1. INTRODUCTION

General definition of radioactive waste (Berlin 1989)

Any material that is no longer useful and that contains radioactive isotopes is, by rigorous definition, radioactive waste. A radioactive isotope emits energy in the form of ionizing radiation. The isotopes are characterized by the type of emission - alpha, beta, gamma, neutron - as well as the frequency of decay and energy of the emitted radiation. The half-life of the isotope defines the length of time in which half of the material will have decayed. The health effects that result from exposure to a given isotope are based on all of these factors as well as the chemical and physical form of the material and the method of exposure. That is, impacts will differ depending on whether the source is external to the receptor or it is ingested, inhaled, absorbed through the skin, or introduced by some other method. Such definition was less than useful, as demonstrated when the Oregon legislature passed an ordinance aimed at preventing the development of a RW disposal facility in the state by banning the burial of radioactive materials. Because we live in a naturally radioactive world the statute, if interpreted literally, would have prevented all human interments as well as RW disposal facilities. Clearly, some narrower limits are needed to define both the potential risk and practical technologies for management and disposal of RW. For purposes of this text RW is defined as any material that is no longer useful and that contains radioactive isotopes in amounts recognized by regulatory authorities as posing a potential risk to human health and the environment sufficient to warrant its isolation from the biosphere.

This definition is deceptively simple. It condenses into one sentence considerations addressed in dozens of federal and state laws and regulations. It allows the consideration of material whether of natural or man-made origin. It freezes the frame of reference at the mid to late 1980s. It addresses the reality of the involvement of social issues as well as the purely "technical" issues with which the reader may be more used to dealing. As will be developed in the text, each of these factors plays an important role in defining RW management as practised today and as will be practised in new facilities now being designed and developed. The options available for managing a specific waste stream reflect consideration of the agent responsible for its generation, its current condition, the population at risk, and the cost of isolation (including any necessary intermediate processing) both in dollars and in occupational exposure. The objective of this text is to provide a single source of information on what is in reality many technological specialties. A quick review of the references cited will show that hundreds of volumes have been devoted to the subject of RW. This text will serve as a guide to much of this more specialized material by providing engineering, regulatory, and health and environmental protection professionals and students with a basic understanding of the characteristics of the materials

important to choosing among available management options as well as the reasons for actions already taken or currently underway.

The general definition of RW provided excludes routine releases of radioactive materials from facilities such as hospitals, power reactors, and industrial installations since regulatory authorities have effectively judged that these releases present potential risks sufficiently low that further isolation (with existing technology) is not required. It includes, however, different sources of waste frequently not considered in a single volume because of different regulatory jurisdictions. For example, the Atomic Energy Act delegates responsibility for waste resulting from nuclear reactor-produced radioisotopes to the Nuclear Regulatory Commission (NRC). Those same isotopes would not be subject to NRC licensing if produced in a linear accelerator.

A key phrase in the definition is "recognized by regulatory authorities." Many of the waste streams described in the text were not initially considered to require subsequent isolation. For example, waste material produced by separating radium from ore and producing luminous products or sealed radiation sources predated the establishment of federal and state regulations and its management was not always well documented. The result has been the identification of several geographic areas requiring evaluation, and large volumes of material that have been subsequently treated and/or relocated. On the other hand, as a result of current efforts to quantify waste streams that contain radioactive materials at "de minimis" levels (levels at which the potential risk from disposal as nonradioactive is below regulatory concern) several of the waste streams discussed in the text may no longer require isolation in the future. One of the main themes of this text is that the field of RW is dynamic, not static. Management decisions reflect risk-benefit and cost-effectiveness evaluations that will change with time as new lessons are learned from operating experience and technological advances increase the choices available. It is entirely possible, for example, that a new requirement for, or application of, a particular isotope or group of isotopes could make reprocessing of spent fuel and recycling of the isotopes a viable option in the future; waste management needs would therefore change accordingly.

Nature and magnitude of the waste management "problem" (Berlin 1989)

Radioactive waste has been-and currently is being-produced by both government and private sources. It consists of large volumes of material containing relatively low concentrations of radioisotopes as well as smaller volumes of more highly concentrated materials. The external radiation levels at a container's surface vary from unmeasurable to levels that would provide lethal exposure and therefore require substantial shielding for handling, shipment, and disposal. The length of time for which isolation is required can vary from days to thousands of years, depending on the specific isotopes contained and the amounts in

which they are present. These differences mean that there are, in reality, several RW management "problems."

Volume

Compared to other waste management needs with which society is faced, RW is relatively limited in scope. For example, sanitary landfills used by many municipalities throughout the country are reaching their capacity. Resistance to developing new facilities to replace those filled up, and in some cases the costs for their development, has resulted in waste being transported to other states for disposal. In one extreme example of the problems involved, a town on Long Island, New York, contracted with a hauler to have removed by barge for disposal elsewhere 3,100 tons of garbage that otherwise would have been placed in the municipal landfill. The barge was denied access to the originally planned disposal site in North Carolina at which it was hoped to use the material to demonstrate the feasibility and economics of recovering methane produced from the decomposition of the waste and using the recovered gas for energy. The barge then set out on a months-long odyssey south along the eastern coast of the United States and through the Caribbean Sea and the Gulf of Mexico seeking a state or country that would allow a disposal facility to accept the waste. It eventually returned and anchored in New York Harbour where its further progress was the subject of multiple court rulings and administrative agreements. Eventual disposition was through incineration in a New York City operated incinerator and disposal of the ash in a landfill in the town from which it originated. By comparison, the total LLW volume disposed at commercial facilities in 1986 was approximately two million cf^3 (6E+7 l). Assuming an average density of 30 lb/ft^3 (480 g/l), the total weight of LLW disposed nationally in 1986 was less than 30,000 tons or less than 10 times the amount on that one barge. In terms of necessary disposal area, RW management needs are also relatively small. Current plans for a high-level RW repository to receive spent fuel rods and defense HLW produced through about 2015 are based on use of a 2000-acre (8 km^2) site. Similarly, a reference low-level RW disposal facility capable of accepting about 35 million cf^3 (1E+6 m^3) of waste over a 20-y period would occupy about 200 acres (0.8 km^2), much of which would be a buffer between the actual disposal area and the site boundary. In contrast, municipal waste was being generated in the State of New York in the early 1980s at the rate of about 15 million tons annually and required the commitment of approximately 400 acres (1.6 km^2) annually for sanitary landfills. However, it is currently expected that there will be multiple LLW sites around the country and the size of each is likely to be at least 100 acres (0.4 km^2) because of buffer zone requirements between the actual disposal area and the site boundary. However, land use considerations are nominal even under such a dispersed disposal system. With respect to the need to provide a management system to isolate the waste from man and his environment, RW may be more appropriately compared to hazardous waste than to general

municipal waste. Hazardous wastes regulated under the Resource Conservation and Recovery Act are produced at a rate of about 150 million metric tons per year according to the Environmental Protection Agency (1985).

Degree of hazard

There is a fundamental difference in the comparison because hazardous waste facilities are designed to retain the material within the disposal unit whereas the underlying philosophy behind RW disposal (of whatever waste type) is that man-made barriers will eventually fail and the site conditions must be a primary barrier to contact between the contained radioactive material and the biosphere. It should also be noted that the degree of hazard of RW decreases with time as decay proceeds. However, the time periods for which isolation is planned-on the order of several hundreds to several thousands of years depending on the waste type considered-exceed the lifetime of most structures and even institutions with which we are familiar. The engineering and institutional arrangements required to isolate this material successfully are new and developing rather than being based on a body of knowledge that can be applied from previous experience. Hazardous wastes, on the other hand, effectively have an infinite half-life and so the tasks being addressed in the field of RW management are far from unique.

A further distinction must be made between the options available to manage waste currently being produced or expected to be produced in the future and those applicable to material either previously disposed and requiring remediation or now in storage and requiring processing prior to final disposition. Both conditions exist for all waste types. High-level waste originally produced with the expectation of long-term care as a liquid in underground tanks is being removed and solidified for subsequent disposal, whereas newly produced material whether reprocessed defense waste or commercial spent fuel rods-will be encapsulated for disposal in a geological repository. Some previously produced transuranic waste has been processed for disposal along with newly produced waste, whereas other such material, originally disposed of by directly releasing it to the ground, is being evaluated for the usefulness of alternatives such as excavation and removal or fusing it in place by application of electric current to the ground in which it is located. At least one previously operated commercial LLW disposal facility will continue to be the subject of efforts to stabilize the contained material and achieve an essentially passive monitoring status. Newly developed facilities will be sited and designed with such conditions built in. Similar considerations will be addressed in new facilities for handling waste material from mining and milling of uranium and thorium ores and phosphate deposits, while methods for retrieving, stabilizing, and/or isolating existing wastes are being applied where necessary to protect public health and safety.

Basic objectives of waste management (IAEA 1981)

The objective in conditioning the waste is to immobilize the radionuclides and to package the waste in order to make it safer for handling, storage, transport and disposal. The conditioned waste (i.e. the immobilized waste form, its container and other packaging) and the geological environment of the waste repository are barriers in the potential pathways of waste constituents to the environment. The final choice of the form of the conditioned waste should take into account any detriment associated with the conditioning processes. Desirable characteristics of the conditioned waste are: stability against chemical, mechanical, thermal, radiation and biological degradation, non-combustibility, low solubility or leachability in groundwater, low specific surface area, dust-free state and freedom from surface contamination, minimum practical volume, safety from nuclear criticality and appropriate packaging for ease of handling and transportation. Particularly important properties of the conditioned waste are: the leach rate of the immobilized waste form and the corrosion rate of the containers) in water of any composition for the period of concern; and the potential of the waste form to break down to material of greater specific surface area.

Classification of radioactive wastes (IAEA 1970)

Radioactive wastes may be classified according a number of different criteria :
activity - high, medium or intermediate, low
phase - solid, liquid or gaseous
origin - spent fuel, operational, decontamination, decommissioning, research, medical waste;
general characteristics - fission products, actinides, heat-producing etc;
lifetime - short or long lived
designation - the disposal route used for the waste.

The terms low-level, intermediate-level and high-level RWs are widely used to describe different concentrations of radioactive materials in wastes. Unfortunately, these terms do not have quantitative definitions and in this way confusion arises when reference is made,simply to high, low or medium-level wastes undefined by concentration or radioactivity level. In various individual countries different considerations have determined the system of classification used for RW. These considerations include environmental limitations for the acceptance of waste and existing operational situations in terms of waste type and waste treatment systems. The different systems in turn lead to different regulations and make it much less easy for communication between countries on waste management topics. Only very few countries, in their legal regulations, have defined the categories of wastes. The terminology is not precise and this may result in an obscurity between waste management staff and health and safety inspection as far as interpretation of such regulations is concerned. The precise standardization of waste categories is a difficult and complex

problem with many opposing views already within one country and the more so on an international scale.

As the first step, classification of waste categories should help people who have to operate waste treatment plants so as to have a common language among themselves. This is the main aim of the standard waste categories proposal which is presented. The information submitted by eleven countries concerning their present systems for the classification of RWs has been examined. There are no countries that have the same classification system and even within one country it may be different. The approach to the classification varies and seems to be dependent on the state of nuclear industry development. There are no countries with official classification of RWs and any regulation of this type. In one country (Japan) there exists the semi-official classification of RWs that was recommended by a special scientific group of the national Atomic Energy Commission. In the US, the US Standards Institute, a private organization sponsored by many US scientific societies and industries, has adopted a standard based on MPC (maximum permissible concentration. Two countries have legal definitions of what is RW and what is not. Varying classifications of liquid effluents are based on treatment, possibilities of discharge into the environment, or ICRP standards. The classification of solid wastes is based on preconditioning and transportation standards. Gaseous effluents have been classified on the basis of the system employed, the quantity of material released, and in terms of multiples of MPC.

Premises of waste standardization

The approach to standardization can be made from different points of view. The categories can be proposed on the basis of health and safety requirements, in accordance with practical experience at waste treatment plants or according to the regulations for the safe transport of radioactive materials. On an international scale the differences between legal regulations are very considerable especially as far as application of MPC is concerned. From all these points of view the proposal of standard categories of RWs must be understood as a flexible proposal, based on the present knowledge and practical experience. With further experience it may be necessary to revise this first proposal. It is not intended to recommend the standard categories to be converted into national regulations, but to use them mainly for improving communication between workers within the nuclear energy industry. The problem of the establishment of national regulations is better left to the responsibility of individual nations or groups of nations. The categorization cannot serve directly as a basis for waste treatment and disposal or definition of safety after discharge, but rather to provide descriptive information about the character of the waste.

Definition of waste categories by MPC

In considering possible methods of defining categories of RWs, the first major alternative considered was the use of the radioactivity content expressed as a ratio of the maximum permissible concentration (MPC). This would have the apparent advantage of including some thought of radiotoxicity. However, MPC of wastes is not, in itself, sufficient information to evaluate the radiation exposures which would eventually result from either intentional release or accidental leakage of the wastes. Having in mind that the primary purpose of the categorization is communication, the use of activity concentration as the basis for categorization, rather than the multiplication factors of MPC values for liquids and gases, was agreed upon as a compromise. Because of widely varying interpretation of the terms low, medium and high, the categories of all types of waste should be identified by number, in order to avoid further confusion by the aide of the existing terminology.

Solid radioactive wastes

The classification of solid wastes is complicated because in different countries different bases are used. In France the solid wastes are classified according to type of container in which wastes are stored so that the exposure dose rate is less than 200 mR/h at contact and 10 mR/h at 1 metre (10 cm concrete wall - low active, 40 cm concrete wall - medium active, lead shielding - high active). In Japan the classification is based on the activity per volume (> 1 mCi/cm^3 - high active, 1 to 0.001 mCi/cm^3 - intermediate active, 1 to 1000 nCi/cm^3 - low active); in Sweden and the UK the activity (mCi) per container is sometimes the basis and in the USSR the activity per unit weight. While the classification of liquid effluents takes into account mainly treatment and discharge into the environment, for solid wastes new factors have to be considered, such as handling and transportation before and after treatment. For the classification of solid wastes the present systems were examined and also considered were the basic parameters which might be involved in categorizing solid wastes. Amongst these were the composition of the waste, which may differ depending upon the nature of the process or laboratory from which it arises. Usually, high-level alpha emitters are segregated from beta and gamma emitters although this may not always be the case. At lower levels, mixtures may occur more frequently but usually, in both cases, one or other of alpha or beta-gamma emitters predominate, and the waste may be categorized in a simple way as one or the other, depending which is more important. Solid wastes may be combustible or non-combustible and are frequently not homogeneous. Activity in such waste may be difficult to measure and, therefore, to classify in terms of activity per unit volume or weight is not satisfactory. Waste combining gamma and gamma plus beta emitters can usually be estimated by measurement of the radiation dose rate and only in the case of pure alpha emitters is this impracticable.

The radiation dose rate may be measured either at the surface of the waste or of its container. In transport regulations the dose

rates at the surface and at one metre from the surface of the container are utilized. Since a measurement made in this way involves the characteristics of the container, e. g. thickness of walls, and nature of construction, the basic nature of the waste may be more difficult to determine from radiation measurements and some beta emitters may remain undetected. Following detailed consideration of these factors the categorization of solid RWs was recommended using the radiation dose rate at the surface for beta and gamma emitters. For some alpha emitters the problem of criticality must also be considered. The overall measurement of the content of a container is always vague and estimates may have a 100% error, therefore the safety coefficient from the point of view of criticality must be considered. The use of the same maximum amount of fissile materials in solid wastes as is given in additional requirements for packages containing fissile material is recommended. In making these recommendations, it is recognized that a practical form of categorization can never define the exact nature of the waste and at best only forms a system which roughly defines the major characteristics of the waste under discussion. It is recommended to classify solid wastes into four categories which comprise solid RW with:

1: beta and gamma emitters and an insignificant amount of alpha emitters whose radiation dose on the surface is not higher than 0.2 R/h. Such solid wastes can usually be handled and transported without any special precautions.

2: beta and gamma emitters and an insignificant amount of alpha emitters whose radiation dose on the surface is higher than 0.2 R/h and equal or lower than 2 R/h. Such solid waste can usually be transported in simple containers shielded with a thin layer of concrete or lead.

3: beta and gamma emitters and an insignificant amount of alpha emitters whose radiation dose on the surface is higher than 2 R/h. Such solid wastes can be handled and transported only if special precautions are taken.

4: dominant alpha emitters and an insignificant amount of beta and gamma emitters which are not suspect from the point of view of criticality. The activity should be expressed in Ci/m^3.

Categories 1, 2 and 3 include beta and gamma activity with insignificant amounts of alpha emitters and category 4 alpha activity with insignificant amounts of beta and gamma emitters. The classification of solid RWs has two specific limitations: unlike the categories for liquid and gaseous wastes, the numbers do not represent increasing significance relative to a constant parameter; no category is provided for waste packages containing both alpha emitters and beta/gamma emitters.

Liquid radioactive wastes

It is common to categorize liquid wastes as 'low', 'medium', and 'high' activity. This categorization may differ within countries and the range of variation which may occur within, as well as between, countries is large. For example, the upper limit

for 'low' active liquid waste ranges between 1E-4 Ci/m^3 and 1E-1 Ci/m^3, and the lower limit of 'high' active liquid wastes between 1E-1 and 1E+3 Ci/m^3. Thus 'high' active wastes in Poland might be designated 'low' active in some establishments in the United Kingdom and Norway, while being considered intermediate or medium in other countries. Bearing in mind the primary requirement for the categorization, to improve international communication, the simplest system of classification of liquid wastes by arbitrary activity concentration levels is recommended. The concentration should be expressed in microCi/ml or Ci/m^3. The proposal of categories of liquid RW contains 5 categories which comprises liquid wastes whose radionuclides concentration is:
1: equal or below 1E-6 mcCi/ml. Liquid effluents are not normally treated but discharged directly into the environment.
2: higher than 1E-6 mcCi/ml and equal or lower than 1E-3 mcCi/ml. Liquid effluents are normally treated by usual methods and shielding of equipment is not necessary.
3: higher than 1E-3 mcCi/ml and equal or lower than 1E-1 mcCi/ml. Liquid effluents are treated by usual methods and shielding of parts of equipment is sometimes needed.
4: higher than 1E-1 mcCi/ml and equal or lower than 10 mCi/ml. Liquid effluents are treated by usual methods and shielding of equipment is necessary.
5: higher than 10 mCi/ml. Liquid effluents are stored and cooling is necessary.

Gaseous radioactive wastes

The experience gained in the classification of gaseous effluents is very limited. There exist considerable differences in activity levels and composition of gaseous effluents, but the range of activity is narrow and methods of treatment are few in comparison with liquid effluents. Gaseous effluents are usually not classified but only described by the total activity and activity per unit volume. In many countries gaseous wastes are not classified at all, sometimes the classification is connected with the ventilation system and effluents are classified in accordance with the origin. The present experience with handling of gaseous effluents is relatively small in comparison with liquid and solid wastes. The range of activity is restricted and methods of treatment are few but nevertheless there exist considerable differences in activity levels and composition of gaseous effluents that justify the classification of gaseous wastes into several categories.

From the hazard point of view, the total activity discharged is of importance and not concentration. The effects of total discharges, however, depend upon many local modifying factors such as location and height of stack, wind direction and wind speed. Since total activity does not usually have any significance in gaseous waste handling, it is accepted that classification by activity concentration appeared to offer the only solution if discharges are to be classified. In the absence of any suitable

alternative, it was recommended that the classification of gaseous wastes should be based on the same units as for liquid wastes, i. e. mcCi/ml or Ci/m^3 and also on the method of treatment before discharge. The classification of gaseous wastes contains 3 categories which comprise gaseous effluents whose radionuclides concentration is:
1: lower than 1E-10 Ci/m^3. These gaseous effluents are usually not treated but discharged directly into the air.
2: higher than 1E-10 Ci/m^3 and equal or lower than 1E-6 Ci/m^3. The radioactivity is connected mainly with particles and gaseous effluents are usually treated by simple filtration.
3: higher than 1E-6 Ci/m^3. The radioactivity is connected mainly with gases and gaseous effluents are usually treated with filtration in connection with other methods.

Table 1 Classification of radioactive waste (Ci/m^3)

Category	gas	liquid	solid
not treated	< 1E-10	< 1E-6	<0.2 R/h
low	1E-10	1E-6,1E-3	0.0-2 R/h
medium	1E-6	1E-3,1E+4	>2 R/h
high	> 1E-6	> 1E+4	alpha

Radioactive waste forms and sources (Berlin 1989)

Radioactive waste is generally described under a variety of classification systems that identify considerations such as the source of the waste (e.g., government, industrial, or academic uses), the relative radiological concerns in handling or disposing of the waste (the high-level and low-level waste distinctions), the actual materials contained therein (such as transuranic wastes and uranium mill tailings), or the procedures that produced the waste (such as decontamination and decommissioning wastes). This classification process is an attempt to group material by characteristics related to methods of production or that may require different methods for packaging, transport and handling, as well as for disposal itself. Characteristics such as external radiation level, half-lives of contained radioisotopes, and, ultimately, the potential health risk from exposures to a specific radioisotope through a specific pathway (such as drinking water, or breathing air containing suspended particulates) are critical inputs to the design, operation, and construction of a successful management and disposal system. In reality, each category includes a range of material types that must often be handled on a case-by-case basis. No single unit such as volume or curies gives enough information by itself on which to base management decisions. However, there are substantial similarities among many waste types and these similarities are used as a point of departure for more detailed studies. The following sections describe the sources of

RW, the fundamental differences between high-level waste (HLW), transuranic waste (TRU), low-level waste (LLW), and waste produced as a by-product of mining other natural minerals such as uranium and phosphates. This breakdown parallels the organization of agency responsibilities and regulations developed to manage these wastes at the federal and state levels.

Radioactive waste results from a wide range of processes and applications in which radioactive materials are used. Such processes are an integral part of current U.S. society and RW generators include the federal and local governments, electric utilities, private industry, hospitals and universities, and mining and milling operations in which the waste material (tailings) contains naturally occurring radioactive material, generally uranium and thorium and their decay products. As discussed below, there is considerable overlap in these distinctions and in evaluating data based on them care must be used to avoid double counting of wastes with different descriptions or inaccurate characterization of a given waste stream.

Nuclear fuel cycle

Nuclear fuel cycle wastes can be considered to include any waste material produced incident to generating electric power using nuclear fuel. This definition would consider uranium mine and mill tailings, waste from conversion, enrichment, and fuel fabrication facilities, waste produced during operation of a nuclear power reactor, spent nuclear fuel, and waste from decontamination and decommissioning of nuclear power reactors and other facilities in the nuclear fuel cycle. The current fuel cycle in the United States considers spent fuel as a waste rather than an energy source. Provision is made, therefore, for direct disposal of spent fuel. Depending on how data are compiled and reported, some of this material may also be classified as industrial waste and uranium mine and mill tailings. As interest in RW management has grown in recent years, greater attention has been devoted to identifying and standardizing reports of waste requiring management and disposal. For the portion of the waste identified as "low level" fuel cycle waste is generally reported as that from nuclear power reactors with the remainder of the fuel cycle being considered as producing industrial waste. Uranium mine and mill tailings are considered separately because of the extremely large volumes involved and the history of development and regulation that differed from other materials.

Industry

Industrial firms may generate RW directly as a result of the production processes in which they are engaged, as a result of research into new or improved products, and/or from instrumentation used for quality assurance or process control. Production processes include such diverse operations as manufacture of radiopharmaceuticals or compounds labelled with radioisotopes as

well as consumer products such as smoke detectors and luminous watch dials. In some cases, particularly for sealed sources used for nondestructive testing (radiography), manufacturers will accept the product back at the end of its useful lifetime and arrange for disposal of the contained, and no longer useful to the customer, radioactive material. The manufacturer may be able to recover and recycle the radioisotopes rather than disposing of them immediately. Defense wastes are primarily the result of the facilities and processes necessary to maintain the nation's weapons arsenal and fuel nuclear powered naval vessels. They include the high-level waste from extracting the uranium and plutonium used for the weapons themselves, materials containing transuranic wastes in concentrations greater than 100 nCi/g, and low-level process waste produced in shaping the material and incidental waste such as compacted trash generated from running the production facilities. Defense wastes are frequently discussed as a separate waste type because the activities that produce them, the administrative agencies responsible for their management, the safety rules to which they are subject, and the funds for their management are all separate from those that apply to commercial waste. Preferred waste management strategies and alternatives will frequently be different for defense and commercial wastes because of these institutional differences. In this text, however, defense wastes are discussed in the sections relating to waste with similar characteristics (HLW, LLW, TRU) rather than as a separate waste type.

Institutions (Berlin 1989, Murray 1989)

Wastes produced at medical and academic facilities are generally sufficiently similar (for purposes of disposal facility design and operation) in chemical and physical form and concentrations of radioisotopes to be considered together as institutional waste. Processes resulting in the production of such waste include medical diagnosis and therapy, usually using radioisotopes that are injected, ingested, or implanted into the patient. Radiation therapy may also involve use of large sources of penetrating radiation (frequently cobalt-60). The useful life of such sources is a function of the isotope's half-life and the exposure times needed to achieve the desired therapeutic results. Medical and academic researchers use radioactive materials and produce RW in projects that have addressed questions such as crop productivity, nutritive value of foods, sickle cell anaemia, and cancer. Medical wastes include animal carcasses and other biological waste, trash, various liquids, sealed radiation sources, and technetium-99m generators. One special type of liquid waste is scintillation detector fluid used as tracers in biomedical research and medical tests, and for measurements of radiation. Millions of vials of these solutions, used for counting radioactivity, are disposed of each year. They typically contain the chemicals toluene or xylene, with a small proportion of tritium or carbon-14. The beta decay of these isotopes triggers the release of light that is detected by a sensor. The total annual activity in scintillation

vials in the U.S. is small, only about ten curies per year, but because of their chemical nature, they often pose a disposal problem. In some cases the fluids have a low enough activity that they can be disposed of in a sanitary sewer. Disposal sites will not accept such liquids for burial. Incineration is regarded as the best method of disposal.

The radioisotope most widely used as a tracer for medical diagnosis is technetium-99m, half-life 6 h. This gamma emitter is extracted from a longer-lived isotope molybdenum-99, half-life 66 h. The Tc-99m is said to be "milked" from the Mo-99 "cow." The half-life of technetium is so short that holding any residues or contaminated material for decay is preferable to shipment to a disposal site. Reduction by a factor of more than a million occurs in 10 half-lives, which is only 2.5 days for this isotope. Rather than dispose of the generator (as the Mo-99 source is called) when it has weakened, it is preferable to send it back to the supplier, who will combine material to produce a new generator. Several medical isotopes have half-lives of only a few days; these can be held for decay and thus pose no disposal problem. Some institutions have tended, however, to ship such wastes away for disposal to avoid the need for monitoring and surveillance. Only iodine-125 (60 day) has too long a half-life for convenient long-term storage. In bioresearch, however, the most important isotopes are tritium (12.3 years) and carbon-14 (5730 years), which must be disposed of by other means. Although it is generally assumed that all radioactivity should be avoided and controlled, there are amounts so low that they can safely be ignored. These are treated as exempt by the NRC in the Code of Federal Regulations, Parts 30.14 to 30.19. Examples are 1 microcurie (mcCi) of cobalt-60 and 5 mcCi of cesium-137. Also scintillation detector fluids or animal carcasses may be disposed of as ordinary biological wastes if the tritium or carbon-14 content is less than 0.05 pCi per gram, with certain limits on annual disposal. Such amounts are termed de minimis; this comes from the Latin phrase "de minimis non curat lex" and is translated as "the law does not concern itself with trifles." A similar term is "below regulatory concern."

Mines

Uranium is a relatively abundant mineral in the earth's surface. It is about as common as tin. Unlike many other elements, however, the processes by which uranium deposits were formed resulted in its being fairly widely dispersed among other rocks rather than existing in large concentrated deposits such as occur with copper. Phosphate rock deposits, in particular, frequently contain sufficiently high concentrations of uranium that, when the deposits are processed to extract the nonradioactive ore, the residue or tailings from the process must be managed to achieve isolation of the uranium and daughter products contained therein. There have been times when uranium prices were sufficiently high that it was recovered as a by-product of phosphate production.

High-level waste in the U.S. (Berlin 1989)

Until the 1970s the only specific definition of a RW type that existed was that for high-level waste (HLW). This definition is contained in Appendix F to the NRC regulations on power reactors and fuel reprocessing plants (10 CFR Part 50). Under this definition, HLW is the aqueous waste resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels. All other waste was defined by default as "other than high level." This is a functional rather than an analytical definition of the HLW. That is, it is perfectly clear that the product of this portion of the reprocessing operation is "high-level waste." However, the exact isotopic and chemical content of the material depends on the type of fuel reprocessed, the operating history of the fuel (how long it was in the reactor and at what power levels), the length of time between removal from the reactor and reprocessing, and the reprocessing technology and solidification method used. The definition of "high-level waste" was administratively broadened by the U.S. Nuclear Regulatory Commission (NRC) in 1981 to include irradiated reactor fuel, liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and solids into which such liquid wastes have been converted.

This change recognized the fact that in the United States there was no reprocessing capacity commercially available and no prospect for near-term resumption of commercial reprocessing. By this definition, high-level waste includes waste produced from the reprocessing of fuel irradiated in government facilities for weapons production, similar waste produced in a commercial reprocessing facility (operation of which ceased in the United States in 1971), and unreprocessed spent fuel. Reprocessing waste was originally stored in liquid form in underground tanks at the reprocessing facilities. Government facilities [now the responsibility of the Department of Energy] are located in Richland, Washington, Idaho Falls, Idaho, and Savannah River, South Carolina. The only commercial reprocessing facility to operate in the United States (from 1966 to 1971) was located at West Valley, New York. Work is underway to solidify all of the liquid waste at each of these sites for eventual disposal in a geologic repository.

Spent fuel (Berlin 1989)

Once fuel has achieved its design power output in a reactor, it is removed from the core and stored on site underwater in a spent fuel storage pool. The fuel contains highly radioactive fission products and the radiation levels require substantial shielding from workers. The fuel is also physically (thermally) hot as a result of the decay of the fission products. Residual activity

at shutdown produces approximately 6% of the power level of the fully operational core. Because of this residual heat production, fuel rods must be cooled even after the fission reaction ceases. Failure to maintain such cooling was the cause of the fuel damage at the Three Mile Island nuclear power plant. All on site operations involving the spent fuel are performed remotely with the fuel remaining underwater to provide both radiation shielding and cooling. Current policy is for the fuel to be transferred eventually to the DOE for disposal. Radioisotopic concentrations in spent fuel are used to develop the shielding requirements, handling procedures, and package heat loadings for spent fuel during transport to a repository as well as to evaluate post disposal performance. Computer codes are used to model the initial fuel content and any changes due to irradiation in the reactor and decay subsequent to removal from the reactor. Computer codes such as ORIGEN (the Oak Ridge Isotope Generation and Depletion code) have been benchmarked to actual conditions in operating reactors and in laboratory analysis of waste samples and spent fuel and are good projections of actual radioisotopic distributions that will exist.

Adequate detailed characterization is needed for several purposes including a developing procedures for packaging and shipping the waste from point of origin to the disposal site in accordance with NRC and Department of Transportation (DOT) regulations, designing the disposal package, specifying waste acceptance and handling procedures on site at the repository and projecting long-term (10,000 y) performance of the waste package in the repository, and of the geologic medium of the repository.

The isotopic analysis of the waste as received is the fundamental input to calculations of the effects of radiation on the waste package, of heat generation and related impact on the host medium (for crystalline rock media, such as granite, the heat load is the limiting condition for the amount of waste that can be emplaced in a given area), and of isotopes present and available for leaching and migration assuming package failure at any given time after emplacement. Table bellow lists the fuel content of major isotopes that contribute significantly to off site doses from a spent fuel repository and the thermal power produced from one metric ton of uranium (MTU) in pressurized water reactor (PWR) fuel. For perspective, a nominal reactor loading would require about 27 MTU each year.

Table 2 Radioactivity (Ci) in Spent LWR Fuel per One Metric Ton of Uranium in Fresh Fuel 0 and 5 years after discharge, Calculated with the ORIGEN code for PWR fuel irradiated to 33,000 MWD/MTU at a specific power of 30 MW/MTU.

Activation P	14-C	55-Fe	60-Co	63-Ni	Total
Ci	0.7,07	2000,500	6000,3000	6000,500	1E+5,4000
Fission P	3-H	85-Kr	90-Sr	129-I	Total
Ci	500,400	1E+4,8000	8E+4,7E+4	0.04,0.04	1E+8,5E+5
Actinides	238-Pu	241-Pu	244-Cm	241-Am	Total
Ci	2700,2800	1E+5,8E+4	2200,1800	84,800	4E+7,9E+4

P = product, based upon 2.5 ppm nitrogen (by weight) in UO_2,

Decay of short-lived isotopes reduces the radioactivity and thermal power substantially in the first few years after discharge from the reactor. The activity (measured in curies) of activation products declines by about a factor of 30 in the first 5 y with most of that decay occurring within the first 2 y. Fission product activity is reduced by a factor of about 300 and transuranic activity by a factor of over 400 after 5 y. The thermal power of spent fuel is equal to 1000 kW, 5900 W and 2100 W after 0, 2 and 5 years. The thermal output decreases by about a factor of 500 over the same period of time. Short term (several years) storage of spent fuel reduces the need for shielding and cooling during handling, transport, and disposal. At longer times after discharge, decay is dominated by longer half-life isotopes and therefore the rate of reduction in radioactivity and thermal output is lower. Fuel assemblies for the two major power reactor designs used in the United States, pressurized water reactors (PWR) and boiling water reactors (BWR), contain slightly enriched (3-4%. 235-U) uranium dioxide pellets within zircalloy tubes that are arranged in square arrays and connected and supported by grid structures and end fittings. BWR and PWR assemblies differ somewhat in physical dimensions and hardware components.

These physical parameters remain unchanged as a result of irradiation in a reactor. There are also differences in the amount of fuel contained in BWR and PWR fuel elements. At discharge, after about 3-4 y residence in the reactor, the fission products, uranium, plutonium, and other transuranic elements, are primarily contained within the sealed fuel rods. The activation products are primarily contained in the hardware components. The spent fuel assemblies will be sealed in canisters prior to disposal. Canister materials and packing will be chosen to enhance the performance of the final repository system. That is, container materials will be chosen to minimize the likelihood of chemical reaction between the package and the geologic medium. Initially, one assembly will be placed in each canister. Subsequently, it is planned that the hardware will be removed and rods consolidated so that fuel from two rods can be disposed in one waste container.

Commercial high-level waste (Berlin 1989)

Approximately 600,000 gallons (2000 m^3) and 3 MCi of liquid high-level RW was produced by the operation of the commercial reprocessing facility at West Valley, New York from April 1966 through December 1971. Planned waste management procedures provided for permanent storage in double-shelled tanks underground at the reprocessing site. Leakage and level detection equipment on the tanks would be used to indicate tank failure. Tank contents would then be pumped to another underground tank nearby for subsequent storage. This management program reflected the then-current practice at government facilities, many of which had been designed and constructed under wartime deadlines. Concern with the need for periodic remote handling of the liquid waste and the long time frames required for active care resulted in the (then) Atomic Energy Commission's promulgation in 1970 of a requirement (Appendix F to 10 CFR Part 50) that all future reprocessing facilities be equipped to solidify the liquid high-level waste within 5 y after production and ship it to a federal repository for permanent disposal. Existing facilities were not required to comply with the new rule but would be addressed on a case-by-case basis. For a variety of technical, economic, and political reasons no other commercial reprocessing facilities have operated in the United States and the West Valley facility, shut down for expansion in 1971, was never reopened. This waste is in the process of being solidified in a glass matrix (vitrification), encapsulated and prepared for shipment to the federal repository. It is the only commercial HLW presently expected to exist in the United States.

West Valley facility

Both uranium and thorium fuels were processed at the West Valley facility. The resulting wastes are identified as PUREX wastes and THOREX wastes, respectively, and refer to the different chemical interactions used to separate the fission products from the uranium, plutonium, and thorium that would subsequently be recycled. The PUREX waste represents about 95% of the total volume and radioactivity requiring solidification. The waste was neutralized with sodium hydroxide prior to being transferred to the storage tank. Insoluble hydroxides have precipitated out of the neutralized waste resulting in both liquid (about 570,000 gallons of supernatant) and solid (sludge) phases being found in the tank. The table bellow illustrates that most of the isotopes in the PUREX waste are found in the sludge with the exception of Cs-137, I-129, and Ba-137 m.

Table 3 The most important radionuclides present in the PUREX (P) and THOREX (T) HLW at West Valley (1987, Ci)

RI	P - Liquid	P - Sludge	T - Liquid	Total
90-Sr	3E+3	7E+6	5E+5	7E+6
125-Sb	5E+1	2E+4	3E+2	2E+4
134-Cs	1E+4	0	3E+2	1E+4
137-Cs	7E+6	0	5E+5	8E+6
147-Pm	6E+2	2E+5	9E+3	2E+5
154-Eu	1E+1	1E+5	3E+3	1E+5
239-Np	0	3E+2	4	3E+2
238-Pu	127	8E+3	480	861
239-Pu	25	2E+3	15	2E+3
241-Pu	2E+3	9E+4	850	9E+4
241-Am	0	5E+4	241	5E+4

The THOREX waste was not neutralized to avoid precipitation of the contained thorium. There are approximately 12,000 gallons (5E+4 l) of acid THOREX waste stored. The final solidified waste product will contain three distinct waste feed streams : spent zeolite ion-exchange media used to remove strontium and cesium from the PUREX waste supernatant; washed PUREX sludge and THOREX waste. This mixture will he combined with glass formers and fed into the melter for research at government facilities. It provides structural integrity even under the heat and self-irradiation conditions to which it will be subjected in the repository, and high-leach resistance to water that might be present in the geologic conditions of the repository. The glass will be sealed in a stainless-steel canister that will be enclosed in a disposal container of whatever material is appropriate to the host geologic medium as described above. It is projected that some 300 canisters, each 2 ft (0.6 m) in diameter by 10 ft (3 m) tall and containing 18.7 ft^3 (530 l) of waste bearing glass, will be produced by the solidification of the West Valley waste.

Defense high-level waste (Berlin 1989)

Reprocessing of fuel and recovery of plutonium produced in a weapons program production reactor are fundamental to the weapons production process. HLW is produced incident to this reprocessing. Another source of defense HLW is the reprocessing of cores used for naval propulsion and recovery and recycle of the highly enriched uranium fuel contained therein. There are several differences between defense HLW and the commercial HLW. The major differences

are. Reactors operated primarily to produce plutonium rather than electric power have different operating cycle lengths, power densities, and fission product inventories from those found in commercial power reactors. Propulsion reactors use highly enriched uranium fuel rather than the 3-4%. enriched fuel in commercial reactors to minimize the amount of fuel needed-and consequently weight and space requirements to produce a given amount of power. These differences result in defense HLW having a lower radioisotope concentration than commercial HLW and a correspondingly lower heat output per canister. This means that the size of the defense HLW canister, particularly the diameter, can be larger than a commercial HLW canister for which the heat transfer capability between the package and the host rock is more restrictive. The similarities between defense HLW, commercial HLW, and spent fuel are more significant than the differences when considering the requirements for handling and disposal of the waste. Therefore the DOE plans to dispose of all these wastes in a single repository. Volumetrically, there are over 10 times more defense HLW than commercial HLW. These wastes are produced (or have been produced and are in storage at) government installations in Hanford, Washington, Idaho Falls, Idaho, and Savannah River, South Carolina. The combined defense and commercial HLW volumes are expected to be on the order of 12% of the spent fuel waste volumes accepted for disposal at the repository. In contrast, DOE estimates for the amounts of radioactivity present in spent fuel and HLW accumulated through 2000 indicate that about 95% of the total is due to spent fuel.

Transuranic waste (Berlin 1989)

Radioisotopes heavier than uranium are called transuranic isotopes (TRU). Very low naturally occurring concentrations of TRU have been measured in uranium bearing ores. Most TRU in existence today, however, has been artificially produced by irradiation of nuclear fuel. It results from the interaction of uranium and thorium with neutrons and subsequent beta decay. For example, plutonium, the best known TRU element, is produced by the following interaction: 238-U(n,gamma) = 239-Np(beta) = 239-Pu. Such materials include isotopes that have long half-lives and are highly radiotoxic because they decay by emitting high energy alpha particles. The primary elements of interest in TRU waste Np-237, Pu-239,240,241 and 242, Am-241,243 and Cm-243,244. Such wastes are primarily produced as a result of reprocessing spent fuel and subsequent recycling of plutonium and uranium. TRU may be present in solidified liquid waste as well as incorporated into fuel cladding hulls and other components filters, sludges, and trash. Decontamination and decommissioning of facilities for reprocessing spent fuel and fabricating plutonium will also result in TRU waste production. Materials that contain TRU in concentrations below 100 nCi/g are eligible to be disposed of as low-level RW in accordance with 10 CFR Part 61. This level was chosen because it is similar to the level of naturally occurring TRU in ore. At concentrations

above 100 nCi/g (3700 Bq/g) the longevity and health impacts concerns are such that the wastes are subject to the requirements of the Environmental Protection Agency's (EPA) rule 40 CFR Part 191, "Environmental Standards for Management of Spent Nuclear Fuel, High level and Transuranic Wastes." TRU waste is produced primarily by the defense program, in the absence of commercial reprocessing of spent fuel. The extent to which isotope separation is performed on plant waste streams will determine what waste must be classified as TRU. That is, if extensive separation is performed, as was once considered for possible commercial recovery of isotopes such as 237-Np, it is possible that a waste stream may be disposed as low-level waste rather than as TRU waste. TRU waste may contain sufficiently high concentrations of gamma emitting nuclides that remote handling is required to maintain occupational exposures as low as reasonably achievable. Other TRU waste may contain primarily alpha emitting nuclides and the dose rate at the package surface does not make remote handling necessary. DOE estimates that approximately 97% of TRU in retrievable storage at the end of 1986 was capable of being contact handled. There is also a substantial volume of TRU waste that was buried under rules in effect through the early 1970s.

Table 4 Inventories and Characteristics of DOE Defense TRU Waste in Retrievable Storage as of December 31, 1986.

	Volume (1000 ft^3)	Volume (m^3)	Mass (kg)	Activity (kCi)	Thermal Power (kW)
Contact handled	1750	47250	1826	2989	76.3
Remotely handled	50	1350	40	472	4.5
Buried	6770	182790	770	232	5.7
Total	8570	231390	2636	3693	86.5

Generation of radioactive waste

Knowledge of the characteristics of wastes is important at every stage of management to assure radiation protection during processing, to achieve proper segregation and packaging, and to meet regulations on shipment and burial. The features that must be known are volume (ft^3 or m^3) according to waste stream and specific activity (Ci/ft^3 or Ci/m^3) preferably by isotope and heat generation rate (W/ft^3 or W/m^3). "Source terms" represent such data, which can be used to plan waste management programs. It is not easy to obtain good data for many reasons. Some commercial organizations regard details as proprietary. Moreover, confusion can exist between wastes that are produced, those resulting from processing, those held for decay and later disposed of as ordinary waste, and wastes sent to a disposal site. It is not possible to determine accurate isotopic concentrations without detailed assay of every batch, which is clearly impractical. In actual practice, waste streams are assumed to be consistent, with occasional checks made to verify this.

LLW Produced by reactors (Murray 1989)

The chart shows some calculated data on the typical annual amounts of different LLW streams produced by a nuclear plant of PWR and BWR types. The data were developed by the Oak Ridge National Laboratory for the Department of Energy. Since the numbers refer to 1000 MW power, they are roughly the annual waste from one reactor. We see that both the volume and the activity generated by a BWR exceeds that for a PWR.

Table 5 Volumes (m^3/y) and activities (Ci) of LLW by Waste Stream and Reactor Type, per 1000 MW power (1986).

Category	Volume		Activity	
Waste Stream	BWR	PWR	BWR	PWR
Spent resin	74.1	32.2	+	+
Filter sludges + cartridges	547	10.4	4203	1326
Evaporator bottoms	334.7	494.2	+	+
Compactible trash	917.4	559.0	+	+
Noncompactible trash	133.4	70.4	+	+
Irradiated components	36	8.9	10820	6006
Total	2043	1166	15023	7332

LLW produced by institutions and industries

In the table that follows, volumes and activities for LLW are compared for reactors, fuel cycle, and institutional and industrial sources in another table. We note that the amounts of institutional wastes are relatively small compared to those from the generation of nuclear power. The sources of these wastes, radioisotopes, are, however, vitally important to the individual users. The cost of LLW waste disposal and fear of adverse public reaction is causing universities and other institutions to pressure researchers to diminish use of radioactive materials. This will impede research, increase the cost of research and slow development of new pharmaceuticals.

Table 6 Low-level Wastes Added Annually to Disposal Sites in 1985.

	Volume	Activity
Source	m^3	Ci
Reactors	47200	388100
Fuel cycle	3800	14
Institutional	11200	660
Industrial	18000	163900
Total	80200	552700

Waste from decommissioning (IAEA 1979)

All of the radioactive material arising from the demolition of the radioactive structures and components are dealt with in a similar manner as is the reactor waste resulting from normal plant operation, with the exception of a few % that require special handling (core components). Depending on the time delay before

decommissioning, the quantities of LLW and ILW from a 1000 MW reactor were estimated to amount to 5000 (Canada), 6900 - 12400 (Germany), 7000 - 15000 (Sweden) and 15200 - 16300 (U.S.) cubic metres. Something like 50 000 m^3 of non-radioactive waste which can be re-used or taken away as landfill. Direct decommissioning experience exists in a number of countries (among others Belgium, France, Switzerland, UK, USA). A large body of related experience has also been built up in more than a dozen countries. This has been acquired in modification and repair work on radioactive plant components and in the course of introducing new equipment into reactors and reprocessing plants which had been in active operation. This experience is directly applicable to large-scale decommissioning work. The tools and the methods that will permit all types of reactors to be decommissioned are available today. Experience even exists in decommissioning prototype plants where incidents involving the spread of radioactivity throughout the plant have occurred (e.g. Lucens). No significantly greater problems or amounts of waste were encountered, but additional costs were incurred ($1-2 million in the case of Lucens). Decommissioning options are dismantlement, mothballing (or safe storage) and encasement (or entombment).

Dismantlement

Dismantlement means that soon after shutdown, the fuel elements are removed, pipes are cleaned, radioactive steel and concrete are cut up by remotely controlled equipment and all RW is shipped to a burial site for disposal. According to DOE the process will take about 5 years to complete, will cost 40 M$ (in 1982) and will generate some 11700 m^3 of RW.

Mothballing

For "mothballing", or safe storage, the primary containment (piping and equipment associated with the primary cooling circuits) is maintained intact. All systems containing liquids that are radioactive are drained and sealed to prevent escape of contaminated material. The secondary containment (building) is maintained in a condition such that the probability of a release of radioactive material to the atmosphere is no greater than during reactor operation. The atmosphere inside the containment building is controlled to prevent the spread of contamination, and access to the inside of the containment building is controlled. The entire facility is maintained under surveillance, and equipment for monitoring radioactivity both inside and outside the containment building is kept in working order. Inspections are carried out to ensure that both the primary and secondary containment systems are being maintained in an acceptable condition. The specific actions involved in mothballing are: remove fuel and coolant from reactor and ship all irradiated fuel from used fuel bays off-site; decontaminate systems as required; process and ship to an active disposal area all active waste such as ion-exchange resin, filters,

and decontamination solutions; perform a detailed radiation survey and calculate the total amount of activity on the site; apply for a change in licence which will specify a reduced minimum staff requirement based on the fact that the potential hazards and risks have been reduced. The surveillance and monitoring requirements will consist of gathering data and submitting reports for quarterly inspection and semi-annual environmental surveys. In addition, effort will be required to maintain and operate the necessary systems. It is expected that the total cost required for activities necessary to mothball a 600 MW CANDU reactor will be approximately $6 000 000 and these activities will occupy one year. The annual expenses to maintain and operate the mothballed facility would be approximately $80 000. The cost of mothballing will not be affected greatly by changes in reactor size. When mothballing is complete, the predominant amounts and types of radioactivity (in curies) remaining will be: Fe-55 : 8E+6, Co-60 : 3E+6, Ni-63 : 7E+5 and Zr-95 : 1E+5. After 25 years, the predominant activities and nuclides will be (curies): 6E+5 nickel-63, 1E+5 cobalt-60, 7E+3 iron-55.

Encasement

For encasement, or entombment, all easily removable parts are dismantled and removed, as are all components that are radioactive to the extent that they will remain a health hazard longer than the life of the proposed encasement structure (<100 years). All radioactive components remaining inside the biological shield are sealed and the building is modified as necessary to provide adequate shielding and containment. The containment building itself and the ventilation system can then be modified or removed since they are no longer required as part of the safety system. If the containment building is left standing, access to it would normally be permitted without any monitoring of personnel for radiation exposure. Surveillance will be required but at a reduced level from that of mothballing since the only concern is to detect possible escape of radioisotopes.

Medical waste (Burns 1988)

Low-level RW generated at university medical centers arises from activities in both the clinical practice of medicine and biomedical research. The clinical practice area includes nuclear medicine, in vitro radioassays, and radiation therapy. Biomedical research involves many types of in vitro studies and animal studies performed with small amounts of radioactivity, predominantly C-14 and tritium. In this chapter, we will discuss briefly these areas of use and the types of waste they generate and, using the Washington University Medical Center in St. Louis, Missouri.

Nuclear medicine

Clinical nuclear medicine is now a required service for full accreditation of hospitals. Nuclear medicine studies are performed

on one in three patients admitted to hospital in the United States; approximately 12 million nuclear medicine studies are performed annually in the United States (with nearly 21,000 per year done at the three hospitals that make up the Washington University Medical Center and operate under a single institutional broad license from the Nuclear Regulatory Commission). In the vast majority of diagnostic examinations performed by clinical nuclear medicine departments, a radiolabeled compound (radiopharmaceutical) is administered to a patient (most commonly by intravenous injection) and, at varying intervals thereafter, images of the distribution of the radioactivity within the patient are obtained by external detection of the emitted gamma or characteristic X-ray photons with an instrument known as a scintillation camera. The resultant images are referred to as scintigrams. Scintigraphic studies provide a wide variety of clinically important diagnostic information, which reflect normal physiologic function vs pathophysiologic aberrations in function, as well as normal vs abnormal anatomy. For example, an image of the lungs obtained after injection of radiolabeled particles that temporarily occlude a small fraction of the pulmonary capillaries reflects the gross anatomic structure of the lungs, but more importantly indicates the relative regional distribution of blood flow within the lungs. Hence, this test is used to diagnose a common disorder, pulmonary embolism, in which thrombi initially formed in the peripheral veins have dislodged and been carried by the blood to the pulmonary vessels they obstruct. In such cases, the pulmonary perfusion scintigrams demonstrate focal areas of decreased or absent perfusion corresponding to the portion of the lungs not receiving normal blood flow. Another common test, bone scintigraphy, employs a radioactive tracer that localizes in normal bone but accumulates to a greater degree at most sites of abnormal bone turnover; this test provides a highly sensitive means to detect skeletal diseases due to trauma, infection, tumour, and other conditions at a time when conventional diagnostic roentgenograms are normal. Similar diagnostic nuclear medicine examinations have been developed for evaluation of the anatomy and function of most organs in the body. The waste generated by clinical nuclear medicine activities includes spent generators, expired vials of radiopharmaceuticals, and contaminated syringes, glassware, gloves, absorbent pads, etc. It should be noted that about 70% of clinical nuclear medicine studies are carried out with the use of the Mo-99/Tc-99m generator; the half-life of the parent radionuclide (Mo-99) is relatively short (T = 67 h), and the daughter, Tc-99m (T = 6 h), is utilized to produce a variety of routine radiopharmaceuticals. The majority of the low-level RW generated by clinical nuclear medicine, then, is Tc-99m. Essentially all waste contaminated with Tc-99m may be held for decay and then disposed of along with nonradioactive trash (with appropriate segregation of biohazardous materials, e.g., used needles). Only a few of the nuclides commonly used in nuclear medicine have half-lives longer than 28 days; these include I-125, Co-57, and Yb-169, all of which are used in very small quantities. All of the radionuclides employed in nuclear medicine are, however,

prepared and processed by radiopharmaceutical manufacturers throughout the country. The separation of several of these radiopharmaceuticals, in particular Mo-99 or I-131, which are products of uranium fission, results in large amounts of RW. The largest disposal problem relating to the clinical practice of nuclear medicine is, in fact, faced by the producers of radiopharmaceuticals rather than by the users themselves.

Table 7 Radionuclides Used in Clinical Nuclear Medicine.

RI	Diagnostic Procedure
99m-Tc	Thyroid,brain,bone,kidney,liver,heart imaging
123-I	Thyroid,brain imaging
111-In	Infection,spinal fluid,radiolabeled antibody imaging
201-Tl	Heart,parathyroid imaging
67-Ga	Tumour,infection imaging
131-I	Kidney,thyroid,radiolabeled antibody imaging
51-Cr	Blood volume and red cell survival
169-Yb	Spinal fluid imaging
125-I	Blood volume
57-Co	Vitamin B12 absorption

Research

The second area that generates low-level RW in medical centers is biomedical research. Radionuclidic tracers are currently used in most types of modern biomedical research. A survey of journals in the areas of biochemistry, immunology, endocrinology, and metabolism shows that almost 50% of all modern biomedical research involves the use of radioactive tracers. At the Washington University Medical Center, over 360 individual faculty members working in over 600 individual laboratories regularly use radioactive materials in their research. Over 40% of all biomedical research grants funded at the present time involve the use of some radioactive materials, most commonly tritium, C-14, P-32, S-35 and I-125. The major RW produced is the small quantity of activity contained in liquid scintillation vials, over a million of which are generated each year at the Washington University Medical Center. Other forms of waste are unused reagents, contaminated laboratory materials, and animal carcasses. It should be noted that as part of the preclinical evaluation of nonradioactive drugs, extensive in vivo studies of the kinetics and metabolism of the drugs are required prior to submission of a new drug application to the Food and Drug Administration. The majority of these studies are carried out with radiolabeled counterparts of the drugs; thereby, low-level RW is produced in the preclinical development of essentially all ethical drugs. The total activity of the low-level RW disposed of at Washington University in 1984 was equal to 9.4 Ci. The short-lived waste (with T < 90 d) accounted for 58.5% (5.5 Ci) of the total. The isotopic composition of the waste was : Radionuclide, % Total Activity : 3-H, 39.6%; 125-I, 25.3%; 32-P, 16.5%; 35-S, 15%; 51-Cr, 1.4%; 14-C, 1%; 45-Ca, 0.5%; 131-I, 0.2%.

Table 8 Sources of medical RW and an estimate of the relative disposal costs from the various areas.

	Annual Volume - m^3,	Disposal Cost - $
Clinical Nuclear Medicine:	0.6	500
Radioassay:	14.	40000
Radiation Therapy:	0.1	100
Research:	235	306000

In vitro radioassays are essential clinical and research techniques for measurement of hormones and other biological substances present in plasma or other materials at very low concentration (ng/ml). Over 100 million of these sensitive assays are carried out annually in the United States (with over 150,000 annually performed at the Washington University Medical Center). The major radionuclide utilized for radioassay is iodine-125, which has a half-life of 60 days. The waste generated in these procedures involves reagents, gloves, test tubes, and other disposable laboratory supplies.

Radiation therapy

The third clinical area is radiation therapy, which involves the use of high intensity radiation sources in the primary or palliative treatment of cancer. Approximately 400,000 patients per year undergo radiation therapy in the United States (with 2,300 treated at Washington University Medical Center). Although much radiation therapy is performed with linear accelerators and thus does not generate RW, a variety of important therapeutic procedures still involves both sealed and unsealed radionuclides. The radionuclides used in these applications include yttrium-90, phosphorus-32, cobalt-60, iodine-125 and iodine-131, cesium-137, and iridium-192; these isotopes have a range of half-lives from 2.6 days to 30 years. The radionuclides are in various forms for use as therapy sources; radiopharmaceuticals, which are administered orally, intravenously, or by intracavitary injection; sealed sources, which are temporarily implanted into patients; sealed sources, e.g., small seeds or wires, which are permanently implanted directly in the area to be treated; and sealed sources used for external beam therapy. The major type of waste generated from radiation therapy, then, is the spent sources; these tend to have the greatest amount of radioactivity per unit mass or volume of all wastes generated at medical institutions.

Table 9 Annual Quantity of Different Forms Radioactive Waste at Washington University in 1984.

	Weight		Volume		Activity	
	(lbs)	(kg)	(ft^3)	(m^3)	(Ci)	
Dry Solid	61000	27450	2200	62	2.80	(30%)
Absorbed Liquid	71000	31950	3100	87	5.80	(62%)
Scintillation Vials + Contents	78000	35100	3100	87	0.31	(3%)
Animal Carcasses	11000	4950	500	14	0.47	(5%)
Total	221000	99450	8900	249	9.38	(100%)

It should be noted that the majority of the volume and the costs are associated with the biomedical research application of radioisotopes, rather than with the diagnostic or therapeutic applications. The bulk of the waste related to clinical activities is generated by the manufacturers of the isotopes. A significant proportion of the waste being produced contains radionuclides with half-lives greater than 90 days or relatively small amounts of radioactivity in 1.7 million scintillation vials also containing organic solvents :

Table 10 Types of medical waste.

Half-life	< 90 d	m^3	> 90 d	m^3	Total
Dry	4200 ft^3	118	700 ft^3	20	140
Organic liquid	500 gal	2	700 gal	2.6	4.6
Animal carcasses	1400 ft^3	39	200 ft^3	5.6	45
Aqueous liquid	4800 gal	134	-		134

Radioactive waste inventories in the U.S. (Berlin 1989)

High-level waste currently exists at federal government facilities at the Hanford Reservation in the State of Washington, the Savannah River Reservation in South Carolina, the Idaho National Engineering Laboratory in Idaho, and the former Western New York Nuclear Service Center in West Valley, New York . As of 1986, the Department of Energy estimated that about 13 million ft^3 (368 E+6 l) of such waste existed in a variety of physical forms (liquid, sludge, salt cake, dry calcine) and containers (single shell tanks, double shell tanks, bins). Less than 1% of the volume of this waste was due to the commercial HLW in West Valley. Volumes are expected to be about the same in the year 2000 because some production will be offset by solidification of liquids with a related volume reduction. By 2020, although the volumes are projected to be still about 13E+6 ft^3, the inventory of isotopes in the waste is projected to increase from 1.4 billion Ci (5E+19 Bq) in 1986 to 1.8 billion Ci (7E+19 Bq). No commercial spent fuel reprocessing services have been available in the United States since 1971, and spent fuel has been stored in water pools, generally at the reactor site at which the fuel was used, since that time. It is not anticipated that new reprocessing capacity will be commercially developed in the United States in the near future. Therefore, the spent fuel will be disposed as HLW in a Federal repository. In response to the unavailability of some off

site storage capacity, utilities have modified the existing spent fuel storage pools and the racks in which the fuel is kept to accommodate extended storage of the fuel on site. In many cases it has been possible to provide life of plant storage capacity, thus reducing the probability that a plant would have to shut down because of lack of spent fuel storage space. Existing legislative authorization would enable the NRC to license emergency transfer of spent fuel to avoid shutdown of reactors because of this problem. Currently existing inventories of spent fuel are estimated to increase by about a factor of 7 through 2020, by which time it is anticipated that two repositories will be accepting spent fuel for permanent disposal.

Table 11 Radioactive Waste Inventories in the U.S. as of December 31, 1986 (Volume - m^3, Activity - Ci, Thermal Power - W):
High-Level Waste : Defense : 3.7E+5, 1.4E+6, 4.4E+6; Commercial : 2.3E+3, 3.1E+6, 9.1E+3; Spent fuel : 6E+3, 1.6E+10, 5.9E+4, 1.4E+4 metric tons of heavy metal. Total = 4E+5, 2E+10.
Transuranic Waste : Retrievably stored : contact-handled : 4.9E+4, 2.9E+6, 7.6E+4, 1800 kg; remotely handled : 1.4E+3, 4.7E+5, 4.5E+3, 4.0 kg; Total = 5E+4, 3E+6
LLW : DOE sites : 2.3E+6, 1.2E+7, 1.7E+4; Commercial : 1.2E+6 Ci [Active sites : 9E+5 Ci, Closed sites : 3.1E+5 Ci, in remediation : 9.5E+4 Ci], 4.6E+6, 3.6E+4; Total = 4E+6, 2E+7
Uranium Mill Tailings : Active sites : 1E+8 m^3, Remediation : 1.1E+6 m^3.
Phosphogypsum Wastes : 1E+9 metric tons.

Toxicity of the waste

Toxicity of radioactive waste depend on its radioisotopic composition. Radiotoxicity of a nuclide is a function of its effective half-life (EHL), type of emitter (alpha emission is the most dangerous) and its energy (high energy means high toxicity). IAEA divided radioisotopes into 4 categories:

1. High toxicity group contains RI which are mostly alpha emitters with a long EHL: Pa-231, Cf-249, Th-Nat, Pu-239, Pu-240, Pu-242, Th-232, Pu-238, Ac-227, Th-230, Np-237, Th-228, Am-241, Am-248, Cm-243, Cm-245, Cm-246, Cf-250, Cf-252, Cm-244, U-232, Ra-226, Ra-228, Sm-147, U-Nat, Nd-144, U-238, Pu-241, Pb-210, U-230, U-233, U-234, U-235, U-236, Cm-242, Th-227, Po-210, Ra-223, Sr-90.

2. Medium toxicity, group A comprises alpha emitters with short EHL and high energy beta/gamma emitters with long EHL : Ra-224, Pa-230, Bk-249, I-129, Eu-154, Ru-106, Ce-144, Bi-210, At-211, Na-22, Co-60, Ag-110m, I-126, I-131, Cs-134, Eu-152(13 y), Cs-137, Bi-207, Pb-212, Ac-228, In-114m, Sb-124, Ta-182, Cl-36, Sc-46, Sb-125, Ir-192, TI-204, Ca-45, Mn-54, Y-91, Zr-95, Sr-89, In-115, Cd-115m, Te-127m, Te-129m, I-133, Ba-440, Tb-160, Tm-170, Hf-181, Th-234.

3. Medium toxicity, group A contains mostly lower energy beta/gamma emitters with shorter EHL: P-32, V-48, Fe-59, Co-58, Ni-63, Zn-65, Rb-86, Rb-87, Tc-99, Cd-109, Sn-113, Pm-147, Sm-151, Os-185, Hg-203, As-76, Y-90, Zr-97, Nb-95, Ru-103, Ag-105, Sn-125, Cs-135, Eu-155, Gd-153, Bi-212, K-42, As-74, Se-75, Sr-85, Nb-93m, Zr-93, Te-125m, Te-132, I-135, La-140, Tm-171, W-181, W-185, Na-24, Sc-48, Mn-52, Y-93, Tc-97m, Sb-122, Ce-141, Pr-142, Re-183, Ir-194, Bi-206, Ca-47, Co-57, Ga-72, Br-82, Cd-115, Te-131m, Cs-136, Pr-143, Ho-166, Re-188, Pa-233, Mo-99, Ce-143, Dy-166, Tc-96, Ag-111, I-132, Nd-147, Pm-149, Re-186, Au-198, TI-202, S-35, Sr-91, Os-143, Zn-69m, As-73, As-77, Sr-92, Y-92, Tc-97, Pd-109, Ba-131, Sm-153, Eu-152(9 h), Gd-159, Er-169, W-187, Os-191, Ir-190, Pt-193, Rn-220, Rn-222, Sc-47, Mn-56, Ni-59, Ni-65, Kr-87, Ru-105, Rh-105, I-134, Er-171, Yb-175, Lu-177, Re-187, Pt-191, Pt-197, Au-196, Np-239, Si-31, Fe-55, Pd-103, Te-127, Au-199, Hg-197m, TI-200, TI-201, Be-7, Ar-41, Cu-64, Hg-197, Th-231, Nd-149, Ru-97, In-115m, Pb-203, Cl-38, Dy-165, Cr-51, F-18, C-14, Kr-85m, Te-129, Xe-135, Cs-131.

4. Low toxicity group includes low energy beta/gamma emitters with short EHL, electron capture nuclides and pure gamma emitters : H-3, Zn-69, Ge-71, Nb-97, In-131m, Cs-134m, Pt-193m, Pt-197m, Tc-99m, Co-58m, Kr-83, Xe-133, Os-191m, Xe-131m, Y-91m, Sr-85m, Tc-96m, Rh-103m, Ar-37.

Laws and regulations (Murray 1989)

For the management of high-level radioactive waste and spent fuel, The Nuclear Waste Policy Act of 1982 was passed by Congress. It was a compromise among industry, government, and environmentalists, containing timetables for action by the Department of Energy leading to underground disposal of HLW. The Act relates primarily to commercially generated materials but provides for the disposal of defense wastes upon Presidential approval. A Nuclear Waste Fund was set up to pay for disposal, with money coming from the waste generators, who in turn charge users of electricity. A fee of 1/10 cent per kWh is assessed. This is to be compared with a typical cost to the consumer of 6 cents per kWh. Following the dictates of the law, DOE set up an Office of Civilian RW Management, with its Director reporting to the Secretary of Energy. Guidelines were Issued for the process to select suitable sites for a repository, a Mission Plan was developed, and geological surveys were begun. Nine sites were Identified as potentially acceptable for the first repository, to be located in the West: in basalt at Hanford, Washington; bedded salt in the Paradox Basin in Utah and the Palo Duro Basin in Texas; salt domes in Mississippi and Louisiana; and tuff at Yucca Flats in southern Nevada. At the same time, possible locations were investigated for a second repository, in the East, in crystalline rock. The Great Lakes area and the Appalachian range were principal candidate regions.

The use of a Monitored Retrievable Storage (MRS) facility was studded, in accord with the law. Congress had visualized the MRS as

an alternative to a repository, but the Civilian Waste Management Program conceived it as one part of an integrated disposal system. Fuel assemblies would be shipped from reactor storage pools to the MRS as a staging area, where fuel would be packaged and shipped to the disposal sites. The MRS could also provide backup storage capacity in case the opening of a repository was delayed. In 1987, the choice of sites was narrowed to Hanford, Washington; Yucca Flats, Nevada; and Deaf Smith County, Texas; and site characterization studies were begun. The search for repository sites and the MRS created much concern among citizens and lawmakers. DOE's decision to suspend the search for an eastern site was questioned. After much political compromise, Congress passed the Nuclear Waste Policy Amendments Act of 1987, which restructured DOE's HLW program. The only western site to be characterized would be Yucca Flats. Nevada would receive financial compensation and special consideration in federal research projects. The status of the MRS was redefined. A study commission would evaluate the need for it, and limits on fuel storage capacity of the facility are set at 10,000 tons. The NRC must issue a repository construction license before the MRS can be built; the license would be the legal device that would prevent the MRS from becoming a permanent storage facility. An administration negotiator would work with the host states for the repository and the MRS. The Act has a number of special features. A Nuclear Waste Review Board in the National Academy of Sciences is created; spent fuel must be shipped in NRC-approved packages, with state and local authorities notified of shipments; authority is given for continued study of the subseabed disposal option, a topic of interest to European countries. No further crystalline rock studies are allowed, and DOE is to submit in the period 2007 to 2010 a study on the need for a second repository. The decision to characterize only one site will save considerable expense unless the Nevada site is found unsuitable, requiring other locations to be considered. The redirection of DOE's HLW program involves the preparation of a new limited scope Mission Plan and the release of only one Site Characterization Plan.

Regulations on low-level wastes (Murray 1989)

Rules on civilian RWs in general are provided by the Nuclear Regulatory Commission. They are based on research by the NRC and its contractors. A Draft Rule with much supporting information is issued for review by those who would be affected, including industry and the public. After refinement, the rule is published officially in the Federal Register and in the Code of Federal Regulations Title 10 Energy. The principal regulation for low-level wastes is Part 61, usually called 10 CFR 61. There is a wide range of activities in the low-level wastes to deal with, from barely above background to those comparable to high-level wastes. The lowest category is "below regulatory concern" (BRC), which can be disposed of without regard to radioactivity. Next are Class A wastes, which require "minimum" precautions for disposal. This

means no use of cardboard containers, a need for liquid waste to be solidified or mixed with an absorbent so there is no more than 1% liquid, no explosive or spontaneously combustible material, at limited pressure if gaseous, and treated if of biological origin. Class B wastes must meet minimum requirements but also have "stability." This means they must keep their size and shape despite effects on containers from soil weight, moisture, or radiation. Class C wastes should be isolated from a future "inadvertent intruder." a person who accidentally comes upon the waste while digging in the area after the site has been closed. He may be drilling a well or excavating for a building or cultivating the land. The C waste should be buried more deeply for his protection. Wastes that are more active than C cannot be given near-surface disposal. These "greater than Class C" (GTCC) wastes must be treated as HLW, to be disposed of by the Department of Energy.

The boundaries between classes of wastes depend both on the isotope's half-life and the specific activity in curies per cubic meter. For example, when the concentration of tritium (12.3 years) reaches 40 Ci/m^3, it becomes B waste; when that of cesium-137 (30 years) reaches 4600 Ci/m^3, it becomes GTCC; when iodine-129 (15.7 million years) reaches 0.008 Ci/m^3, it goes from A to C. The regulation 10 CFR 61 gives details for all radionuclides. The waste disposal facility is licensed either by a state or by the NRC for use by a commercial operator. The site is selected from several candidates on land owned by the state or federal government. All pertinent facts about the geology, water flow patterns, and nearby population must be known. Operations are inspected to be sure that the wastes are properly managed, and If so the license is renewed. At the end of the useful period of the facility, 20 to 30 years, the site is closed. The license is transferred to the state or federal agency, which will continue to monitor the site for the period of institutional control, which is 100 years. Then the license is terminated and no further maintenance is needed, but the design should have assured protection for a period of 500 years. Supplementing the regulations are NRC documents called Regulatory Guides, providing information on such things as quality assurance, design bases, calculation methods, and the form for reporting. An example is No. 4.18, "Standard Format and Content of Environmental Reports for Near-Surface Disposal of Radioactive Waste" 1983.

Regulations on the disposal of high-level wastes (Murray 1989)

The disposal of HLW is also controlled by the Nuclear Regulatory Commission, in the Code of Federal Regulations Title 10 Energy, Part 60, known as 10 CFR 60. Some of its important provisions are distilled from more than 30 pages of regulations, as follows:

1. The design and operation of the facility should not pose an unreasonable risk to the health and safety of the public. The radiation dose limit is a small fraction of that due to natural background.

2. A multiple barrier approach is to be used, including the waste form, the containers, and the host rock.
3. Performance objectives are set for both the components and the system.
4. A thorough site characterization study must be made, with features such as possible flooding regarded as sufficient to disqualify, and features such as great geologic stability and slow water movement regarded as favourable.
5. The repository should be located where there are no attractive resources, far from population centres, and under federal control. Good records and prominent markers are required.
6. High-level wastes are to be retrievable for up to 50 years from the start of operations.
7. The waste package must be designed to take account of all possible effects; it must be dry and chemically inert.
8. The wastes in the package should be secure for at least 300 years. Groundwater travel time from repository to the source of public water should be at least 1000 years. The annual release of radionuclides must be less than a thousandth of a % of the amount of the radioactivity that is present 1000 years after the repository is closed.
9. Predictions of safety must be made with conservative assumptions and by calculations that take account of uncertainties, using expert opinion.

Cumulative releases from the depository (Berlin 1989)

Recognizing the inherent uncertainty in projecting performance of a depository for long periods, the standard provides that a judgment must be reached that there is less than 10% probability that cumulative releases will exceed the quantities in Table 1.12 and less than 0.1% probability that the releases will exceed 10 times that amount. The term "unit of waste" is defined to enable the release limits to be appropriately adjusted for differences in characteristics of the several waste types addressed in the standard (i.e., spent fuel, high-level waste, and transuranic waste). Groundwater contact with the waste emplaced in the repository may provide a mechanism for leaching of the contained radionuclides and transport through the geologic medium to the accessible environment. The following limits (as found in Section 191.16) are placed on the allowable concentrations of radionuclides in a "special source of groundwater" (defined as a Class I groundwater identified in accordance with EPA procedures that are within the controlled area of the disposal system or an area up to 5 km beyond the controlled areas, that supply drinking water for thousands of persons at the time a site is chosen, and are irreplaceable as a source of drinking water for that population).

Table 12 EPA HLW Standard for Cumulative Releases for 10,000 Years. Release Limit per 1000 MTHM of Waste :
10 000 Ci for Tc-99m; 1 000 Ci for Cs-135, Cs-137, Sr-90, Sn-126 and any other radionuclide with a half-life greater than 20 y that does not emit alpha particles; 100 Ci for Am-241, Am-243, C-14, I-129, Np-237, Pu-238,239,240 or 242, Ra-226, U-233,234,235,236, or 238 and any alpha-emitting radionuclide with a half-life greater than 20 y; 10 Ci for Th-230 and Th-232.

For undisturbed performance of the disposal system for 1,000 years after disposal there must be a reasonable expectation that the annual average concentrations in water from a special source of ground water will not exceed : 5 pCi/l of radium-226 and radium-228; 15 pCi/l of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or the combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ greater than 4 mrems per year if such an individual consumed 2 litres per day of drinking water from such a source of ground water. Development of the LLW standards in 40 CFR Part 193 is continuing at EPA and it is anticipated that a proposed regulation may be promulgated sometime in 1988. The regulation may substantially reduce the volume of material that is technically classified as LLW by identifying an amount or concentration level below which the risks of disposal because of the radioactive characteristics of the waste are of no regulatory concern. This determination, described in the literature as below regulatory concern or "de minimis," is an attempt to channel finite economic and regulatory resources to achieve the most public protection possible. It is based on the legal principle originally expressed in Latin that "de minimis non curat lex" or "the law does not concern itself with trifles." In concept it is similar to the radiation principle of "As Low As Reasonably Achievable" (ALARA) because it recognizes that social and economic effects must be considered in decisions on how strictly to limit radiation exposure. It would effectively establish a floor for exposures below which reductions would not be necessary. Also to be included in the Part 193 standard are requirements for worker protection during predisposal management procedures, protection of the public after the closure of the disposal facility, and protection of groundwater from possible releases from a disposal facility. The standard will also provide requirements for disposal of certain types of naturally occurring and accelerator produced waste in a manner similar to LLW regulated under the authority of the Atomic Energy Act of 1954, as amended.

Environmental standards (Murray 1989)

The technical basis of licensing and regulation of potentially harmful substances Is normally provided by the Environmental Protection Agency (EPA). Rules appear in Code of Federal Regulations Title 40 Environment. In the case of radiation

protection, standards were delayed and NRC initiated the rules. Also, some EPA rules have been challenged by the courts, requiring new rulemaking. Thus some EPA rules are in place while others are being developed. The approach to standards taken by the EPA is to look at the possible hazards under a variety of situations ("scenarios") involving different sources of radionuclides, their method of treatment, protective measures taken, and health consequences. The dollar cost of each case is also calculated. For radiation exposure to members of the public from the uranium fuel cycle, which excludes mining and waste disposal, annual dose limits are 25 mrems whole body, 75 mrems thyroid, and 25 mrems any other organ. These correspond to NRC limits, and the EPA sees no justification for deviating from them. Slight variations from the above limits are applied for other sources of radiation, and exceptions within certain bounds are allowed. Distinctions are made among facilities: DOE, NRC-regulated; and non-DOE Federal. Air emissions are considered differently from groundwater contamination. Active uranium mill tailings are treated differently from inactive sites. A few of the typical standards are noted. For the whole uranium fuel cycle (40 CFR 190), in addition to dose limits, annual air releases (in curies) of certain long-lived isotopes are limited: Kr-85 (50,000), I-129 (0.005) and Pu-239 (0.0005). For spent fuel, HLW, and TRU, for 1000 years after disposal, groundwater requirements in 40 CFR 191 are set at 5 pCi/l of radium and a beta-gamma dose of no more than 4 mrems/y. Release limits for 10,000 years after disposal are stated for different isotopes. Plutonium-239 and other typical materials are limited to 100 curies for every thousand metric tons of heavy metal (U + Pu) originally emplaced as spent fuel. For mill tailings (40 CFR 192), control of the radon release rate to 20 pCi/m^2 per second should be assured for at least 20 years. The cleanup of old tailings sites should strive for a reduction of radium-226 to less than 5 pCi/g in the top soil layer. Rules are being developed for low-level RW. The rules expect to define wastes 'below regulatory concern" (BRC) as those yielding a dose to any member of the public of no more than 1 mrem/y. BRC wastes will be able to go in a sanitary landfill, unless they have a hazardous waste component, which is subject to the Resource Conservation and Recovery Act of 1976 (RCRA). LLW rules will also govern naturally occurring and accelerator-produced radioactive materials (NARM) of activities above about 1 nCi/g. The rules will take account of different classes of waste, modes of treatment, and methods of disposal.