Chapter 4

Understanding LLW—Its Characteristics, Volumes, and Health Effects

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OVERVIEW

Commercial low-level radioactive waste (LLW) in the United States is classified as Class A, Class B, Class C, or Greater-Than-Class C (GTCC), with GTCC waste being the most radioactive. About 97 percent of the total LLW volume is Class A waste. About 3 to 10 percent of all LLW is also considered mixed LLW because it contains low-level radioactive constituents as well as hazardous constituents. Principal generators of commercial LLW and mixed LLW include nuclear power plants, other industries, and academic and medical institutions.

In 1988, about 1.4 million cubic feet of commercial LLW was generated in the United States and disposed of at licensed disposal sites at Barnwell, SC; Richland, WA; and Beatty, NV. This volume of waste would fill about 390 average-size tractor trailers, forming a line over 3½ miles long. [1]This volume contains about 260,000 curies of radioactivity.

Over the last 9 years the volume of commercial LLW shipped for disposal has decreased by about 55 percent. If this trend continues, the volume of LLW shipped for disposal in 1989 should remain at 1988 levels of 1.4 million cubic feet; however, another significant decrease in waste volume will likely occur in 1990 when disposal surcharges are scheduled to double. If available volume reduction techniques are more widely applied and below regulatory concern (BRC) limits are finalized (see ch. 3), LLW volumes will probably continue to decrease over the next several years, perhaps by another 40 to 50 percent (see section on '' Implications of Waste Minimization and Treatment Techniques on Future Waste Volumes").[2]

WHAT IS LOW-LEVEL RADIOACTIVE WASTE?

Low-level radioactive waste (LLW) is defined in the Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA) of 1985 by what it is not, rather than by what it is. **LLW includes all radioactive waste that is not classified as spent fuel, high-level waste, or uranium mill tailings (see** box 4-A). The majority of LLW volume—Class A waste-contains very low levels of radiation and heat, requires no shielding to protect workers or the general public, and decays in less than 100 years to levels that the Nuclear Regulatory Commission (NRC) finds do not pose an unacceptable risk to public health and safety. The remaining 3 percent of LLW volume-Class B, Class C, and GTCC—requires shielding and can remain harmful for 300 to 500 years or more.[3]

Generators of commercial LLW include: nuclear power plants; fuel fabrication facilities; research reactors; industrial plants using radioactive materials; manufacturers of radioactive instruments and radiopharmaceuticals; hospitals, clinics, and other medical facilities; and other private sector and university laboratories. LLW typically includes an assortment of materials that table 4-1 lists in three general categories of generators.

COMMERCIAL LLW

Each business, institution, or organization that handles radioactive material must be licensed by the NRC or an Agreement State that has been granted licensing authority by the NRC. There are about 17,000 licensees in this country authorized to handle radioactive materials (17). However. each licensee may employ many individuals who work with radioactive material. For example. on nine Univer-

[1]This analogy using tractor trailers applies to volumes only, not actual transportation scenarios, since tractor trailer weight limits would prohibit the *transport* of such heavy loads.

[2]Most treatment techniques, versus waste minimization techniques that keep waste from ever being generated, have little effect on reducing the waste's radioactivity.

[3]GTCC waste is the responsibility of the Federal Government to dispose. Isolation of GTCC waste needs to be for a few hundred to a few thousand years. For a thorough discussion of GTCC waste, see U.S. Congress, Office of Technology Assessment, *An Evaluation of Options for Managing Greater-Than-Class C Low-Level Radioactive Waste*, OTA-BP-O-50, October 1988

Box 4-A—Types of Radioactive Wrote

The following types of radioactive waste are differentiated by the nature and intensity of the radiation they emit, as well as by their physical and chemical forms. They are listed roughly in order of decreasing risk to humans.

Spent fuel consists of fuel rods that have been "burned" (irradiated) in commercial, defense, or research nuclear reactors to the point that they no longer contribute efficiently to the nuclear chain reaction. Spent **fuel is** being stored at **113 operating commercial nuclear power plants pending the availability of a federally monitored retrievable facility for storage or a deep-geologic repository for disposal.**

High-level waste (HLW), as the term is used in this report, is generated when spent fuel is reprocessed to recover plutonium and uranium. The vast majority of HLW in the United States has been generated over the last four decades in support of national defense programs. HLW is highly radioactive, generates some heat, and requires heavy shielding. Most HLW is now stored at Richland, WA; Aiken, SC; and Idaho Falls, ID, pending availability **of a deep-geologic repository.**

Transuranic waste is generated from the production of plutonium for nuclear weapons, from the manufacturing of sealed radioactive sources, and from the refurbishing or decommissioning of nuclear power plants. Transuranic waste contains radionuclides that have atomic numbers greater than 92, the atomic **number of uranium. Defense transuranic wastes are currently being stored pending disposal in a deep-geologic repository called the Waste Isolation Pilot Project (WIPP), located near Carlsbad, New Mexico. *Commercial* transuranic waste** is **included as low-level radioactive waste.**

Low-level radioactive waste (LLW) includes radioactive waste not classified as uranium mill tailings, high-level waste, or spent fuel. About 97 percent of all LLW-Class A--has relatively low levels of radioactivity. Class A waste remains hazardous for less than 100 years, Class B and C waste remains hazardous for a few hundred years, while Greater-Than-Class C waste remains hazardous for a few hundred to a few thousand years. GTCC waste is the responsibility of the Federal Government to manage. All classes of commercial LLW can contain transuranic elements.

Uranium mill tailings are the earthen residues--coarse sand and a "slime' of clay-like particles-that remain after extracting uranium from mined uranium ore. These tailings contain low concentrations of radioactive material, but tailing volumes are very large. Mill tailings are found in New Mexico, Wyoming, Colorado, Utah, Texas, Washington, and South Dakota.

Byproduct material is material contaminater or made radioactive during the production or use of special nuclear material.

SOURCE: I.P. Weber and S.D. Wiltshire, ***The Nuclear Waste Primer: A Handbook for Citizens, The League of*** Women Voters Education Fund (New York, NY: **Nick** Lyons **Books, 1985).**

sity of California campuses there are over 15,000 individual users of radioactive material **(20).**

As shown in figure 4-1, about 1,440,000 cubic feet of commercial LLW (containing about 260,000 curies) was disposed of in 1988 at the three operating commercial disposal sites in Barnwell, SC; Richland, WA; and Beatty, NV. Figure **4-2** indicates that nuclear power plants throughout the country produce over **50** percent of the volume of LLW generated nationwide and over 80 percent of the radioactivity. The LLW from decommissioned nuclear power plants is addressed in appendix B. Industries account for most of the remaining volume and radioactivity. Some of the principal radionuclides found in LLW from different generators are listed in figure **4-2** while their half-lives[4] and type of radiation emitted[5] are listed in table **4-2.**

In light of the wide range of materials, their half-lives, and the type of radiation they emit, NRC uses a four-tiered classification system for commercial LLW based on the types and concentrations of different radionuclides in the waste. This classifica-

[4]Half-life is the time in which half of the atoms of a particular radioactive substance disintegrate to another nuclear form. For example, wrote containing *50 curies* of a radionuclide with a half-life of 10 years will contain only 25 curies in 10 years. In 10 more years the waste will contain *12.5 curies* and this decay process continues. Each radionuclide has a specific half-life. Measured half-lives vary from millionths of a second to billions of years.

[5]Radiation can be emitted as a particle—alpha or beta, or as a ray—a gamma ray or an X-ray. To understand the differences in how these particles and rays affect humans, see the section on "Understanding Radiation and Its Health Effects."

Table 4-1-Principal Generators and Types of Commercial LLW

Nuclear power plants:
Dry solids (e.g., protective clothing, rags, paper, plastics, and other trash); used equipment; sludges, organic solvents, and other liquids; water purification filter media and "resins"; irradiated hardware; and gases.

Industries:
Radiopharmaceuticals; wastes from fabricating nuclear fuel; sealed sources.

Academic & medical institutions:
Dry solids, glassware, plastics, and other laboratory equipment; scintillation fluids and other organic liquids; animal carcasses, medical treatment and research materials; and gaseous wastes.

SOURCE: Adapted from U.S. Department of Energy, Managing *Low-Level Radioactfie Wastes: A* Proposed Approach, DOE/LLLW-9, April 1983, p. 206,

Table 4-2-Principal Radionuclides Found in Commercial LLW

Radionuclide	Approximate half-life	Type of radiation emitted
Technetium-99 . . .	6 hours	Gamma
Xenon-133	5 days	Beta, gamma
Phosphorus-32 . . .	14 days	Beta
Cobalt-58	2 months	X-rays, beta, gamma
iodine-125 , ., ... ,	2 months	Gamma
Sulfur-35	3 months	Beta
Magnesium-54 . . .	10 months	X-rays, gamma
Cesium-134	2 years	Beta, gamma
Cobalt-60	5 years	Beta, gamma
Tritium	12 years	Beta
Cesium-137	30 years	Beta, gamma
Strontium-90	30 years	Beta
Nickel-61	90 years	Beta
Carbon-14	5,700 years	Beta
Nickel-59	80,000 years	X-rays
iodine-129	15,700,000 years	Beta
Uranium-235	700,000,000 years	Alpha, gamma
Uranium-238	4,470,000,000 years	Alpha, gamma

SOURCE: Office of Technology Assessment, 1989.

tion system, which NRC describes in 10 CFR Part 61.55, generally reflects the waste's potential long-term hazards to humans.

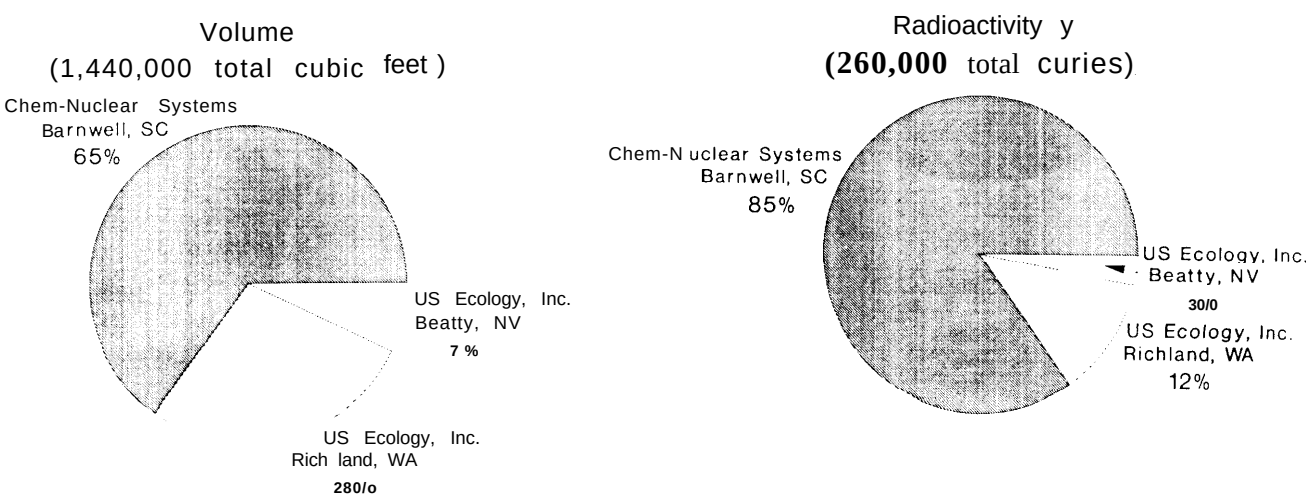
Class A Waste

Class A waste, the least radioactive of the four types, must meet numerous minimum requirements on packaging to facilitate handling of the waste and to protect the health and safety of workers at disposal sites (see ch. 5). Class A waste is normally segregated from other LLW waste at disposal sites, unless the waste meets the more stringent physical stability requirements for Class B and C waste. As indicated in figure 4-3, most of the volume of LLW is Class A waste, although it actually accounts for only a small portion of the radioactivity in LLW.

Class B Waste

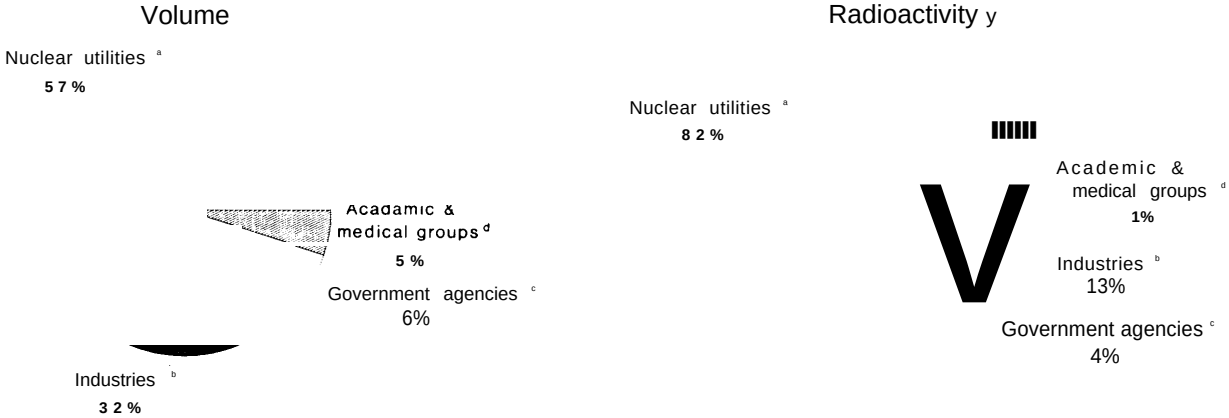
Class B waste has intermediate levels of radioactivity that are generally 10 to 40 times higher than levels for Class A waste. In addition to satisfying all the packaging requirements for Class A waste, Class B waste must be structurally stable for at least 300 years to prevent collapse of the caps that typically

Figure 4-1--Commercial LLW Disposal in 1088



SOURCE: Data provided by EG&G Idaho In May 1989 during the preparation of U.S. Department of Energy, *DRAFT Integrated Data Base* for 1989; Spent *Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006,* Rev.5, August 1969.

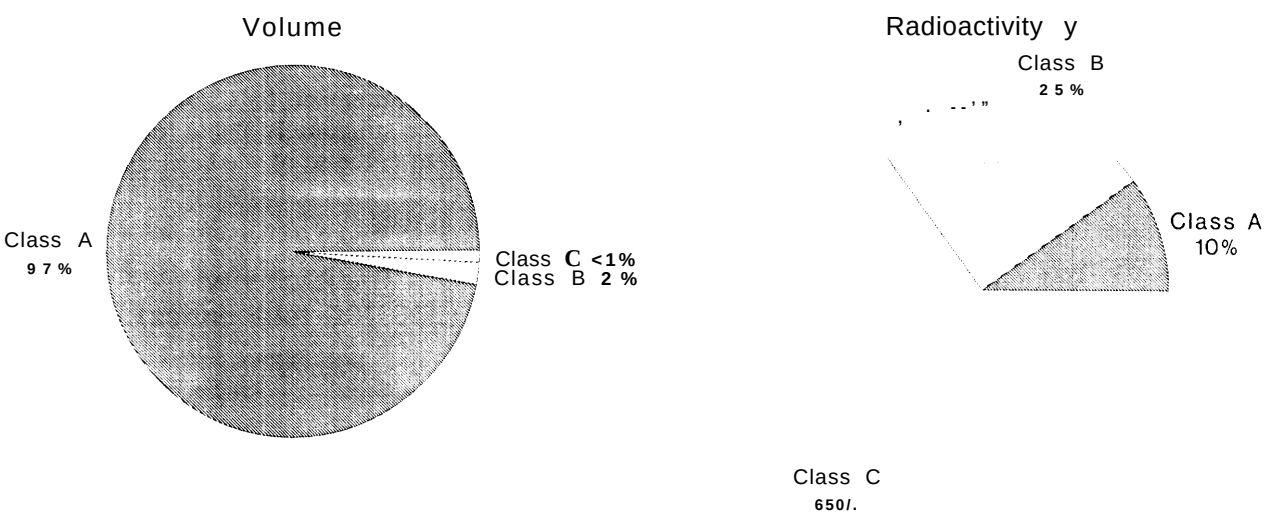
Figure 4-2-Generators of Commercial LLW Received at Disposal Sites in 1987



Typical radionuclides from different generators:
[a]Nuclear power plants: cobalt-58 and -60, chromium-51, manganese-54, cesium-134 and -137, nickel-59, tritium (i.e., hydrogen-3), zinc-65, and iodine-131
[b]Radiopharmaceutical wastes: carbon-14, tritium, iodine-125, phosphorus-32, sulfur-35, and technecium-99; fuel-fabrication wastes: uranium-235 and -238; and sealed sources: cesium-137, and cobalt-60.
[c]Government (commercial sites accept LLW from non-DOE government agencies for disposal): phosphorus-32, cobalt-60, chromium-51, nickel-63, tritium, and carbon-14.
[d]Hospitals and universities: tritium, carbon-14, iodine-125, phosphorus-32, sulfur-35, rubidium-37, calcium-45, sulfur-35, chromium-51, iridium-192, and technetium-99.

SOURCE: Adapted from U.S. Department of Energy, *The* 1987 State-by-State *Assessment of Low-Level Radioactive Wastes Received at Commercial Disposal Sites,* National Low-Level Radioactive Waste Management Program, DOE/LLW-69T, December 1988, p. 141

Figure 4-3-Estimated Annual Generation of Commercial LLW in 1987



Category	Volume (10^3 ft^3)
class A	1,388
Class B	39
Class C	12
Total	1,449
GTCC*	1

Category	Radioactivity (10^3 Ci)
class A	26
Class B	67
Class C	177
Total	270
GTCC*	400

•*Sine the disposal of GTCC waste is the responsibility of the Federal Government, GTCC waste is usually excluded from most discussions about LLW.

SOURCE: U.S. Department of Energy, *The* 1987 State-by-State *Assessment of Low-Leve/ Radioactive Wastes Received at Commercial Disposal Sites,* National Low-Level Radioactive Waste Management Program, DOE/LLW-69T, December 1988, and Office of Technology Assessment, *An Evaluation of Options for Managing Greater-Than-C/ass C Low-Level Radioactive* Waste, OTA-BP-O-50, October 1988, p 43.

cover disposed waste; stability is also important in limiting exposure to an inadvertent intruder. High integrity containers are used for Class B and C waste. (See ch. 5 for more detail on packaging and chs. 3 and 6 for more detail on disposal regulations.)

Class C *Waste*

The levels of radioactivity in Class C waste are generally 10 to 100 times higher than levels for Class B waste. Packaging and stability requirements for Class C waste are the same as those for Class B waste. Because of its relatively high levels of radioactivity, some Class C waste must also be shielded and handled remotely to avoid excess exposures to workers. To prevent inadvertent exposure to human intruders, Class C waste must be buried at least 16 feet below the Earth's surface or covered with a thick intrusion barrier (e.g., concrete slab). (See ch. 5 for more detail on packaging and chs. 3 and 6 for more detail on disposal regulations.)

Greater-Than-Class C Waste

Greater-than-Class C (GTCC) waste is more radioactive than Class C waste, but less radioactive than spent fuel. GTCC waste is generally not acceptable for near-surface disposal. In the LLRWPAA of 1985, the Federal Government was given the responsibility for the disposal of GTCC waste, The Department of Energy is currently developing an inventory of GTCC waste and evaluating alternative disposal technologies, including disposal in deep-geologic repositories along with commercial spent fuel and defense high-level waste. GTCC waste is now being stored onsite pending a decision about its offsite storage and/or disposal (13).

At present, there are about 15,000 cubic feet of packaged GTCC waste now in storage at several hundred generation sites; an additional 1,400 cubic feet of GTCC waste are generated each year. The radioactivity of this waste is about 5 million curies, or an amount of radioactivity equivalent to all other commercial LLW that has been generated and disposed of to date (13).

SPECIAL CATEGORIES OF LLW

The following categories of LLW do not fall neatly into commercial LLW but can be considered in some way special because of their composition, volume, or unique characteristics.

Mixed LLW

Several studies performed in the mid-1980s indicated that about 3 to 10 percent of all commercial LLW is mixed LLW because it contains both radioactive and chemically hazardous constituents (12). Commercial mixed waste is defined and identified in a document issued jointly by NRC and the Environmental Protection Agency (EPA) in 1987 (19). This waste is produced by a full range of LLW generators (e.g., nuclear power plants, medical and academic institutions, and various industries such as pharmaceutical and biotechnology firms) and waste processors.

As shown in table 4-3, the hazardous constituents in mixed LLW typically include: organic liquids, metallic lead, cadmium, chromates, and waste oils (12). Several of the types of mixed LLW listed in the table have been consolidated into five categories:

1. **Organic liquids: Organic** liquids are produced by a full range of LLW generators. Scintillation fluids, which are used in diagnostic tests and general laboratory counting procedures for environmental and facility monitoring, comprise the largest volume of mixed LLW. These fluids typically contain toluene and xylene. Organic liquids are also generated by industries during the manufacture of sealed sources, pharmaceuticals, radiopharmaceuticals, and diagnostic tests. Industries and nuclear power plants use organic chemicals, such as acetone and chlorofluorocarbons (CFCs), commonly referred to as freon, for cleaning protective clothing, tools, equipment, and instrumentation. Trash can also be contaminated with organic chemicals.
2. **Metallic lead:** Metallic lead becomes radioactively contaminated when it is used to store radioactive materials in a shielded container or to shield workers from radiation exposure during product manufacturing and laboratory research. This lead may be in the form of foil, sheets, bricks, or containers for storage or shipping. If lead is decontaminated, the cleaning solutions containing dissolved lead and radioactive material will also be classified as a mixed LLW.
3. **Cadmium:** Nuclear power plants generate radioactively contaminated cadmium waste when welding rods containing cadmium are used. Equipment with such welds and the

Table 4-3-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	Laboratory counting procedures	Laboratory counting procedures	Laboratory counting procedures	NA	Processing to separate fluid from vials	Laboratory counting procedures	Laboratory procedures	Laboratory counting procedures
Organic chemicals	Residue from research Residue from manufacturing Cleaning of laboratory and process equipment	Spent reagents from experiment Cleaning of laboratory equipment	Residue from research Residue from manufacturing Cleaning of laboratory and process equipment Expired product	NA	NA	NA	Cleaning of laboratory equipment	Cleaning of laboratory equipment Cleaning of contaminated components
Trash with organic chemicals	NA	Used equipment	NA	NA	NA	NA	NA	NA
Lead	Contaminated during use	Contaminated during use	Residue from manufacturing	NA	NA	Contaminated during use	Contaminated during use	Contaminated during use
Lead decontamination solutions	NA	NA	NA	NA	Decontamination of lead Shielding	NA	NA	Decontamination of lead shielding
Waste oil	011 from contaminated equipment	NA	Oil from radioactive systems/areas	NA	Oil from radioactive systems	NA	011 from radioactive systems	011 from radioactive systems 011 from hot shop
Trash with oil	NA	NA	NA	NA	NA	*MA*	NA	Oil from radioactive systems (xl from hot shop
Chlorofluorocarbon (CFC) Solvent	NA	NA	NA	NA	NA	NA	NA	Clothes laundry
CFC concentrates	NA	NA	NA	NA	Clothes laundry Tool decontamination	NA	NA	Clothes laundry Tool decontamination
Aqueous *corrosive* liquids	NA	NA	NA	Cleaning of spent fuel casks Backflush of resin filters	NA	NA	NA	NA
chromate waste	NA	NA	NA	M	NA	NA	*NA*	Resin Changeouts
Cadmium waste	NA	NA	NA	NA	NA	NA	NA	Spent welding rods Weld cleaning Equipment dicontamination

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

liquids and solid materials used to clean such equipment may also be contaminated with cadmium. This waste may not be found to be mixed if it passes EPA's EP toxicity test, which tests for leachability.

4. **Chromates:** Some nuclear power plants use chromates to inhibit corrosion in water circulation systems. When the water purification resins are periodically changed, they will be considered mixed wastes if they fail EPA's EP toxicity test.
5. Waste oils: When the oil in pumps and other equipment located in radioactive areas is periodically changed, the oil is generally contaminated. Such waste oils and oily trash, principally from radioactively contaminated machine shops, are considered hazardous under some State regulations, EPA is currently making a determination on whether waste oil will be listed as a hazardous waste (see ch. 3).

Until 1985, most commercial mixed LLW was disposed of in NRC-licensed LLW disposal facilities. In the future, disposal facilities for mixed LLW will be licensed by NRC and EPA or by States with NRC/EPA licensing/permitting authority. However, **neither the three currently operating LLW disposal facilities nor any hazardous waste landfills are licensed to accept mixed LLW. (The** only exception is that some waste oils and lead may be accepted at LLW sites if they meet requirements of the individual sites.) The vast majority of commercial mixed LLW that cannot be treated and disposed of as ordinary trash, LLW, or hazardous waste, therefore, will have to remain in storage until mixed LLW disposal facilities are developed by States or compacts. (See chs. 3 and 5 for more detail on this situation.)

Naturally Occurring and Accelerator Produced Radioactive Material (NARM)

NARM includes such naturally occurring material as radium-226 used in some smoke detectors and watch dials, and polonium-210 used in some industrial gauges; NARM also includes accelerator produced radioactive material generated in linear accelerators for use in medical instruments, Twenty-eight States regulate NARM and existing commercial disposal sites can accept such waste. Under Federal law, however, neither the States nor the Federal Government is presently responsible for disposal of NARM.

Other LLW

Some LLW is also generated by certain special projects. Two examples are the decontamination of Unit 2 of the Three Mile Island nuclear power plant and the cleanup operation at West Valley, NY, the site of a no-longer operating commercial spent-fuel reprocessing plant.

COMPARISON OF LLW TO OTHER TYPES OF RADIOACTIVE WASTE

By the end of 1988, the United States had cumulatively generated over 135 million cubic feet of LLW, consisting of 19 million curies, from both commercial and defense activities. Defense activities have generated about 66 percent of this volume and about 74 percent of the radioactivity. These percentages are equivalent to the defense program having generated about twice the volume and three times the radioactivity of commercial LLW.

Commercial LLW and defense LLW include almost 85 percent of the volume of all categories of radioactive waste (including high-level waste, spent fuel, and transuranic waste) generated in this Nation. However, the radioactivity in commercial LLW and defense LLW only contains about 0.1 percent of the total radioactivity in all categories of radioactive waste. As shown in table 4-4, the vast majority of the radioactivity is in the spent fuel generated by 113 operating commercial nuclear power plants.

IMPLICATIONS OF WASTE MINIMIZATION AND TREATMENT TECHNIQUES ON FUTURE WASTE VOLUMES

Although the NRC encourages waste minimization techniques, which eliminate wastes from being generated, and treatment techniques, which reduce the volume of wastes once they are generated (18), waste generators are not required to use any of the techniques noted in box 4-B and described in more detail in chapter 5. The 250 percent increase in LLW disposal costs over the last decade, due to costs associated with new disposal regulations and disposal surcharges established in the LLRWPAA, has been the driving force behind reducing LLW volumes, In fact, between 1980 and 1988 the volume of commercial LLW shipped for disposal has de-

Table 4-4-Cumulative Amounts of Radioactive Waste Generated Through 1988[a]

Waste type	Volumes (in 10^3 ft^3)	Percent	Activity (in 10^6 Ci)	Percent
Low-level *waste*				
Commercial	46,000	29.3	5	0.02
Defense	87,000	55.5	14	0.06
High-level waste				
Commercial[b]	80	0.05	30	0.2
Defense	13,500	8.6	1,175	5.4
***Commercial** spent fuel*	270	0.17	20,400	94,3
Defense TRU waste	10,000	6.4	4	0.02
Total	156,850	100.02	21,628	100.00

[a]Does not include mill tailings or waste from remedial action projects.
[b]Commercial waste now located at West Valley, NY Also assumes no commercial reprocessing of spent fuel.

SOURCE: U.S. Department of Energy, DRAFT *Integrated Data Base for 1989: Spent* Fuel and Radioactive Waste *Inventories, Projections, and* **Characteristics,** DOE/RW-0006, Rev. 5, August 1988, p. 22.

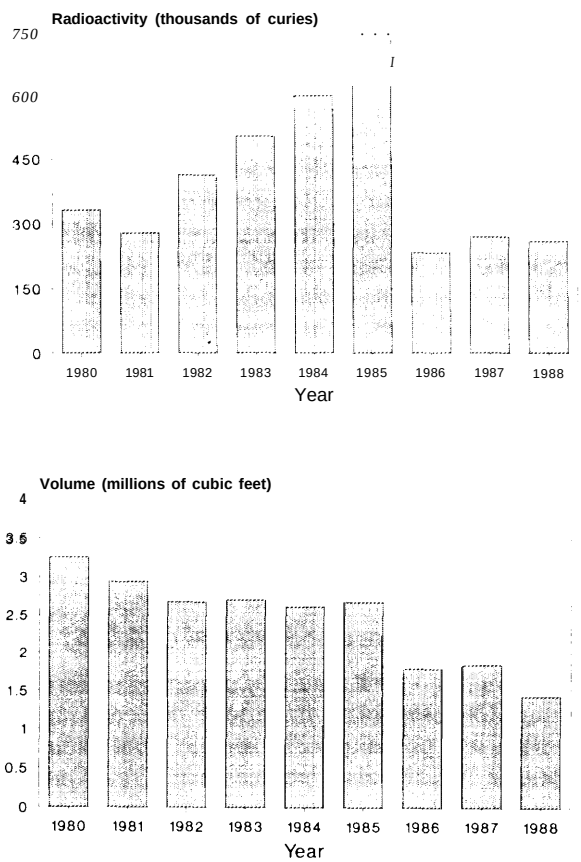
creased by about 55 percent. This trend of decreasing LLW volume is shown in figure 4-4 for the Nation, and in appendix A for each State and compact.

As shown in figure 4-1, the most significant reductions in waste volumes are directly related to notable increases in unit disposal costs (i.e., cost per cubic foot). If trends continue, the volume of LLW shipped for disposal in 1989 should be about the same as in 1988; however, another significant drop in waste volumes will probably come in 1990 when the disposal surcharge doubles from $20 to $40 per cubic foot, as allowed in the LLRWPAA of 1985. If unit disposal costs continue to increase during the 1990s as smaller, more expensive disposal facilities are brought on line, the trend of decreasing LLW volumes shipped for disposal will probably continue. (Disposal costs are discussed in more detail in ch. 6.)

The LLRWPAA of 1985 limits the amount of LLW that will be accepted for disposal at each of the three existing disposal sites. These annual limits are listed in figure 4-5. In addition, volumes of LLW from commercial nuclear power plants cannot exceed about 60 percent of the total limit for all three sites. Due to the increasing use of volume reduction technologies, the average volumes of LLW accepted for disposal over the last 3 years are well within the overall volumetric limitations and within the individual limits and the licensed capacities for all three sites. If present trends continue, it is unlikely that any volumetric limits will be exceeded.

Table 4-5 presents an approach to estimate the potential for further volume reduction if currently

Figure 4-4-Yearly Volumes and Radioactivity of Commercial LLW Shipped for Disposal (1980-1988)



SOURCE: U.S. Department of Energy, DRAFT, *Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 5, August 1989, p. 146.

Box 4-B—Waste Minimization and Treatment Techniques

Several waste minimization and treatment techniques are briefly discussed below. With the exception of the first three techniques listed, these techniques have little effect on reducing the waste's radioactivity.

- **Using nonradioactive substitutes.** In many industrial and research applications, nonradioactive material can be effectively substituted for radioactive materials. If radioactive material must be used, it may be possible to use smaller amounts of material or isotopes that decay more rapidly.
- **Improving the management of radioactive materials.** Volumes of radioactive material may be reduced through better scheduling of material use, reducing excess purchases of radioactive material, and coordinating purchases through a "clearinghouse." Simply segregating radioactive from nonradioactive material can also lead to significant volume reductions.
- **Storing radioactive material to allow decay.** Many radionuclides in LLW decay to lower levels within a relatively short time. By storing wastes at their generation sites for a few months to a few years, the radioactivity may be reduced enough to allow its disposal with other less radioactive wastes or with municipal waste, should the radioactivity be below background levels.
- **Compacting and shredding dry wastes.** Compactors can achieve a S-fold to lo-fold volume reduction, depending on the size of the unit and the type of waste. These units can reduce the height of 55-gallon drums of waste by 60 to 90 percent within just a few minutes simply by crushing them into large "hockey pucks' (6, 8). Shredders can be used with or without compaction to reduce waste volumes.
- **Decontaminating materials.** LLW generators have been successful in decontaminating large pieces of equipment, tools, glassware, and clothing so that they can be reused.
- **Incinerating wastes.** Combustible liquids and solid wastes can be incinerated with a 20-fold to 30-fold reduction in volume. For example, about 80 percent of the dry LLW (i.e., trash) from an average nuclear power plant is combustible (4). At present, about 100 small on-site incinerators are used mostly by hospitals, research laboratories, and universities. No commercial incinerator, however, is presently available for offsite LLW incineration.

SOURCE: Office of Technology Assessment, 1989.

available waste minimization and treatment techniques are more widely applied. The approach is based on maximizing decontamination with material reuse and future incineration.

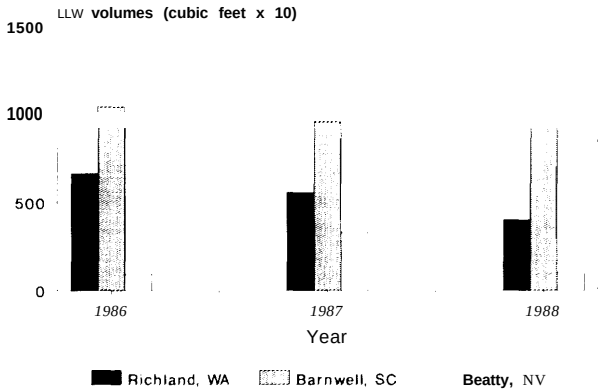
Utility waste accounted for 58 percent (840,000 cubic feet) of the Nation's LLW volume in 1988 (1,440,000 cubic feet). Approximately 43 percent (360,000 cubic feet) of this waste is combustible. A substantial portion of the remaining 57 percent (480,000 cubic feet) of utility LLW consists of metallic material that, in many cases, could be decontaminated. If it is conservatively assumed that half of the 57 percent could be decontaminated, 240,000 cubic feet of waste would be added to the 360,000 cubic feet of combustible waste, totaling 600,000 cubic feet of volume reduction. Therefore, nuclear utilities **alone could be responsible for reducing the total LLW volume by 42 percent from their 1988 volume level. Industrial waste generators,** which generated 35 percent of the Nation's LLW in 1988 and generate similar waste products, **could also increase their** use of these two **techniques, potentially increasing the total percentage of volume reduction to around** 50 **percent.**[6] Because of the uncertainty of costs being tied closely enough to volume versus radioactivity to drive volume reduction practices, a range of 40 to 50 percent reduction in waste volumes is estimated.

Volume reductions could also result from BRC limits being finalized (see ch. 3) which may enable some dry wastes that are now classified as Class A to be disposed of in a municipal landfill or hazardous waste landfill, depending on its hazardous characteristics. Likewise, liquid BRC LLW not containing hazardous waste constituents may possibly be disposed of through a municipal sewer system. The nuclear utility industry estimates that a BRC limit of

[6]This degree of volume reduction will only occur if disposal fees are based primarily on volume. In the future, site operators could decide to base fees only on radioactivity, which would remove generators' incentives to reduce volume.

93-406 - 89 - 4 : QL 3

Figure 4-5-Volumes of Commercial LLW Disposal in 1986,1987, and 1988



Disposal site	LLW volumes (10^3 cubic feet) Annual limit	Licensed capacity	Volume used
Richland, WA	**1,400**	**52,700**	**10,790**
Barnwell, SC	**1,200**	34,400	20,684
Beatty, NV	200	4,900	3,990
Total	2,800	92,000	35,458

SOURCE: U.S. Department of Energy, DRAFT, *Integrated* **Data Base** *for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics,* DOE/RW-0006, Rev. 5, August 1989, p. 157. **Date on** licensed capacity taken from U.S. Department of Energy, **The** *1987* ***State-by-State*** *Assessment of Low-Level Radioactive Wastes Received* **at** *Commercial* **Disposal** *Sites,* National Low-level Radioactive Waste Management Program, DOE/LLW-66T, December 1988.

15 millirems per year could decrease its LLW volume by as much as 30 percent.[7]

UNDERSTANDING RADIATION AND ITS HEALTH EFFECTS

Radiation is a natural phenomenon of our environment that has been present since life evolved. Ionizing radiation is a form of energy generated by the activity of atoms, which are the basic building blocks of matter. Some atoms are unstable and spontaneously change into another form. An unstable atom is said to be **radioactive** and the process by which it changes into a new atom is called **radioactive decay.** More specifically, an unstable atom releases excess energy when an electron is lost or gained. This energy is in the form of waves or fast-moving particles. An atom that spontaneously produces radiation is called a **radionuclide.** Within a certain period, called a **half-life,** half of an unstable atom decays and gives off radiation. All radionuclides have a known half-life. Half-lives range from fractions of a second to billions of years. Refer to table 4-2 for the half-lives of the principal radionuclides found in commercial LLW.

Table 4-5-Projected Volume Reduction of Commercial LLW

	Volume (cubic feet) (based on 1988 shipment data)
LLW volume shipped for disposal	
Utility (58°/0)	840,000
Industrial (35%)	500,000
Other (7%)	100,000
Total	1,440,000
	Possible volume reduction (cube feet)
utility	
Combustible@	360,000
Recyclable	240,000
Total utility reduction (42% of total shipped)	600,000
Industry	
Combustible + recyclable= 20?/' reduction (7% **of** total shipped)	100,000
Possible *total* volume *reduction (49% total* volume reduction)	700,000

[a]Figure deduced from Electric Power Research institute, ***Radwaste*** *Generation* ***Survey*** *Update,* **prepared** by Analytical Resources, Inc., Sinking Spring, PA, February 19S8.
[b]Conservative estimate representing a 20% reduction of industrial disposal of LLW.

SOURCE: Office of Technology Assessment, 1989.

Sources of Ionizing Radiation

An individual is routinely exposed to ionizing radiation from several natural sources: cosmic rays from the sun and stars, natural radioactive elements from the earth (e.g., radium, uranium, and potassium), and naturally occurring radionuclides in the human body (e.g., carbon-14), Internal exposure can come from naturally occurring radioactive elements in food, water, and air. Milk, for example, contains potassium-40, which emits a small but measurable amount of radiation. The levels of natural background radiation vary greatly from location to location. For example, in Denver, CO, the levels of cosmic radiation are twice as high as they are in Washington, DC, because of Denver's higher elevation. Furthermore, there are large regional differences in background radiation due to minerals in the ground at a particular location. For example, the background level in certain parts of Colorado can be

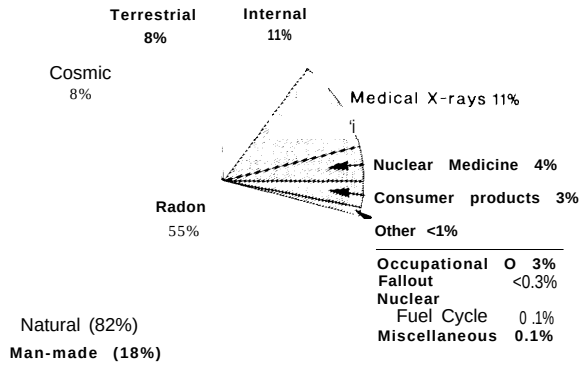
[7]Comment made by Patricia Robinson, LLW Program Manager, Electric Power Research Institute, at the *Fifth Annual Decisionmakers' Forum—Low-Level Radioactive Waste* ***Management*** *The Available Options and Costs,* Wild Dunes, South Carolina, June 6-8, 1989.

three times higher than Gulf Coast States such as Mississippi and Alabama. Increased exposure can also result from living in a brick or stone house versus wood due to radon gas released from stone and brick. On average, all natural sources of radiation together represent about 82 percent of all radiation an individual receives (1 1). (See figure 4-6.)

Individuals are also exposed to man-made sources of ionizing radiation, such as radiotherapy for disease and X-rays for medical and dental tests. As with natural sources of radiation, the level of radiation received by man-made sources varies greatly with the individual, For example, the radiation from diagnostic X-rays received for a lower gastrointestinal test is almost 10 times greater than that received for a chest X-ray (8). On average, these man-made sources of radiation for medical uses represent about 15 percent of all radiation an individual receives (1 1). (See figure 4-6.)

The remaining amount of ionizing radiation comes from industrial uses of radioactive materials, emissions from certain consumer products, radiation from fallout of previously conducted above-ground tests of nuclear weapons, nuclear power plant operations, and miscellaneous activities. The amount of radiation from all of these sources is estimated to be about 3 percent of the total (1 1). The amount of radiation from LLW is some fraction of 1 percent (1 1). (See figure 4-6.)

Figure 4-6-The Percentage Contribution of Various Radiation Sources to the Total Average Effective Dose Equivalent in the U.S. Population



SOURCE: National Council on Radiation Protection and Measurements, *Ionizing Radiation Exposures of the Population of the United States,* NCRP Report 93, Bethesda, MD, 1987, p. 55.

The Nature of Ionizing Radiation

There are three types of ionizing radiation—alpha particles, beta particles, and gamma rays or photons—that result from the decay of radionuclides. The radioactivity of radionuclides is measured in units called **curies,** with 1 curie describing the radiation from 1 gram of radium for 1 second, or about 37 billion disintegrations per second.[8]

Alpha radiation consists of positively charged, highly energized particles that rapidly lose energy when passing through matter. They are emitted from naturally occurring radioactive elements, such as radium and uranium, and from man-made elements such as plutonium. Alpha particles are larger and heavier than the particles of beta radiation. Alpha particles can be stopped by a sheet of paper or by human skin so that holding a piece of plutonium in your hand would be perfectly safe. If ingested or inhaled, however, alpha particles would damage internal tissues with grave consequences (see section on "Biological Responses to Radiation"). Inhalation of even tiny amounts of plutonium can cause lung cancer. Low-level radioactive waste generally does not contain alpha-producing radionuelides.

Beta radiation consists of smaller particles that travel more quickly in air and can penetrate several cell layers of skin. Beta radiation can be reduced or stopped by a layer of clothing or through the use of a few millimeters of aluminum, glass, or plastic shielding. Beta-emitting radionuclides are found in most LLW.

Gamma radiation is in a wave form like light and X-rays and consists of photons—small packets of energy that can travel great distances and penetrate matter. Gamma rays can pass through the human body or can be absorbed by tissue or bone. Three feet of concrete or 2 inches of lead will reduce or stop 90 percent of typical gamma radiation. Gamma photons are used in cancer treatment to destroy the cells of a tumor without causing major damage to healthy cells nearby. Gamma-emitting radionuclides are found in most LLW.

Radionuclides in LLW that emit both beta particles and gamma photons are classified as either beta emitters or gamma emitters according to which emitter is biologically more harmful. For example,

[8]The international unit for radioactivity is the becquerel (Bq), which equals one disintegration per second.

cobalt-60 is referred to as a gamma emitter because the accompanying beta radiation is biologically less damaging.

Measuring Radiation

The amount of ionization that a given quantity of radiation produces is the **exposure.** A common unit for measuring exposure is the roentgen; one roentgen is 2.58 x 10^{-4} coulombs per kilogram of air.

When radiation penetrates biological material it gives up its energy in a series of collisions or other interactions with the atoms of the material being irradiated. The consequences of these interactions may be the dislocation of atoms, the breaking of chemical bonds, or the loss of electrons. These molecular alterations may in turn impair the biological functions of the irradiated material. The amount of energy deposited in the material is the **absorbed dose.** A common unit used to measure absorbed dose is the **rad, an** abbreviation for radiation absorbed dose.[9] Note that exposure and absorbed dose are very different. Exposure describes a property of the radiation, while the absorbed dose describes something that happens to a particular material when the radiation is absorbed.

Biological Responses to Radiation

The amount of biological damage resulting from a particular absorbed dose is the **dose equivalent. The** dose equivalent depends on the kind, amount, and rate of the radiation; on the nature of the organism exposed; on the organism's age, sex, state of health, and surroundings; and on the particular biological effect being considered (10).

The dose equivalent is often referred to as simply the **dose,** when the absorbed dose is equivalent to the dose equivalent. This equivalence is generally true for X-rays, gamma rays, and for most beta particles (10). The major exception is alpha radiation, which can lead to more serious biological damage. Once alpha particles are absorbed by tissue, their large size and density and the slow speed at which they travel results in more energy being released in a smaller area. The radiation is, therefore, more concentrated and causes more damage. Since this study primarily deals with beta rays and gamma rays, the term dose is used for dose equivalent. Dose is measured in reins, or ''roentgen equivalent man."[10]

The average annual whole body dose to a person in the United States from natural and man-made sources is about 360 millirems (1 1).[11] An actual dose to any given individual could vary widely, however. Over the course of a lifetime, an individual may accumulate doses from background exposures of between 5 and 10 reins (6).

An excessive dose of radiation can result in somatic damage (i.e., damage to the cells of the body that compose the tissues and organs) and in genetic damage that can become hereditary. Somatic damage is most common in cells that divide more frequently, such as blood-forming cells of the bone marrow and cells that line the intestinal wall (10). The body concentrates certain radionuclides selectively in one or another organ (3). Iodine-129 and iodine-1 31, for example, concentrate in the thyroid; strontium-90 concentrates in the bone; and nickel-59 concentrates in the intestine. Radiation damage to these kinds of cells are caused mainly by the acute (short-term) effects of large doses of radiation.

Embryos are particularly sensitive to somatic effects from radiation. They are more susceptible to malformities and death than adults (6).

Cancer can result if cell reproduction is impaired by radiation and uncontrolled growth occurs. Leukemia and lung, breast, and thyroid cancers appear more common than other types of cancer due to radiation (6),

Radiation doses can also cause two types of genetic damage-whole chromosome damage and gene mutation. With whole chromosome damage, the number of chromosomes in a genetic cell may change or a chromosome may break, in which case the broken pieces may reattach in a way that leaves the chromosome's function impaired. With gene mutation, a gene may change such that the individual inheriting the gene demonstrates an observable malfunction such as mental retardation, or, more drastically, the gene may be so damaged that it cannot reproduce itself (10). Table 4-6 gives the types of effects that can be expected from certain ranges of radiation doses. Data have also been collected on actual doses that individuals have

[9] The international unit for absorbed dose is the gray (Gy), which is equal to one joule per kilogram. The rad is equal to 10^{-2} Gy.

[10] The international unit for dose is the sievert (Sv); a rem is equal to 10^{-2} Sv.

[11] A millirem is a one-thousandth of a rem (10-3 rem).

received on average from certain radiation events (e.g., doses to people from nuclear weapon tests, the dose to nuclear power plant workers on average, and the dose to survivors of the Japanese A-bomb explosions.

The Chernobyl reactor accident has provided invaluable information on health effects, As a result of Chernobyl, 237 individuals had radiation sickness in the Soviet Union. Of these 237 people, 31 died from the dose received. Of the 50,000 people who received 50 rads or more, 4,000 apparently received an average of 200 rads. Experts predict that over the next decade the fatal leukemia risk of this group of 4,000 is projected to increase by about 150 percent (l). The irradiated population is also at risk for genetic disorders in future generations. Up to 1,500 additional cases of genetic damage may be added to the 35 to 40 million normally expected in the population of Europe and the Soviet Union (l). Experts also predict a doubling of cases of radiation-induced severe mental retardation in children who lived in the area around Chernobyl (l).

Other actual radiation effects were seen in a group of women who painted radium watch dials in the 1920s. These women pointed their paint brushes with their lips to paint the fine numerals of the watch faces. By 1950, 41 deaths had been reported as a result of bone destruction and blood disorders caused by the radium absorbed in bone marrow (1 O).

Uncertainties in Estimating Health Effects From Low Radiation Doses

Some experts predict that small radiation doses given at very low dose rates do not necessarily produce an effect that is linearly proportional to the radiation dose (6). Furthermore, a given radiation dose delivered over a long period is generally less severe than the same dose delivered acutely (6). However, for several reasons it is difficult to precisely measure health effects from low radiation doses.

One reason is that health effect estimates are frequently calculated by extrapolating from measurements made at high exposures. Because health effect and dose are not linear, these calculations may not reflect actual effects at low dose levels. A conservative approach used by many experts is to assume a no-threshold linear model, with risk increasing linearly as dose increases (6).

Table 4-&Acute Health Effects Estimated From Whole Body Irradiation

Dose (reins)	Heath effect
5-20	Possible late effect; possible chromosomal aberrations
25-100	Blood changes
>50	Temporary sterility in males (>100rem = 1 year duration)
100	Double the incidence of genetic defects which is normally expected
100-200	Malaise, vomiting, diarrhea, and tiredness in a few hours; reduction in infection resistance, possible bone growth retardation in children.
200-300	Serious radiation sickness; bone marrow syndrome; hemorrhage; $LD_{10\text{-}35/30}$
>300	Permanent sterility in females
300-400	Resulting loss of blood defenses and vascular integrity; electrolyte imbalance; marrow/ intestine destruction; $LD_{50\text{-}70/30}$
400-1,000	Acute illness, early death; $LD_{60\text{-}95/30}$
1,000-5,000	Acute illness, early death in days; intestinal syndrome $LD_{100/10}$
>5,000	Acute illness; death, early death in hours t. **days; central** nervous syndrome; $LD_{100/2}$

*Lethal dose to percentage of the population in number **of days (for example, $LD_{10\text{-}35/30}$ =** lethal dose in 10 percent to 35 percent of the population in 30 days.

SOURCE: Adapted from Marvin Goldman, **"ionizing Radiation and Its** Risks," The *Western Journal of Medicine, vol.* 137, No 6, December 1982, pp. 540-547, and Gilbert W. Beebe, "Ionizing Radiation and Health," American *Scientist, vol. 70, No. 1,* January-February 1982, pp. 35-44,

Another reason is the difficulty of tracing a particular health effect to a particular low radiation dose. For example, if a person contracted lung cancer, it would be very difficult to determine the cause of the cancer if he/she lives in a house with an elevated radon level, has had multiple dental and medical tests using radionuclides in some form, and works in a nuclear power plant. It would be difficult to know whether all the sources of radiation were responsible for the cancer, or whether one source was more responsible than another.

Compounded environmental cancer risks from chemicals further complicate health matters, In the lung cancer example above, if the person smoked it would be extremely difficult to estimate what percentage each of the radiation doses and the chemical dose from smoking is responsible for the cancer. One source of dose may mask another or may exacerbate the overall impact to the individual. This potential synergism between physical risk from ionizing radiation and the potential environmental cancer risks from chemicals is not well understood (6).

Another problem with estimating low-dose health effects is the radiation latency factor—the time from a brief exposure to the first appearance of disease. For example, the minimal latent period for leukemia and bone cancer is 2 to 4 years. It may be 10 or more years for other types of cancer (2). The incidence of leukemia among Japanese A-bomb survivors reached a peak 6 years after the explosion. Most solid tumors require 10 to 20 years to develop (10).

A further complication is that much of our data is based on animal studies (8). For humans, the full significance of age and sex on cancer response is not known, nor is the significance of biologic factors such as immune competence, hormonal status, capacity for DNA repair, and genetic composition.

Finally, conducting a valid epidemiologic study is difficult because of too small an exposure group and because of the time necessary to conduct a study. In most cases of radiation exposure events, the population size is too small to conduct a study where statistically significant risk estimates can be calculated. The exceptions are victims and survivors of the Japanese A-bombs and Chernobyl accident. Even with these two events, health effect estimates for the low-dose population are difficult to calculate because of the competing unrelated sources of radiation exposure and environmental risks from chemicals.

With respect to LLW disposal, no actual data on radiation exposures to the general public from past disposal practices exists. The collective dose to nearby residents is calculated to be well below the operating limits established by the Nuclear Regulatory Commission (NRC). Furthermore, no member of the public is known to have received a measurable radiation dose from disposal practices. Workers at the disposal sites during the operational period of the site receive the greatest dose. Workers wear radiation detection devices to ensure that the exposure they receive is below the allowable limits set by NRC. NRC requires that at all times exposure be kept as low as reasonably achievable (ALARA).

The ALARA concept developed from the scientific consensus that there is no clearly definable threshold level of exposure. The ALARA concept requires that the cost of achieving an incremental reduction below regulatory limits be weighed against the benefit received in terms of reduced occupational or population exposures (3). At LLW disposal sites, ALARA has influenced:

- imposition of engineered controls and barriers to limit effluent releases,
- the improvement of instrumentation to validate lower objectives for allowable concentrations in conjunction with enhanced monitoring of the workplace and the surrounding regions, and
- evolution of radiation protection programs in the facilities designed specifically to achieve ALARA conditions (3).

A Department of Energy study estimates that the highest dose rate to the maximally exposed member of the public from a properly functioning LLW disposal facility would be 10 millirems per year (15). The collective dose rate to nearby residents would be much lower. If a LLW disposal facility had a major failure, it is estimated that a maximally exposed member of the public could receive as much as 500 millirems per year (8). This **dose** rate is equal to the limit that a worker is allowed to receive within 1 year in the unrestricted areas of a site (10 CFR Part 20). In a restricted area, a worker may receive a dose an order of magnitude higher. Even at the 500 millirem dose rate, however, the facility would have to be remediated immediately; therefore, this dose rate would not be expected to continue.

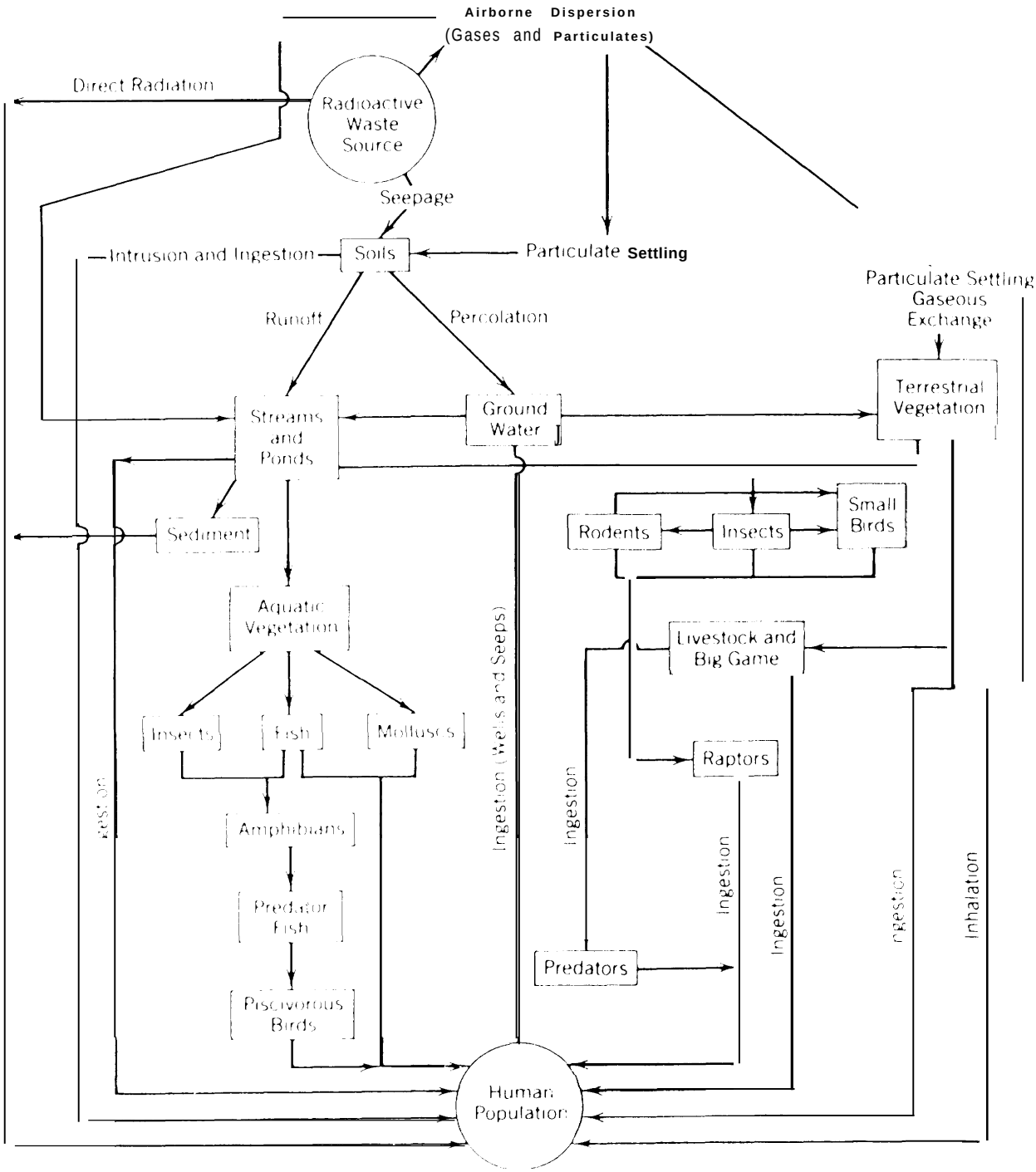
Migration Pathways and Mechanisms of Radiation Exposure

Figure 4-7 outlines the migration pathways and mechanisms of human exposure from radionuclides in a LLW disposal site, These pathways include seepage or runoff from surface water, groundwater transport, and atmospheric transport. Computer analyses indicate that the groundwater is the major pathway at humid sites (8). No single pathway appears to be dominant for dry sites.

The primary mechanisms for human exposure include:

- direct radiation of individuals near the source or near disposed material;
- inhalation of emissions dispersed directly into the air;
- direct ingestion of groundwater and/or surface water;
- ingestion of contaminated vegetation on which particulate have settled, or where gaseous exchange has occurred, or which have grown in concentrated soils; and
- ingestion of fauna (e.g., livestock, fish) in the food chain that have ingested and concentrated

Figure +7—Pathway Analysis to Biota and Man: Generation and Disposal Locations on Common Site



SOURCE. Robert E Berlin and Catherine S Stanton, Radioactive *Waste* Management (New York NY John Wiley & Sons, Inc. 1989), p 128

radionuclides from a lower species in the chain. (3)

As noted above, the annual dose to an individual would likely not exceed 10 millirems for a properly operating facility and would not exceed 500 millirems in case of an accident. NRC sets the annual dose limit of a LLW disposal site at 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to arty other organ (10 CFR Part 61). Some States have set their site annual dose limits much lower—at 1 millirem in the Central Midwest Compact and at background levels for the Appalachian Compact (see ch. 2). Releases that would result in doses above these levels would require immediate remediation.

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