.

Lead is also used as shielding in the form of foil, bricks, or sheets. To ensure that this lead does not become contaminated, some generators cover it with a plastic-like substance such as herculon (20).

TREATMENT TECHNIQUES

It is not always possible to use material substitution or a good housekeeping practice to avoid generating a particular waste. Several treatment techniques are, however, available to reduce the waste volume and sometimes the toxicity after the waste has been generated.

[3] A tri-valent chromate that is not defined as RCRA hazardous has been used in some cases.

Post-Generation, Good Housekeeping Practices Including Waste Decontamination

Liquid waste can be concentrated through evaporation, ion-exchange, filtration, precipitation and centrifuging, and distillation. For example, biomedical institutions use these techniques to separate or concentrate their organic liquids (32). Nuclear utilities use them on several waste streams. For example, evaporation systems and ion-exchange resins are used extensively to treat-concentrate and decontaminate-the large volume of liquid wastes generated during a plant's normal operation. Evaporation is used to concentrate radioactive contaminants; the water is boiled off of liquid wastes, leaving behind most of the dissolved and suspended solids. Ion-exchange resins (demineralizers) are used to remove dissolved radionuclides by adsorption processes. Improvements in the use of these techniques in the nuclear power industry can lead to a 75 percent reduction in ''liquid'* waste volumes (5).

Neutralization is another practice that could be used to better manage some liquid wastes. Aqueous corrosive liquids, which are mixed LLW due to their corrosiveness, are stored today in tanks. These liquids can be neutralized by raising their pH and then handling them as a purely radioactive waste **(20).**

One "problem' liquid waste, which is a mixed LLW, is contaminated organic chemicals. In some cases, it is possible to distill the liquid and condense the portion that contains the nonradioactively contaminated chemical. This process would enable the chemical liquid to be reused. Nonetheless, the waste volume would be reduced, not eliminated. The residue would still be a mixed waste. (See section below on "Types of Mixed LLW for Which No Minimization or Treatment Techniques Are Currently Available.

A second problem liquid waste is used oil. Some States consider this waste a mixed LLW, but the EPA is currently deciding whether or not waste oil should be a RCRA-listed hazardous waste.[4] If waste oil is determined to be hazardous, mixed LLW volumes will increase dramatically.

Some generators are filtrating their waste oil, a procedure that removes particulate radioactive contamination. This practice has worked sufficiently well for some generators to allow the ''clean'" oil to be released to oil recyclers (20). The used filters are disposed of as nonhazardous radioactive waste. Some generators, however, have not been able to filter their waste oil adequately to separate the radioactive constituent from the hazardous constituent. (See section below on "Types of Mixed LLW for Which No Minimization or Treatment Techniques Are Currently Available.")

A third problem liquid/wet waste, which is a mixed LLW, is CFC solvents and their concentrates, As mentioned above, CFCs used to dry clean contaminated clothing can be substituted with water-based laundry systems. Nonetheless, problem CFCs are those stored from past dry cleaning services and those generated now or from future cleaning of contaminated tools and equipment. The concentrates can be distilled and heated, thereby reducing the CFC concentration in the waste. Then the recovered CFC solvent can be reused. The residue, however, remains a mixed LLW unless it can be delisted by EPA or found to be a "below regulatory concern" (BRC) waste—waste ''not subject to regulatory control to assure adequate protection of the public health and safety because of its radioactive content.

For solid waste, sorting can greatly reduce waste volumes. Sorting nonradioactive from radioactive wastes as well as sorting wastes into different categories (e.g., combustible, recyclable, compactible) are important steps in reducing waste volumes. These sorting techniques are well suited for lightly

[4]EPA expects to make this determination in late 1989.

[5]The Nuclear Regulatory Commission (NRC) developed a BRC rule for specific radionuclides in animal carcasses and scintillation fluids In 198 1 (10 CFR Part 20 306). This regulation states that these wastes containing tritium and carbon-14 in concentrations less than 0.05 microcuries per gram can be disposed of without regard to their radioactivity. This regulation enables such wastes that also contain hazardous constituents to be incinerated (see section below on incineration'). NRC is now evaluating BRC limits for more general cases. EPA ha.. a draft LLW standard which includes limits for BRC. The proposed limits by these agencies are in conflict and this conflict will have to be resolved. Refer to ch. 3 for more detail on the BRC rule. See also 51 Federal Register 168, Aug. 29, 1986; and T. Johnson, ''Below Regulatory Concern Wastes-Identification and Implications for Mixed Waste Management," *Proceedings of US Environmental Protection Agency Mixed Waste Workshop,* Denver, CO, July 19-20, 1988.

contaminated dry solid materials such as paper, glass, plastics, metals, rags, and wood. These techniques, in fact, have been argued to achieve the highest overall reduction in waste volumes (32). For example, onsite, semi-automated waste sorting programs can reduce by 40 percent the volume of radioactive dry waste generated by a nuclear power plant (22).

A number of relatively inexpensive techniques can be used to decontaminate radioactive materials so that they can be reused, reclaimed, or disposed of as nonradioactive waste. A variety of cleaning techniques, including sand blasting, high-pressure steam, acid baths, and electrochemical polishing, can be used to remove surface contamination from metal equipment and tools (e.g., condensers, turbine blades, and scaffolding) that would otherwise be shipped for disposal (27).

A centralized waste processing facility -Quadrex Corp.-for example, cleaned about 6,000 pounds of metal scaffolding over the last several years. In 1987, Quadrex processed approximately 200,000 cubic feet (2 million pounds) of metallic LLW at its facility. Over 90 percent (180,000 cubic feet) of this waste material was cleaned to recover its scrap metal value or so that it could be reused.[6] One estimate places the amount of potentially recyclable metallic LLW at about 540,000 cubic feet per year, roughly 2.5 times the current national recovery rate (14).

Practices are also available to reduce and potentially eliminate lead—the one problem solid waste that is a mixed LLW. In some cases, contaminated lead shielding is cleaned by wiping and rinsing. In other cases, a high-pressure water and chemical hose is used to decontaminate the surface. Chemicals by themselves have also been used to remove contamination. These techniques allow 95 percent of the lead processed to be released as nonradioactive material (20). Lead decontamination solutions can be solidified to pass EPA leachability tests. The solids are then no longer defined as hazardous waste and can be disposed of at a currently operating LLW disposal site (20).

An additional technique for decontaminating lead is separation. If the surface of a particular lead shield is fairly contaminated and the above techniques cannot remove the contamination, it may be possible to physically separate (cutting or scrapping) the surface of the shield so that most of the lead can be released as nonradioactive.

Finally, if surface contamination cannot be removed by the above practices, lead can be smelted so that the contamination is distributed homogeneously throughout the metal matrix. Once EPA and NRC agree on limits for BRC, it may be possible to reduce the radioactivity to such a degree that the lead is found to be BRC. At the Department of Energy (DOE) National Engineering Laboratory's Waste Experimental Reduction Facility (WERF) in Idaho, this smelting technique is used. In the Federal Republic of Germany, ingots of these melts are used as shielding materials at nuclear power plants.

The BRC rule could also have a significant impact on reducing LLW volumes in general. The Electric Power Research Institute estimates that the nuclear utility industry alone could see a 30 to 40 percent drop in its volumes from 1988 figures.[7]

Storing Radioactive Material for Decay

A large fraction of the radioactive material generated by medical and biomedical research institutions is composed of relatively short-lived radionuclides. By storing these LLW materials for time periods equivalent to 10 to 20 half-lives, the radioactivity can decline to background levels. This waste is essentially nonradioactive in that it can be regulated without regard to its radioactivity.[8] After storing such radioactive waste for the necessary period, it can be disposed of with other solid wastes in a landfill, or it can be released into the sewer system in regulated amounts (see 10 CFR Part 20.303).

Most of the radionuclides used in nuclear medicine have half-lives that are less than 7 days (26). Storage for decay is typically done by collecting all the waste generated within specific periods, usually

[6] Norman Dudey, Quadrex Corp., personal communication, Dec. 15.1988.

[7] Patricia Robinson, LLW Program, Electric Power Research Institute, presentation made at *The Fifth Annual Decisionmakers' Forum—LLW Management The Available Options & Costs*, Wild Dunes, SC, June 6-8, 1989.

[8] The actual storage time needed for a radionuclide to be at or below its concentration in the natural environment (background level) depends on its concentration in the waste and its half-life.

30-day intervals, and then storing the waste as one unit. Each unit of waste is segregated by radionuelides. Either shielded or unshielded storage containers are used, depending on the waste. The waste is stored until it is no longer considered radioactive.

Without storage-for-decay programs, the combustible dry waste and animal carcasses generated by medical institutions could not be incinerated, and approximately 30 percent of the aqueous waste could not be emptied into the sewer. A typical biomedical research institution can reduce the volume of LLW requiring disposal by 30 to 40 percent through an in-house storage-for-decay program (32).

Storage-for-decay programs may also help eliminate certain categories of potential mixed LLW. For used scintillation liquids, it may be possible to use less radioactive material or radionuclides that have very short (measured in minutes) decay periods. These modifications may be possible by using detection equipment with increased sensitivity. The liquid waste in this example could be considered no longer radioactive and, thereby, handled as only a hazardous waste (32).

Two problem arise with some of these storage-for-decay programs. First, a RCRA permit for short-lived radionuclides is required for 90-day or longer storage.[9] Furthermore, even with such a permit, RCRA land disposal restricted waste can only be stored if storage is for the sole purpose of accumulating sufficient quantities to facilitate proper recovery, treatment, or disposal (40 CFR Part 268.50). Since no treatment facilities are available that meet the RCRA treatment standard and no disposal facilities are available, it is unlikely that storage would be allowed. The storage prohibition does not apply, however, if one of the exemptions to the RCRA land disposal restrictions are in effect.[10] Some procedures generate LLW, as well as mixed LLW, with longer-lived radionuclides. For example, iodine-125, which has a half-life of 60 days, should be stored for about **2** years before it can be disposed of without regard to its radioactivity. If this iodine were mixed LLW, storage would not be allowed according to EPA. This prohibition is a particular problem for some mixed LLW when no alternative minimization or treatment technique can alter it so that it is either solely radioactive or solely hazardous. For mixed LLW containing radionuclides that must be stored longer than 2 years before they decay to such low levels that they can be disposed, generators have no choice but to either stop the practice responsible for generating the waste, which can often mean going out of business, or illegally store the waste.

Most mixed LLW generators have not yet submitted their RCRA Part A permits for storage, and EPA has not begun to enforce its storage regulations. Once enforcement begins, generators will have problems handling these mixed waste streams. (See section below on "Types of Mixed LLW for Which No Minimization or Treatment Techniques Are Currently Available.")

Second, some storage-for-decay programs lack quality control over long-term storage. Degradation of waste packages, for example, can result in excessive radiation exposure to workers.

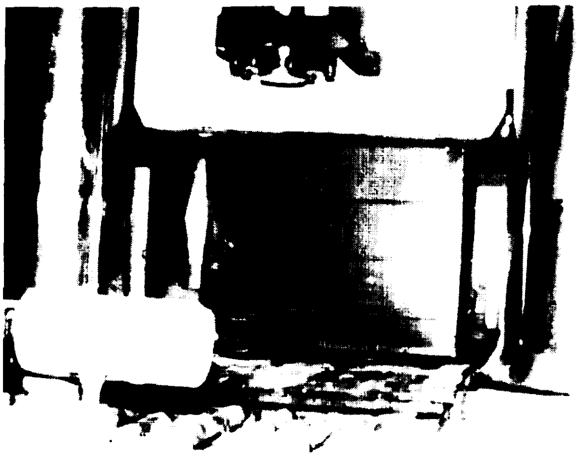
Compaction and Shredding Techniques

The volume of dry LLW (i.e., trash) can be substantially reduced before disposal by mechanical compaction and shredding techniques. For example, from 50 to 65 percent of the dry waste generated by nuclear power plants can be compacted to reduce the disposal volume (3).

In general, compactors are simple to operate and relatively inexpensive: an exception is supercompactors which are more complex and cost between $1 million and $5 million to purchase and install. Compactors must be equipped with air filtration

[9] Generators that qualify as conditionally exempt small quantity generators (they generate less than 100 kilograms (kg) (220 pounds) of hazardous waste per month) do not need storage permits as long as the total amount of all hazardous waste (including mixed LLW) does not exceed 1,000 kg (2,200 pounds), Generators that produce between 100 and 1,000 kg (220 to 2,200 pounds) of hazardous waste per month may store this waste onsite for up m 180 days without a storage permit, provided that the total amount of all hazardous waste (including mixed LLW) accumulated onsite does not exceed 6,000 kg (13,200 pounds). The 180-day limit can be extended to 270 days if the distance the waste must be transported for offsite treatment, storage, or disposal is 200 miles or more (40 CFR Part 262).

[10] Existing provisions for exemptions under the RCRA i and disposal restrictions include a 2-year national capacity variance, an approved *no-migration* petition, or an approved case-by-case extension. Case-by-case extensions arc only allowed if the applicant can demonstrate that he/she has entered into a binding contract with a treatment facility operator/developer that will construct or otherwise provide alternative treatment, recovery, or disposal capacity for the entire waste stream after the extension expires (1). See ch. 3 for a more detailed discussion of storage prohibitions and their relationship to treatment standards and land ban restrictions.



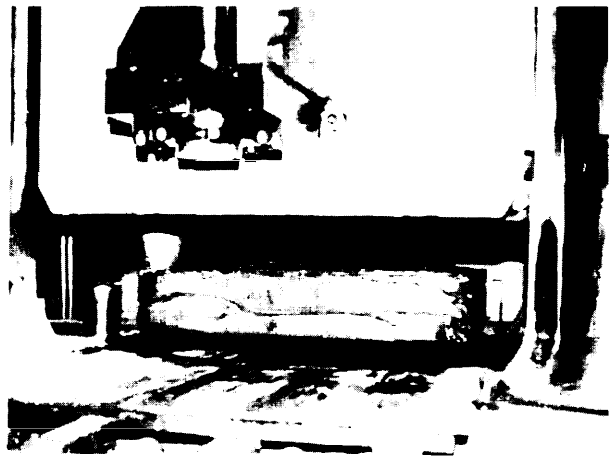


Photo *credit:* Scientific Ecology Group

Before and after photos of box compaction using a 5,000-ton supercompactor

units to control the release of airborne contaminants and to minimize worker exposure. An added advantage of compactors is that the processed waste is of uniform geometry, which facilitates handling and packaging and reduces the space needed for interim onsite storage (21).

Super-compactors in use today are either stationary or mobile units capable of producing a force of 1,000 tons or greater. These units can crush containers of waste (55-gallon drums or boxes) into ''hockey pucks'' in a manner of minutes (11). These high-tonnage systems are capable of handling a larger fraction of the so-called noncompatible wastes, which represent a large part of a nuclear power plants' waste volume (8).

Using a 5,000-ton device, centralized waste processing companies like the Scientific Ecology Group, Inc. (SEG), a waste processing company in Tennessee, can supercompact the dry wastes from a wide variety of generators. In 1988, SEG processed more than 800,000 cubic feet of waste, an increase of 40 percent from 1987. Only 167,000 cubic feet of this waste-a volume reduction of almost 80 percent—was left to be shipped for disposal.[11] Before the waste is compacted, materials like wood and metal that are nonradioactive or that can be decontaminated are separated from the waste stream. Liquids that are released in the compaction process are solidified in cement and placed with the compacted waste.

Size reduction devices such as shredders cart also be used to reduce waste volumes (27). Shredders tear, rip, shatter, and/or crush waste materials into smaller sizes. By using supercompactors and/or shredders, it is possible to achieve up to a seven-fold or about an 85 percent volume reduction (27). Shredders can also provide a more uniform feed material for incinerators.

Incineration

Incineration is one of the most efficient ways of reducing waste volumes. The techniques discussed below have mainly been used to treat municipal solid waste, but they could be used to treat low-radioactivity, combustible liquid and solid dry LLW. The major differences in applying this technology to LLW involve shielding requirements, the use of high-efficiency filters, and methods of ash disposal (27). Incineration can reduce waste volumes by a ratio of at least 25:1 (or 96 percent). Although this experience indicates that it is rather difficult to design a universal incinerator capable of treating all the various waste types at equal efficiency and performance **(7).** With respect to some

[11] Bud Arrowsmith, Scientific Ecology Group, Inc., personal communication, Oct. 19, 1988.

mixed LLW, incineration can convert the waste into carbon dioxide and radioactive ash (7). Incineration is likely to be inappropriate for treating LLW, including mixed LLW, that contains radionuclides that cannot be trapped by an off-gas system.

Types of Incinerators

Three major types of incinerators are currently used worldwide to reduce LLW volumes: 1) rotary kilns, 2) controlled-air incinerators, and 3) fluidized-bed incinerators.

A typical incinerator facility consists of a waste sorting system, a waste feeding mechanism, a main combustion chamber, often an afterburner, an elaborate off-gas cleaning system, an ash collection and removal system, a waste conditioning unit, and instrumentation to monitor critical operating parameters to ensure that health and safety-related limits are met. Incinerators differ in their design based on the amount of air used, the special characteristics of the combustion chamber, and the form of the incineration residue.

In a rotary kiln, waste is decomposed (oxidized) by burning in a slowly rotating, refractory-lined combustion chamber mounted at a slight incline so waste gradually gravitates toward the ash discharge point. This chamber contains more oxygen than necessary to completely oxidize the waste. Liquid injection units are often coupled with this design for liquid wastes. To ensure complete combustion, a secondary combustion chamber (afterburner) is often used to increase the time that wastes are subjected to high temperatures. A relatively large amount of ash and particulate can be produced by this type of incinerator (24).

In a controlled-air incinerator, waste is fed onto a platform in the bottom of a combustion chamber. This primary chamber as well as the secondary combustion chamber can be operated under either starved-air (pyrolytic) or excess-air conditions. The conditions chosen depend on the waste type. With LLW incinerators, it is common to operate the primary chamber under pyrolytic conditions because the amount of fly ash produced is greatly reduced. Liquid injectors can also be attached to this chamber to destroy liquid wastes. Particles of incomplete combustion are then fed into a secondary high-combustion chamber that is oxygen enriched. The advantage of this design is that less fly ash is produced, therefore less radioactive dust is carried out with escaping combustion gases (24, 7). Nonetheless, an elaborate off-gas system accompanies this design (see following discussion on air pollution control technologies).

A fluidized-bed incinerator uses a layer of small particles (e.g., sand, limestone) suspended in an upward flowing stream of air like a fluid (hence, the name) to help burn highly viscous liquids and sludges not easily burned by other incinerators (24). The flowing particles help the mixing and the combustion efficiency. This design can also remove acid gases (27). A disadvantage of this design is that combustion gases can contain high levels of particulate (24).

Two other technologies—wet air oxidation and supercritical water oxidation—are similar to incineration but involve water. Wet-air oxidation is used by hazardous wrote facilities to oxidize organic contaminants in water (24). Low temperatures can be used with this technology because the water modifies the oxidation reactions. and the reactor vessel is maintained at a pressure high enough to prevent excessive evaporation. Supercritical water oxidization is similar, but temperature and pressure are higher than with the wet-air oxidation process. By raising primarily pressure and to some degree temperature, the rate and efficiency of thermal oxidation can be enhanced (24). Neither of these water-based thermal oxidation processes is commercially available. The DOE Los Alamos Laboratory has an on-going research project under its Hazardous Waste Remedial Action Program (HAZWRAP) using supercritical water oxidation. These technologies, particularly supercritical water oxidation, may hold promise for destroying organic chemicals containing radionuclides like tritium and carbon-14, which are nearly impossible to trap in conventional off-gas incinerator systems.[12] One European report noted a trend toward using special incineration systems for less voluminous wastes with special characteristics (e.g., solvents) and/or special contaminants (7).

[12]This consensus was reached at the *Workshop on Supercritical Fluid Processing of High Risk Wastes*, held at the Los Alamos National Laboratory, Los Alamos, New Mexico, Aug. 1-2, 1989.

Air Pollution Control Technologies

Air pollution technologies are used to control the emission of gases and radioactive particulate. The amount of radioactivity released into the atmosphere from an incinerator depends in part on the volatility of a particular radionuclide during the combustion process. As mentioned above, it is very difficult to prevent the release of volatile radionuclides, like carbon-14, tritium, and iodine-131, with current technologies.

A small amount of the waste's total radioactivity is transported in particulate matter by combustion gases leaving the chamber, while most radionuclides are trapped in the ash or slag (melted ash) that settles to the bottom of the combustion chamber. The concentration of radioactivity in the fly ash can be even higher if the volume of dust particles produced is limited. A combination of technologies is used to remove these radioactive particles from the combustion gases: fabric baghouses, high-temperature ceramic filters, electrostatic precipitators, and high-efficiency particulate air (HEPA) filters. For example, in some systems, gases pass through the baghouses, and fly ash is collected on the outer surface of the bags. On a periodic basis, the fly ash is driven off of the bags by injecting a burst of compressed air through a venturi in the top of each bag. This burst of air knocks the fly ash off the bags and into a hopper at the bottom of each baghouse. This fly ash is collected, processed (e.g., solidified using a cement waste form), and disposed of. After gases pass through the baghouses, they are sent through HEPA filters designed to remove over **99** percent of particles larger than 0.3 microns (2).

Operating Experience

Incineration has been used extensively in Europe (e.g., Federal Republic of Germany, Sweden) and in Japan since the early 1970s to treat commercial LLW generated by hospitals, nuclear power plants, and industry. In Sweden, more than 600,000 cubic feet of dry active waste were incinerated between 1976 and 1983 at a central LLW processing facility (16). During this period, less than 2 percent of the maximum permissible amount of beta and gamma radionuclides were released into the atmosphere via the stack gases. A strict quality control program-to ensure that a waste package's manifest accurately reflects the waste's contents-has been found to be critical in minimizing emissions (4).

In the United States, no commercial incinerator is licensed to treat LLW or mixed LLW. About 100 individual licensees have incinerators for certain combustible wastes generated at their sites, but incinerators for commercial use are not available. In contrast, the DOE has incinerators within its weapons complex sites that can treat both LLW and mixed LLW, and these wastes are shipped between weapon sites for treatment. The WERF incinerator at the Idaho National Engineering Laboratory, for example, routinely burns LLW and on a smaller scale bums liquid mixed LLW. The incinerator is currently operating under RCRA interim status (27). The DOE Oak Ridge National Laboratory is planning to open in February 1990 its Toxic Substance and Control Act (TSCA) incinerator, which will be permitted to burn mixed LLW. Both of these incinerators bum or will burn wastes from other DOE sites.

The only U.S. commercial facility that is scheduled to be available in November 1989 is a controlled-air incinerator operated by SEG in Oak Ridge, TN. The incinerator will be capable of burning 800 to 1600 pounds of dry solid waste per hour. Included in the design is a system to handle liquid wastes and a glass furnace to stabilize final ash products. This incinerator will be permitted to bum only non-mixed LLW

Incineration of Mixed LLW

In Europe, mixed LLW is defined simply as radioactive waste. Operators of treatment and disposal facilities, therefore, do not have to obtain special permits or meet special standards for this waste.

In the United States, in contrast, there are incinerators to treat hazardous waste, but not commercial mixed LLW. Although SEG has the technical capability to treat mixed LLW at its soon-to-be operating incinerator, the company has not filed for the necessary permits.

The bulk of mixed LLW—scintillation fluids-is incinerated because it is not regulated as a mixed LLW. From a regulatory standpoint, most of these fluids are below the established limits set by the Nuclear Regulatory Commission to be BRC and, therefore, are regulated for their nonradioactive characteristics. Most of these BRC fluids are shipped to one company in Florida-Quadrex Corp.—that burns them to recover their energy value. The fluids are an energy supplement to the fuel that runs an incinerator. The heat from the incinerator, in turn, is used to make cement blocks. Because the incinerator is an energy recovery system, it does not require a RCRA permit. This situation will likely change due to the amendments EPA is currently drafting;[13] EPA will likely determine that energy recovery facilities, like the incinerator Quadrex uses, will require a RCRA permit. Quadrex plans to use an incinerator that has a RCRA permit, if this determination is made.

As with the BRC scintillation fluids, waste oil has typically been burned as a fuel substitute because usually it is only slightly contaminated. This oil is produced in large quantities by nuclear utilities and some industrial generators. Many generators incinerate their waste oil onsite, while others ship it to a waste processor. SEG, for example, treats approximately 30,000 gallons of waste oil annually.[14]

The status of waste oil may soon change. EPA is reevaluating whether waste oil should be listed as a hazardous waste and is expected to make a decision in late 1989. If waste oil is found to be hazardous, then generators/waste processors will need a RCRA permit to incinerate their waste oil. All States will have to amend their regulations to include this definition. If waste oil does become defined as a RCRA-listed hazardous waste, the volume of mixed LLW will rise dramatically. Without a RCRA-permitted incinerator available, the waste oil that cannot be successfully filtered will have to be stored. This volume would only be reduced if this waste falls below the yet-to-be-finalized BRC limits.

Another type of mixed LLW for which no incinerator is available is organic chemical waste. Several technologies (e.g., supercritical water oxidation) have been identified in the laboratory as being able to possibly treat this waste effectively but they have not been developed nor tested commercially (25). (See section below on "Types of Mixed LLW for Which No Minimization or Treatment Techniques Are Currently Available.")

Waste Stabilization

Stabilization techniques are used to fix the constituents of LLW, including mixed LLW, in a solid form that is inert, that has low exchange or release rates in water, and that can be safely transported or stored. The solid form in which a waste is fixed is called the waste form. For example, incinerator ash can be stabilized in a cement-based waste form that fixes the ash and retards the migration of radionuclides in the waste. Several different stabilization media are available. Finally, a waste packaging container designed for a particular waste form is critical to ensuring long-term stabilization of the waste and, in turn, the protection of public health and safety and the environment during storage, shipment, and disposal.

Technical Requirements

LLW must be stabilized based on the following requirements (10 CFR Part 61) (28, 30):

Minimum Requirements for All Classes of LLW

1. Minimum packaging requirements must be met (e.g., no cardboard boxes are allowed), but the waste does not have to be solidified or placed in a special container.[15]
2. Liquids are to be solidified or packaged in twice the volume of liquid absorbent. (The use of absorbents is, however, prohibited in some Agreement States.)
3. No more than 1 percent of a solid waste's volume shall contain liquids.
4. The waste must not be explosive, pyrophoric, capable of generating harmful gases, toxic, or infectious.
5. Waste should not generate gas pressure greater than 1.5 atmospheres at 20°C and must contain less than 100 curies per container.

[13] EPA issued a supplemental notice on October 26, 1989, that requires energy recovery facilities to be permitted. This supplemental notice is effectively a reproposal of a proposed rule issued on May 6, 1987. EPA plans to issue a final rule in early 1991.

[14] Arrowsmith, op. cit., footnote 11.

[15] In Washington and South Carolina, certain Class A wastes (those having radionuclides with half-lives greater than 5 years in concentrations greater than 1 microcurie per cubic centimeter) must also be stabilized (27).

6. Waste containing hazardous, biological, pathogenic, or infectious material must be treated to reduce to the maximum extent practicable the potential hazard from the nonradiological materials.
7. A process control (testing) program must be used to ensure that the waste product is of consistent quality.

***Additional Requirements for Class B and C** Waste*

1. The waste form must be structurally stable.
2. Liquid waste must be converted into a form that contains no more than 1 percent of the waste's volume, when the waste is in a disposal container designed to ensure stability, or 0.5 percent of the waste's volume, when the waste is processed to a stable form.
3. Void spaces within the waste and between the waste and its package must be reduced to the extent practicable.
4. The gross physical properties of the waste form must be retained for at least 300 years under all disposal conditions (e.g., irradiation, high compressive loads, exposure to moisture, and biological degradation).
5. Instead of using solidification agents (e.g., cement) to fix the waste, Class B and Class C waste may be stabilized in a suitable high-integrity container (HIC). When a HIC is used, the maximum amount of free liquid cannot exceed 1 percent of the waste volume.
6. Class C waste must be disposed of so that the top of the waste is at least 15 feet below the surface or disposed of with intruder barriers designed to protect against inadvertent intrusion for at least 500 years.

Waste Form Types

Typical stabilization techniques include solidifying wastes using lime-based cements, bitumen (asphalt), and synthetic polymers (e.g., vinyl ester-styrene and urea-formaldehyde). Wastes are also stabilized by certain waste packages. HICs composed of organic polymers like polyethylene and various stainless steel alloys are used to stabilize waste,

In the United States, cement mixtures have been preferred as stabilizing materials, while in Europe bitumen has been used for over 20 years to stabilize radioactive wastes.

In cement-based waste forms, waste solidification occurs by a complex chemical hydration reaction (i.e., water and lime are added to produce a calcium oxide). The advantages of this waste form are that:

- it effectively stabilizes most LLW,
- it has a high structural strength,
- it is inexpensive to produce and easy to use, and
- it exhibits a low leachability for most radionuelides.

The disadvantages of cement-based waste forms are that:

- it, unlike bitumen, increases a waste's volume by 10 to 30 percent,
- it is difficult, though not impossible, to use in solidifying mixed LLW composed of untreated detergent, oils, and other organic liquids because these substances interfere with the hydration process (27), and
- it may also be incompatible with mixed LLW composed of metallic-salts.

In a recent NRC Notice (31), other disadvantages with cement-based waste forms were listed. These include:

- its failure to solidify completely,
- swelling and bulging of liners, and
- disintegration over relatively short periods following solidification.

In particular, bead resin, decontamination solutions, berates, sulfates, and oils were listed as wastes that had problems when solidified using a cement. The NRC announced at one of its workshops that several cases of full-scale and lab-scale waste forms have had these problems (18). Likewise, the Idaho National Energy Laboratory reported that it had similar problems in using cement-solidified waste forms and that the waste formed cracks during leaching (18).

In the United States, cement is often combined with numerous natural and synthetic sorbable materials to stabilize waste. This combination makes it easier to stabilize some organic mixed LLW. However, waste fores that depend on sorption techniques are, by themselves, inadequate stabilizing agents due to the reversible nature of most sorption processes.

Bitumen systems are considered to be both waste stabilization and volume reduction technologies because the heat required to melt the mixture assists in evaporating any liquid wastes (27). The hot bitumen coats the waste particles, thus encapsulating the waste in a solid matrix that is impermeable to water and structurally stable once it cools. Bitumen can be used to stabilize almost all LLW materials with the possible exception of certain mixed LLW, such as those containing liquid organic chemicals (e.g., oil). The major advantages of using bitumen are:

- its good leach resistance characteristics,
- the low operating costs of producing it,
- the ease of handling it. and
- its high waste loading capacity.

The major disadvantages of using bitumen are:

- its relatively low ignition temperature (i. e., it is flammable),
- its instability at high temperatures,
- its relatively low (in comparison to cements) structural strength, and
- its susceptibility to biological degradation (27).

Polymers, in contrast, solidify wastes by a chemical reaction process called polymerization. Advantages of this waste form are that:

- wastes are very resistant to chemical leaching, and
- they exhibit high compressive strengths.

The major disadvantages of using this waste form are:

- the high material costs,
- the complexity of the mixing process, and
- the fire and explosive hazard posed by some of the chemical ingredients of the polymer.

Table 5-2 summarizes the advantages and disadvantages of these three waste forms. Cement has many advantages, but its quality is inconsistent and it produces higher waste volumes. Bitumen exhibits the opposite characteristics, in that its quality is consistent and it reduces waste volumes; however, it is not as structurally strong as cement, Neither cement nor bitumen can adequately stabilize some mixed LLW, particularly organic chemical waste, In comparison to either cement or bitumen, polymer waste forms appear to have no major advantage. A combination of these waste forms may be most appropriate for some mixed LLW. NRC has an active research program in this area to improve waste form reliability.

Table 5-2—A Critique of Waste Forms

Characteristic	Cement	Bitumen	Polymer
Leach resistant	Y	Y	Y
High structural strength	Y	N	Y
Not flammable nor ignitable	Y	N	N
Easy to use	Y	Y	N
Consistent quality	N	Y	u
Appropriate for organic chemical mixed wastes	N	N	u
Reduces waste volume	N	Y	I
Inexpensive	Y	Y	N

KEY: Y = yes
N = no
U . unknown
I = Indifferent

SOURCE Off Ice of Technology Assessment, 1989

Waste Packaging Materials

A variety of different packaging materials are used for LLW containers. Wooden boxes are used at some disposal sites (in arid regions) for Class A waste. Steel drums and steel boxes are also used for Class A waste. HICs made from a variety of materials (e.g., polyethylene, steel-reinforced concrete, and stainless steel) are used for Class B and C waste. As noted, these packaging materials are designed to retain their physical and chemical integrity for at least 300 years (30).

In general, polyethylene is a highly corrosion-resistant material, but its long-term structural integrity is of concern. Studies conducted at the Brookhaven National Laboratory found that polyethylene containers may become brittle, crack. and rupture when exposed to certain chemical contaminants (e.g., organic liquids such as oils) and to high doses of radiation (23). The NRC allows the use of these containers for disposal but only if the required structural stability is provided by other packaging materials or engineered structures (17), Containers made of various steel alloys are also used to stabilize LLW and some mixed LLW because of their high structural strength and their ability to resist corrosion (though not to the same degree as polyethylene).

A number of containers on the market use a combination of several materials to form a container with improved stability characteristics (27). For example, a polyethylene container within an inner steel or concrete container has been used. Polymer-impregnated cements have also been used to reduce the leaching of some radionuclides (e.g., cesium and strontium) (19). As with waste forms, more research is needed on packaging materials that may be appropriate for various mixed LLWs.

Long-Term Stability Predictions

It is important to be able to predict how the materials used to stabilize LLW and mixed LLW will behave in a disposal environment over the long term. The most common prediction methods are based on the results from short-term laboratory tests. Leachability, due to groundwater, is one of the most important factors in determining the long-term stability of a waste form or container. Leaaching tests measure the ability of a particular waste form or container to retard the release of specific radionuclides or hazardous chemicals. These tests are conducted by placing a sample of the stabilized material in water and then measuring the release rates (of individual chemical species) over a period of about 90 days.

Experimentally determined leaching rate predictions must be viewed with caution for several reasons:

- the tests are based on short-term studies (often 90 days or less);
- the experimental conditions are generally not representative of the variety of geochemical conditions encountered in a disposal environment;[16] and
- very little to no quantitative information exists on the long-term stability of containment materials under disposal conditions.

With respect to the third reason, the only long-term database available is for concrete. Two-thousand-year-old concrete structures (e.g., bridges, aqueducts, and harbors) from the Roman era are still in existence. Studies of these structures show that the concrete has retained most of its structural strength, but often has undergone extensive chemical transformation as a result of exposure to ambient environmental conditions (12). Many examples can also be cited where modern concretes have performed satisfactorily for at least 100 years. It is difficult to be certain, however, that concrete will remain structurally stable and resistant to leaching for much more than a few hundred years (12).

TYPES OF MIXED LLW FOR WHICH NO MINIMIZATION OR TREATMENT TECHNIQUES ARE CURRENTLY AVAILABLE

A major problem for mixed LLW generators is that no commercial facility is available to treat their wastes. According to EPA regulations. a particular treatment standard must be met for a particular hazardous waste before it can be disposed. The standard may be expressed as a specified technology (e.g., incineration), as a total concentration in the waste, or as a concentration in the waste extract (i.e., by using a leaching test called the Toxicity Characteristic Leaching Procedure or TCLP) (l). In all cases, these treatment standards are based on the performance of the best demonstrated available technology (BDAT).

EPA treatment standards for solvents, dioxins, and the hazardous constituents that fall on the California List[17] are in effect and apply to mixed LLW that contains these hazardous constituents. Therefore, mixed LLW generators are required to treat these wastes accordingly. **There are three types of mixed LLW identified for which treatment is necessary, but a treatment facility is unavailable.**

16 Because of the variety of possible geochemical conditions at a site, it is difficult to devise a standardized leaching test that represents the potential mobility of radioactive (or chemical) contaminants.

17 The California List includes free cyanides, corrosives, hazardous waste mixed with polychlorinated biphenyls (PCBs), and certain metals (i.e., arsenic, cadmium, chromium, lead, mercury, nickel, thallium, and selenium) (RCRA sections 3004[d][1], [d][2], 42 U.S.C. 6924 [d][1], [d][2]). For treatment standards for these wastes, see EPA's final rule-52 Federal Register 25760, July 8, 1987.

First, organic chemicals, in some cases, can be distilled and the nonradioactively contaminated chemical can be concentrated for re-use. Nonetheless, the residue is still a mixed LLW. For the most part, organic chemical mixed LLWs fall into the solvent category, and the BDAT for solvents is incineration. No commercial incinerator, however, is available to treat organic chemical mixed LLW. Furthermore, as mentioned, some organic chemicals contain high concentrations of radionuclides (e.g., tritium and carbon-14) that would escape through a conventional off-gas filtering system if incinerated. Newly designed incinerators or completely new techniques (e.g., some water-based thermal oxidation process, like supercritical water oxidation, or some new stabilization technique) may be needed to treat these wastes.

Second, **waste oil** may be a problem with respect to treatment. If EPA decides that waste oil is a RCRA-listed hazardous waste, the overall volume of mixed LLW will dramatically increase, All generators of mixed LLW oil will have to meet the established treatment standard, and the BDAT to meet this standard will likely be incineration, Based on comments from some generators, it appears unlikely that filtration will successfully work in all cases for separating radioactive particulate from oil. Therefore, incineration will be required. As with organic chemicals, no commercial mixed LLW incinerator is available.

Third, **chlorofluorocarbons** (CFCS) used in dry cleaning of clothing may also be a problem with respect to treatment. Even though many generators have shifted to water-based laundry systems, CFC solutions from past practices are in storage. Moreover, CFC solutions and sludges from decontaminating tools and equipment are in storage and will continue to be generated. As with organic chemicals, these solutions can be distilled and the nonradioactively contaminated solution can be concentrated for re-use. Nonetheless, the residue is still a mixed LLW. Because the concentration of radioactivity in these solutions is generally very low, generators hope to have them delisted or found to be BRC once the standard is finalized. The BDAT for CFCS is incineration, and, until a delisting petition is granted or the BRC standard is finalized, generators should be incinerating them. However, no commercial mixed LLW incinerator is available.

All generators that have land-disposal-restricted mixed LLW for which no treatment technique is available have no options but either to stop the practice that generates the waste, which in many cases means going out of business, or to store their waste. Storage is, however, only allowed for a period long enough to accumulate enough volume to further manage the waste. With no treatment or disposal capacity available, it is unlikely that the accumulation argument can be used by generators. They can apply for a case-by-case extension to a land disposal restriction for up to 2 years, during which time the storage prohibition does not apply. However, to receive the extension, the generator must be able to demonstrate that a good-faith effort has been made to locate and contract with facilities nationwide to manage its waste, and that a binding contract has been entered into with a treatment operator/developer that will construct or otherwise provide alternative treatment, recovery, or disposal capacity for the waste. The contract must ensure that this capacity will be available at the end of the extension period.

It will unlikely be possible to provide a treatment technique for some mixed LLW types in this timeframe. In particular, developing techniques and making them available for some organic chemical solvents with long-lived radionuclides or high concentrations of radionuclides may be difficult. If storage of such wastes extends significantly, excessive radiation exposures to workers could result if adequate storage conditions are not maintained and waste packages degrade (20).

Another problem with mixed LLW management is that EPA has not completed establishing treatment standards for all hazardous wastes. Nonetheless, it appears that treatment standards have been established for the majority of commercial mixed LLWs (e.g., organic solvents) identified that cannot be treated so that they are no longer a mixed LLW. A comprehensive national survey, however, has not been conducted to determine all the possible mixed LLWs that are being generated. A survey may uncover some types of unalterable mixed LLW for which treatment standards are not available.

A survey could also serve other needs, States would have a database to draw on to know which institutions/facilities are generating mixed LLW and to know the waste types and their volumes. This information would help States in their regulation of mixed LLW as well as in their development of a mixed LLW disposal facility. Furthermore, a mixed LLW survey could provide the treatment industry with the necessary information to develop treatment facilities to meet RCRA standards. This industry has often argued that it is leery of developing treatment facilities (e.g., incinerators) because it lacks this information. A survey could meet these needs.

A BRC standard could also help resolve some of the mixed LLW management problems. As mentioned above, by using a BRC standard, generators may be able to dispose of CFC residue and lead as hazardous waste, thereby omitting these two waste types from the mixed LLW category. Depending on the concentration of radioactivity in waste oil, it too might be removed from the mixed LLW list.[18] **Theoretically, this would leave one problem mixed LLW-organic chemicals containing high concentrations of radionuclides that cannot be trapped in an incinerator off-gas system. A new treatment or stabilization technique may be needed for these wastes.**

THE FUTURE FOR WASTE MINIMIZATION AND TREATMENT TECHNIQUES

Future Disposal Volumes

In reaction to the volume restrictions (i.e., disposal allocations established in the Low-Level Radioactive Policy Amendments Act of 1985[19]) at existing disposal sites, the slow progress in siting new disposal facilities, and increasing disposal costs, LLW generators have been reducing the volumes of waste they ship for disposal. Between 1980 and 1988, these factors were responsible for a 55 percent volume reduction in commercial LLW shipped for disposal (see ch. 4). From 1984 to 1987, the nuclear power industry reduced its waste volume by about 42 percent, while at the same time the industry built 20 new reactors (6). Since the late 1970s, institutional generators have used a variety of the technologies discussed in this chapter to reduce their LLW volumes shipped for disposal by 94 percent (32).

Waste minimization techniques can be used more extensively to avoid generating some LLWs by improving technology transfer between generator communities. Once the waste has been generated, incineration and decontamination techniques appear to have the greatest potential for reducing future LLW volumes.

Interstate LLW Management Services

The cost of disposing of LLW will almost certainly continue to rise in the future, due to the increased costs of constructing the newer engineered disposal facilities (see ch. 6). Higher disposal costs alone, however, may not drive waste volumes down to the maximum extent practicable, particularly if compacts decide to prohibit interstate processing of LLW. It probably will not be economically viable for States and compacts with a small waste volume to develop their own incinerators. The capital costs of constructing an incinerator are high, ranging from $7 million to **$9** million for a system capable of handling 85,000 pounds of waste per year, while annual operating and maintenance costs are around $500,000 (27). Incinerators have also been proven to be very difficult to site and license. With no access to an incinerator, volumes in these regions will not decrease significantly. It appears that the overall costs and some handling and transportation risks (see below) can be reduced by encouraging interstate processing of wastes.

Mixed LLW Management

The waste minimization and treatment techniques discussed in this chapter will continue to reduce the volume of mixed LLW. Generators will be pressured even more to maximize their use of these techniques, once EPA enforces its RCRA regulations and requires all generators to obtain a permit **for treating and/or storing their mixed LLW.** To avoid dual jurisdiction-to avoid having to obtain a RCRA permit in addition to the NRC or

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[18] By defining a mixed LLW as BRC with respect to its radioactivity, however, does not guarantee that a hazardous waste landfill will accept the waste. The landfill may have stricter requirements in its permit and refuse the waste. In such instances, the waste generator is left with no disposal option at present.

[19] Public Law 99-240, Jan. 15, 1986.

Agreement State license they currently have—mixed LLW generators will try to change their practices and not generate mixed LLW or will try to treat all mixed LLW such that it is either solely radioactive or solely hazardous.

The generation of some mixed LLWs is, however, unavoidable. Of primary concern is the storage prohibition that applies to mixed LLW. As a remedy, EPA could decide, in establishing its treatment standards for the final third of hazardous wastes (due to be released in May 1990), that the storage prohibition does not apply to generators of wastes for which no treatment capacity and/or no disposal capacity is available. In other words, storage would be allowed if it is not being used in place of disposal.

An advantage of this approach is that mixed LLW generators would have an intermediate option until treatment capacity and disposal capacity are available. Furthermore, by generators applying for a storage permit, EPA would have a record as to what types and volumes of mixed LLW are being generated. EPA could use the data to better ensure that wastes are not being illegally disposed. The waste treatment industry also could use the data as a marketing tool to develop necessary waste treatment facilities, as it could with data from a national survey.

Generators claim that dual jurisdiction is very burdensome in that they have to meet two separate agencies' requirements, including filling out separate forms that often request the same information. EPA has stated, however, that it will try and "accept, to the extent possible, information already submitted to the NRC when processing a RCRA permit."[20] Likewise, NRC has said that the two agencies will work toward ''resolving the difficulties of simultaneous licensing and permitting processes, making the overall process more uniform, and exploring the possibility of using the same application documerit, ' but NRC notes that this effort is of low priority compared to joint guidance efforts (13). Even given these intentions, generators are discouraged and anxious about dual jurisdiction because of the lack of progress they have seen the two agencies make toward streamlining the permitting/licensing process for the treatment, storage, and disposal (which is discussed inch. 6) of mixed LLW.

Dual jurisdiction is likely to be difficult until EPA and NRC agree to joint rulemaking or joint guidance concerning several regulatory issues. In some cases, the two agencies have different approaches and these approaches may be in conflict. Joint rulemaking and/or joint guidance will likely be needed on waste package manifest requirements, waste package sampling and testing, and inspection and enforcement of treatment, storage, and disposal facilities. For sampling, EPA requires a 100-gram specimen. NRC is concerned that this size sample is too large and in conflict with its principle of keeping worker exposure as low as reasonably achievable. EPA headquarters has told its regional offices that, if this conflict does arise, the office should accept smaller samples.[21] In addition to other cases of possible regulatory conflict and overlapping and duplicative regulations (see ch. 1 and ch. 3), the NRC and EPA may find other regulatory areas that will require joint rulemaking and/or joint guidance.

Of all the types of mixed LLW discussed, three types stand out as the most difficult for generators to manage-organic chemicals, waste oil, and CFC residue. Of these three wastes, organic chemicals seem to offer the greatest challenge from a treatment perspective. **If a comprehensive survey of mixed LLW is conducted and/or EPA develops a record of stored mixed LLW by permitting such practices, States would have the information they need to regulate these wastes and to develop disposal capacity. In addition, industry would have a clearer idea of the technology and capacity needed to treat these three wastes.**

Risks of LLW Management

Neither incineration nor decontamination—the two most efficient waste volume reduction techniques-will reduce the total curies generated, because curies cannot be destroyed. Through current incineration techniques, some radio-

20 53 Federal Register 185, Sept. 23, 1988.

21 To justify this decision, EPA regional offices can cite Section 1006 of RCRA. It states ''nothing in this chapter shall be construed to apply to (or (o authorize any State, interstate, or local authority to regulate) any activity or substance which is subject to [numerous laws including] the Atomic Energy Act of 1954 except to the extent that such application (or regulation) is not inconsistent with the requirements of such Acts. "

nuclides (e.g., tritium and carbon-14) will be released into the atmosphere and some will be fixed in the ash. The total radioactivity emitted from these two pathways will be equivalent to that in the waste prior to incineration. Likewise, the radioactivity extracted during decontamination is equivalent to the radioactivity in the waste prior to decontamination. It is difficult to determine which exposure pathways have the greatest risk to humans and the environment. Nonetheless, aside from the limited radioactivity that escapes via stack gases, all radioactivity disposed of under either scenario (disposal without incineration or decontamination versus disposal following these techniques) will be the same. Thus, the risks of environmental contamination and human exposure through disposing of radioactive material remain the same. However, with **less waste disposed of and the waste being more stabilized before disposal, these techniques may reduce the number of handling and transportation accidents but not necessarily their severity.**

Waste stabilization techniques are an important component of waste management, as is clearly indicated by the failure of past disposal practices to prevent radionuclide migration. NRC regulations do not require generators to stabilize Class A LLW. Stabilization, however, is a relatively inexpensive method of reducing the risk of environmental contamination. By **stabilizing Class A waste, which is about 97 percent of LLW, more assurance may be gained in the stability of disposal sites.** However, under certain environmental conditions (e.g., low precipitation) and given certain engineered disposal designs, the potential gain in short-term and long-term site stability may not justify stabilizing Class A waste.

With Class B and C wastes, it is difficult to predict with high certainty the long-term stability of various waste forms and container technologies. This uncertainty is primarily due to the relatively small database on their behavior. Furthermore, the variability in geochemical conditions encountered in a disposal site make it difficult to model site conditions. Nonetheless, the stability of most wastes can be significantly improved by using a combination of containment techniques.

Stabilization of different mixed LLWs requires more research to determine which technique or combination of techniques are most appropriate. EPA recommends monitoring the Superfund Innovative Technologies Evaluation Program for information on new techniques (15).

The uncertainty about the long-term stability of solidification and containment materials implies that long-term in-situ testing of waste stabilization materials will be necessary to manage LLW disposal sites. Test results can provide the scientific community, policy makers, and the public with the necessary information to plan for the *next generation* of disposal facilities.

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