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MASTER

**NUCLEAR CARRIER BUSINESS VOLUME
PROJECTIONS: 1980-2000**

ORNL/Sub--1381/1

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ABSTRACT

The expected number of shipments of commodities in the nuclear fuel cycle are projected for the years 1980 thru 2000. Projections are made for: yellowcake (U_3O_8); natural, enriched and reprocessed uranium hexafluoride (UF_6); uranium dioxide powder (UO_2); plutonium dioxide powder (PuO_2); fresh UO_2 and mixed oxide (MOX) fuel; spent UO_2 fuel; low level waste (LLW); transuranic (TRU) waste; high-activity TRU waste; high-level waste (HLW), and cladding hulls. Projections are also made for non-fuel cycle commodities such as defense TRU wastes and institutional wastes, since they also are shipped by the commercial transportation industry.

The majority of commodity shipments are presented as shipments between specific facilities in the fuel cycle, such as natural UF_6 transported between the conversion and enrichment facilities. However, shipments to and from light water reactors (LWRs), and shipments of U_3O_8 from the mine/mill facilities are too numerous and originate from too many locations to be projected in any practical manner. Therefore, to simplify the task of projecting the total number of shipments of these commodities (i.e. LWR wastes, U_3O_8 from mills, and institutional wastes), a regional breakdown scheme was utilized. Then weighted centroids were determined by regions for the facilities which ship/receive numerous commodities and are not centrally located. For instance, with LWRs the United States was divided into six regions based on Regional Electric Reliability Council areas. For the mine/mill facilities, state centroids were determined, and for institutional wastes the same six regions used for LWRs were utilized to project the percentage of the total waste originating from each region.

Projections of waste shipments from LWRs are based on the continuation of current volume reduction and solidification techniques now used by the utility industry. Projections are also made based on a 5% per year reduction in LWR waste volume shipped which is assumed to occur as a result of increased implementation of currently available volume reduction systems. This assumption results in a net 64% decrease in the total waste shipped by the year 2000. LWR waste shipment projections, and essentially all other projections for fuel cycle commodities covered

in this report, are normalized to BWR and PWR generating capacity projections set forth by the Department of Energy (DOE) in their low-growth projection of April, 1979. Therefore these commodity shipment projections may be altered to comply with future changes in generating capacity projections.

Projected shipments of waste from the reprocessing of spent UO_2 fuel are based on waste generation rates proposed by Nuclear Fuels Services (NFS), Allied-General Nuclear Services (AGNS), Exxon Nuclear, and the DOE. Reprocessing is assumed to begin again in 1990, with mixed oxide (MOX) fresh fuel available for shipment by 1991.

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PREFACE

Information on the business potential for transporting nuclear materials and how transportation of these materials fits into the nuclear industry is necessary to develop background material for workshops with motor, water, and rail carriers. The workshops will be coordinated by Battelle Columbus Laboratories and are sponsored by the Transportation Technology Center at Sandia National Laboratories.

The needs of this audience have dictated the type of information and its format in this report. The first section contains a description of the nuclear materials to be transported and a discussion of the uncertainties in making projections through the year 2000. The second section contains information useful to carriers: number of shipments, mileages, weights, etc. Detailed back-up material is contained in the appendices.

ACKNOWLEDGEMENT

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SECTION 1

NUCLEAR MATERIALS TRANSPORTED

The nuclear materials that are transported in the United States by exclusive-use vehicles are described in this section. The majority of the nuclear commodities are transported in the nuclear fuel cycle, i.e., the facilities and activities that support the production of electricity in nuclear power plants. The fuel cycle facilities and nuclear materials are discussed in Section 1.2. A large number of institutions (e.g., hospitals and universities) use nuclear materials for research or health-related purposes. These materials are usually shipped to the facilities as normal commodities; however, once used, the discarded nuclear materials are usually shipped from the facilities in exclusive-use vehicles. A general discussion of institutional wastes shipped in exclusive-use vehicles is contained in Section 1.3. The shipment of nuclear material for defense purposes which is generally classified will not be addressed in this report. The shipment of waste generated from defense-related activities is discussed in Section 1.4.

In preparing the projections given in Section 2, a number of assumptions are made either to simplify a complex situation or to establish a reference case where there exists several alternatives for future decisions. Section 1.1 contains a discussion of the major uncertainties and the future decisions that could significantly change the projections of Section 2.

1.1 MAJOR UNCERTAINTIES

To develop the shipment projections tabulated in Section 2, several assumptions about the future were made. In this subsection the major uncertainties and/or decisions that may be made in the future, which are perceived as having the potential to significantly alter the projections, are discussed briefly. The topics which are of interest can be generally categorized into three major areas: institutional considerations, nuclear parameter variations, and transport mode changes.

1.1.1. Institutional Considerations

The topics that have been grouped under the heading of institutional issues are:

- o The use of away-from-reactor (AFR) facilities for spent fuel storage.
- o The possibility of reprocessing spent fuel and when it would start.
- o The extent to which safeguards requirements will be imposed.
- o The number and location of LLW burial sites.

AFR Storage

The current government policy is to develop AFRs as a solution to the continued buildup of spent fuel at reactor sites. The storage capacity at the various reactor sites may be extended in order to delay the need to ship spent fuel offsite and to reduce the amount of fuel that must be shipped someplace in the 1980's. It has been assumed in this report that fuel will be stored an average of 10 years at the reactor site before it is moved to an AFR. The shipping projections given in Table 2.28 reflect this assumption. In addition, a deep geologic repository is projected to begin operation in the mid-1990's. The flow of spent fuel from reactors would continue to either an AFR or the repository, depending upon which facility is able to accept it in that time frame, but the flow from reactors would remain as given in Table 2.28.

Reprocessing

The assumption to reprocess, or not to reprocess, spent fuel would have no effect on the shipments of spent fuel from reactors shown in Table 2.28 as long as there were receiving sites (i.e., AFRs) available in the mid-1980 time frame to take the fuel when storage space at the reactors are filled.

If reprocessing should be initiated, then waste shipments from the reprocessing facilities would be initiated. To provide a complete shipment scenario for this report, it has been assumed that reprocessing begins in 1990.

Reshipment

The shipping schedule shown in Table 2.28 is a minimum schedule since if the early movements are to a temporary storage facility, then the fuel would have to be reshipped from there to another facility once a decision is made as to what that other facility is to be and when it is to become operational. The fuel receiving rate of the final facility would have to be such that it could accept fuel directly from the reactors as well as from the temporary facility. Because the dates of a final facility have a great deal of uncertainty associated with them, no reshipment schedule was assumed.

Safeguards

Safeguards regulations for shipments of spent fuel or other significant quantities of fissile material are still evolving, but the effect of future changes is most likely to be on the number of guards, routing, and so forth. These considerations are enormous problems, but the effect on the payload, and hence the number of shipments, is not expected to be substantial.

Should the spent fuel reprocessing option be chosen, the projected shipments of PuO_2 in this report have taken safeguards considerations into account. A PuO_2 transporter with a penetration-resistant design is discussed in Section 2.4.7. Implicit in the use of this transporter is a low PuO_2 payload. Projections for the number of shipments of fresh MOX fuel took safeguards into consideration by lowering the PWR fuel elements per shipment from 12 to 8 and the BWR fuel elements per

shipment from 36 to 16. In both the PuO₂ and MOX fresh fuel cases, the payload values assumed may increase or decrease with future safeguards requirements, and the number of shipments projected will change accordingly. Safeguards considerations are not expected to change the projected number of spent fuel shipments, but might delay them for reasons discussed above.

LLW Burial Sites

Three LLW burial sites are now receiving wastes from commercial and non-DOE institutional facilities. Much stricter regulations have recently been applied to all three sites, and in some cases, limitations on the amount of material that can be buried have been set. Section 1.2.7 discusses some of the more recent restrictions in detail. One effect has been for various elected officials to call for an LLW burial ground in each state, or at least many regional LLW burial sites. The addition of new LLW burial sites before the year 2000 will lower the mileage figures, but not the overall number of shipments.

At least one utility has begun plans to reduce its LLW shipments and to compact and store LLW indefinitely onsite. A trend to onsite storage is not expected unless the current burial regulations are tightened significantly. But should a trend develop, the number of shipments would be reduced from the values used in this report.

Location of Geologic Repository

Several geologic media have been studied for use as a geologic repository, and although R&D efforts in non-salt rock types have been renewed, current indications are that salt is the most likely geologic medium for the first commercial repository. Therefore it has been assumed that the commercial repository will be located in the Gulf Coast area where most of the large salt deposits are located. The specific location, whether in Gulf Coast salt deposits or in another medium in another area, may become a significant institutional issue. The effect of setting a specific location will be a change in the estimated shipment distances, either larger or smaller than those used in this report.

1.1.2 Nuclear Parameter Variations

The following topics have been grouped under the title of nuclear parameter variations that could have a significant effect on the number and cost of radioactive material shipments:

- o The LWR generation projections.
- o The burnup of future fuel cycles.
- o The HLW form.
- o The time spent fuel is cooled before transport.
- o The effect of increased volume reduction and potential requirements for solidification of LLW.
- o The impact of the geologic repository conditions on waste shipments.

These factors are in addition to the possible variations in the many single parameters that were picked to simplify the discussion (e.g., one resin cask size, one value for pounds of ore per shipment, etc.). The increased capacity of the various fuel cycle facilities required to meet future demands has been assumed to be provided by increasing the size of existing facilities. Although this is likely to be valid in many cases, in many others it will not be valid, and such events will affect the mileage estimates of this report.

Nuclear Power Generation Projections

The estimated amount of electrical power generated by LWRs in the year 2000 has declined by a factor of 4 in the last 5 years. In Section 1.2.5, the DOE low growth estimate for the amount of nuclear power generation is used, and the basis for selecting this estimate and a comparison with other estimates is given in Appendix C*. Generally, the shipments of fuel cycle commodities can be directly related to changes in the amount of power generated by LWRs.

*Just prior⁵ to the publication of this report, a new DOE nuclear growth projection⁵ was made which, compared to the values in this report, resulted in somewhat higher capacity in the late 1980s and early 1990s and a lower capacity (180 GWe) in the year 2000. The net effect on the total number of shipments estimated in this report is not expected to be significant.

Reactor Burnup

One measure of the length of time that the reactor fuel remains in the reactor producing power is called the burnup. Fuel cycles that would permit the fuel to generate about 2/3 more power for the same number of fuel assemblies are technically feasible. The fresh and spent fuel shipments would be reduced proportionally, but the number of LLW shipments originating at the reactor would not change appreciably. Generally, the other shipments in the fuel cycle would also decline by about 2/3 of the values estimated in this report.

HLW Form

The HLW from reprocessing spent fuel is usually assumed to be in a glass form, but other options exist, in particular the calcine form. Changing the form from glass to calcine results in a 75 percent increase in the volume of HLW. There are no casks designed specifically for HLW; therefore, a shift in waste form could be partially accommodated in the cask design. Generally, the cask design accommodations would be small, and the projected number of HLW shipments would increase by 50 to 75% over the values estimated in this report if the calcine form is used.

Spent Fuel Cooling Time

Current spent fuel casks are designed and licensed to transport spent fuel cooled for as short as 120 to 180 days; however, the current practice is to let the spent fuel cool for at least 5 years. Cooling periods of up to 20 years might be expected as routine. A truck cask designed for fuel cooled for 5 to 10 years could accommodate about twice as many fuel assemblies as the 120 day design. A similarly designed rail cask could accommodate only about 20% more PWR fuel assemblies and about 33% more BWR fuel assemblies. The projections given in this report are based on the use of currently available casks; therefore, if casks are developed based on longer-cooled fuel, the effect would be to reduce the number of shipments given in this report.

LLW Volume Reduction and Solidification

Improvement of current volume reduction practices and/or techniques by 5% per year can dramatically reduce (64% by year 2000) the number of

shipments of LLW. This is discussed in Sections 1.2.5 and 2.1.5. On the other hand, solidification of LLW increases the volume by 22 to 36%.¹ The projections of this report are based on no improvement in volume reduction and no increase in the use of solidification.

Geologic Repository Impact

The geologic repository is expected to be used for HLW, cladding waste, and TRU waste. The shipping projections are based on waste package sizes that are expected to be acceptable at the repository, although the sizes are not generally the optimum from a standpoint of transport efficiency. Handling or other considerations such as thermal loading will dictate the waste characteristics and the length and diameter of the waste containers. These considerations may permit an increase in transport efficiency, or they may result in a decrease in the efficiency.

1.1.3 Transport Mode Changes

In this report we have generally assumed that the shipments are made by legal-weight trucks or by unrestricted rail. Other options include barge, overweight truck, or restricted rail. A subset of the overweight truck option is the question of whether the overweight limit is 73,280 or 80,000 lb. The effect of using overweight trucks would be to reduce the number of shipments given in this report. Should barges be utilized to transport spent fuel, shipping time and cask fleet requirements would increase.

The Barge Option

Barge transport may be a viable alternative to rail and truck transport for many of the nuclear commodities, especially spent fuel. Intermodal transport, using a combination of barge and overland transport (rail or truck) is a possible alternative for 80% of the reactors projected to be operational by 1985.² Spent fuel casks licensed for truck or rail use are considered licensed for barge use unless the certification explicitly limits the transportation mode.³ Barge transport of spent fuel or other nuclear wastes requiring a reusable cask is more costly than either rail or truck transport because the time the cask is

used per trip is longer; however, future institutional factors may outweigh the economic penalty.

It is not clear that either the truck or the rail mode would be impacted more heavily by a shift to the barge mode, but the result would be fewer truck and rail shipments for those reactors located on a navigable waterway and extremely short truck and rail shipments for those reactors that require intermodal transfer. The total number of barge shipments would be less than the number of truck and rail shipments which are replaced because more than one cask is expected to be transported in a single barge shipment.

Rail Usage

In this report it was assumed that a large fraction of the spent fuel, HLW, cladding waste, UF_6 , and defense TRU wastes would be transported by rail. Clearly, the projections could be increased significantly if the material projected for rail shipment were shipped by truck instead.

Overweight Truck Shipment

For the projections in this report it was assumed that all truck shipments are legal-weight. Currently, one of the four types of existing truck spent fuel casks can only be used at its rated capacity if an overweight permit is obtained. The capacity of the overweight cask is about three times as great as that assumed for the projections; therefore, depending on the penetration of this type cask into the marketplace, the use of this cask could reduce the projections of number of truck shipments by a few percent to around twenty percent. Also, one of the rail spent fuel casks is designed to be shipped short distances to a railhead (and potentially to a barge-loading point) by truck with an overweight permit. The use of the overweight truck would not change the number of shipments projected by rail, but it does represent an additional number of very short truck shipments.

The projections of this report were based on the use of a large, 300-ft³ cask for resins from reactors, and it was assumed that this could be done on a legal weight basis. In some cases use of this large cask may not be possible without exceeding the legal weight. The other

alternative would be to use a smaller cask, thus increasing the number of shipments by up to 50%.

The limit for a legal-weight shipment is 73,280 lb in some states and 80,000 lb in others. In some cases the extra 6720 lb allowed would be reflected directly in payload weight increase, but in many cases a payload weight increase would also require a corresponding increase in shielding and/or structural materials. Therefore, an increase in the allowed weight would probably result in a decrease of only several percent in the overall number of shipments.

Restricted Rail Shipment

Casks exceeding the unrestricted weight of 263,000 gross vehicle pounds have been proposed for spent fuel and HLW. The impact of using the larger cask would be to lower the number of shipments in proportion to the increased capacity. No existing cask has been designed specifically for HLW, and it is estimated that there could be a 50% difference in the capacity between the restricted and unrestricted proposed casks for HLW (See Section A.3.1). In such a case, the effect could be to reduce the number of shipments by about 50% if the restricted HLW cask is used exclusively, 25% if the restricted cask is used about 50% of the time, etc.

1.2 FUEL CYCLE FACILITIES

Most shipments of nuclear materials in the United States that are transported by exclusive-use vehicles involve commodities in the nuclear fuel cycle. These shipments involve various materials, including U_3O_8 , natural and enriched UF_6 , UO_2 and PuO_2 powder, fresh and spent fuel, and several categories of waste products. Facilities that are included in this report and that are briefly described in this section are:

- o Uranium mine/mill facilities
- o Conversion facilities
- o Enrichment facilities
- o Fuel fabrication facilities
- o Light water reactors
- o Reprocessing facilities
- o Shallow-land burial facilities
- o Deep geologic disposal facilities

These numerous facilities are connected by transportation links, which are denoted by arrows in Figure 1.1. The various commodities that are transported from facility to facility and that are addressed in this report include:

- o Yellowcake (U_3O_8)
- o Uranium hexafluoride (UF_6) (natural, enriched, and reprocessed)
- o Uranium dioxide powder (UO_2)
- o Plutonium dioxide powder (PuO_2)
- o Fresh UO_2 and mixed oxide fuel (MOX)
- o Spent UO_2 fuel
- o Low-level waste (LLW)
- o Transuranic (TRU) waste
- o High-activity TRU waste
- o High-level waste (HLW)
- o Cladding hulls

NOTE: DOTTED LINES INDICATE TRANSPORTATION LINKS IF REPROCESSING OCCURS

FIGURE 1-1 TRANSPORTATION LINKS IN THE LIGHT WATER REACTOR FUEL CYCLE

There are over 200 reactors projected for the year 2000, and considering shipments to each would be impractical; therefore, to simplify the task of projecting shipments of commodities to and from reactors, the United States was divided into six regions, based on the Regional Electric Reliability Council areas.⁴ These regional breakdowns, illustrated in Figure 1.2, are designated as follows:

- Region 1 - Northeast
- Region 2 - East Central
- Region 3 - South
- Region 4 - North Central
- Region 5 - South Central
- Region 6 - West

In addition, the uranium mine/mill facilities are too numerous to treat individually. Therefore, the mine/mill facilities were grouped (generally by state) and a centroid determined. The procedure is explained in more detail in Section 2.1.1.

1.2.1 Uranium Mine/Mill Facilities

Essentially all active mining and milling operation facilities are located in the western United States, with the majority being in the states of Wyoming, Colorado, and New Mexico. Uranium ore from open pit mines or underground mines is transferred to the milling facility by large dump trucks. The milling facilities are either located at or near the mine sites.

The combined capacity of the U.S. milling industry as of November 1979 is estimated to be about 42,000 MT ore/day.⁶ The average U_3O_8 content of the ore is about 0.15% by weight, with the final U_3O_8 product being about 10% inerts. A typical milling facility may be expected to have a recovery rate of 90 to 95% for U_3O_8 .⁷ This rate results in a net production rate for U_3O_8 product of about 64 MT/day (10% is inerts). The U_3O_8 powder is shipped by common carrier from the milling site to a conversion facility exclusively in 55-gal steel drums. A typical truck-load will consist of 50 drums, each of which will hold about 800 lb of U_3O_8 product.

FIGURE 1-2 REGIONAL BREAKDOWNS FOR THE UNITED STATES

Obviously, to produce the quantities of U_3O_8 demanded by the increasing installed nuclear generating capacity, existing mining/milling facilities must be expanded in the future. Additional mines and mills will probably also be opened to meet this demand. The locations of these future mine/mill sites will most likely be in the southwest areas of the United States, where most of the known uranium reserves are located.

Other methods of uranium recovery, which account for less than 10% of the Nation's present industry capacity, include heap leaching from low-grade ores, recovery from mine water or mill raffinates, in-situ solution mining, and recovery of by-product uranium from the copper and phosphate industries.⁸ The first three methods mentioned will not significantly alter the normal transportation routes from the mine/mill sites to the conversion facilities, except that the uranium may be transported as a water slurry in special stainless steel cylinders. The fourth method, recovery of by-product uranium from the copper and phosphate industries, will alter the transportation routes somewhat, since the mine locations are located in Florida and along the Gulf Coast. However, the net effect of this method on the overall transportation situation will probably be negligible since the increase in quantities produced from these sources is expected to be small.

1.2.2 Conversion Facilities

The U_3O_8 powder is converted to UF_6 at one of two conversion facilities: (1) The Kerr-McGee plant in Gore, Oklahoma, which has a capacity of 9000 MT/year as UF_6 , and (2) the Allied Chemical plant in Metropolis, Illinois, which has a capacity of 12,700 MT/year as UF_6 .⁶

Because the Gore plant uses a wet process to convert the U_3O_8 to UF_6 , most of the contaminated waste comes from liquid effluent from the solvent extraction process. Treatment of this scrubber effluent produces calcium fluoride solid wastes; however, no wastes are shipped off-site.⁹

The Metropolis plant uses a dry process for U_3O_8 conversion, which produces relatively large quantities of radioactive ash as a waste product. As a general rule, about 1000 MT of solid waste is produced per 10,000 MTU processed as UF_6 . This results in a waste stream of 0.45 m^3

of solid waste per metric ton of uranium as UF_6 .¹⁰ This solid waste is packaged and shipped to a shallow-land burial site.

To meet the growing demand for naturally enriched UF_6 resulting from increased installed nuclear capacity in the United States, additional conversion capacity must be supplied in the future. Although some expansion at existing conversion facilities is expected to occur, additional new conversion facilities may have to be built, at locations somewhere between the milling sites in the western United States and the enrichment facilities in the central-eastern United States. In this report it is assumed that existing facilities are expanded.

1.2.3 Enrichment Facilities

Enrichment services for the U.S. nuclear power industry are supplied by three government-owned and contractor-operated gaseous diffusion plants. The facilities are located at Oak Ridge, Tennessee, Paducah, Kentucky, and Portsmouth, Ohio. Currently, the Paducah facility produces only low-enriched UF_6 (0.96% enriched), which is sent to both the Portsmouth and Oak Ridge sites (assumed 50/50 split) for further enrichment. The Portsmouth plant produces both LWR-grade UF_6 (2 to 4% enriched) and highly enriched UF_6 . The Oak Ridge plant produces only LWR-grade UF_6 .

Beginning sometime in the late 1980s, additional enrichment capacity will be provided by the planned construction of a new gaseous centrifuge enrichment facility at Portsmouth, Ohio.

Essentially all LLW generated from the enrichment process is now buried onsite. In the future, when the gaseous centrifuge facility begins operation, the contaminated equipment, process waste, and failed centrifuge machines are also expected to be buried onsite.

1.2.4 Fuel Fabrication Facilities

Five companies in the United States now produce LWR fuel for nuclear power plants. At three of these facilities the enriched UF_6 is converted to UO_2 pellets and subsequently manufactured into fuel assemblies. The other two facilities are involved in converting UF_6 to UO_2 , which is then shipped for final fabrication into fuel assemblies at a separate facility.

Babcock & Wilcox operates a conversion facility at Apollo, Pennsylvania, where it converts enriched UF_6 to UO_2 powder. The UO_2 powder is then transported to the Lynchburg, Virginia, plant, where the fuel assemblies are manufactured. Combustion Engineering converts enriched UF_6 to UO_2 powder at its Hematite, Missouri, plant and then ships the UO_2 powder to Windsor, Connecticut, for manufacturing into fuel assemblies. Exxon, at its Richland, Washington, facility, converts the enriched UF_6 to UO_2 powder and also manufactures the fuel assemblies. General Electric, at its Wilmington, NC, facility converts the enriched UF_6 to UO_2 powder and manufactures the fuel assemblies. Westinghouse converts enriched UF_6 to UO_2 powder and manufactures fuel assemblies at its Columbia, South Carolina, facility.

It was assumed that 80% of the total industry production of LWR fuel assemblies was shipped to domestic reactors to meet installed capacity projections and necessary lead times, and 20% of LWR fabricated fuel was shipped to overseas interests. Fuel shipped overseas leaves from ports at either Baltimore, Maryland or Norfolk, Virginia.

1.2.5 Light Water Reactors

There are two basic types of LWRs now operating in the United States--BWRs and PWRs. The present installed generating capacity of nuclear plants is represented by about a 2:1 PWR/BWR mix, and this ratio will be assumed to remain essentially the same for the period from 1980 to 2000 considered in this report. The installed nuclear capacity projections chosen for this report, which were based on projections made by the Department of Energy in May 1979,¹¹ represent a low growth case for the period 1980 to 2000. These projections are given in Table 1.1 and illustrated in Figure 1.3; the rationale for their selection is detailed in Appendix C. Essentially all the projections of material volumes shipped and estimated shipment numbers in this report are based on these generating capacity projections. Therefore, if in the future, the nuclear generating capacity projections change substantially, all of the projections for commodity shipments can be adjusted easily by the ratio of the new to current power projections.

There are numerous commodities shipped from LWRs, and they include spent fuel and other reactor components and a variety of wastes such as

TABLE 1.1
PROJECTIONS OF INSTALLED U.S. NUCLEAR CAPACITY

Year ¹	Capacity (MWe) ²				
	Additional PWR	Additional BWR	Total PWR	Total BWR	Total LWR ³
1965	175	326	175	326	501
1966	---	---	175	326	501
1967	---	---	175	326	501
1968	1,011	---	1,186	326	1,512
1969	---	1,278	1,186	1,604	2,790
1970	987	1,352	2,173	2,956	5,129
1971	1,405	1,336	3,578	4,292	7,870
1972	2,728	2,728	6,306	7,076	13,872
1973	5,478	---	11,784	7,076	18,860
1974	5,276	4,520	17,060	11,596	28,656
1975	3,645	3,464	20,705	15,060	35,765
1976	4,010	---	24,715	15,060	43,225
1977	3,449	1,857	28,164	16,917	45,081
1978	3,820	786	31,984	17,703	49,687
1979	---	---	31,984	17,703	49,687
1980	8,200	2,000	40,184	19,703	59,900
1985	25,900	13,200	66,100	32,900	99,000
1990	34,700	15,300	100,800	48,200	149,000
1995	20,000	10,000	120,800	58,200	179,000
2000	34,700	17,300	155,500	75,500	231,000

¹Data through 1978 are actual data.

²Based on DOE 1979 Low-growth case for nuclear power. See Appendix C and Section 1.1.2.

³Does not include Hanford N (860 MW) or Indian Point 1 (265 MW) since they will not produce commercial spent fuel or LLW.

**FIGURE 1.3
PROJECTED INSTALLED U.S.
NUCLEAR CAPACITY**

spent resins, concentrated liquids, precoat filter sludge and cartridge filters, compactible trash, and noncompactible trash. The waste volumes generated and the projected shipments of spent fuel and LWR wastes are enumerated in Section 2.1.5.

1.2.6 Reprocessing Facilities

Reprocessing of spent commercial LWR fuel is not currently practiced in the United States as a result of the Administration's 1977 decision to indefinitely defer civilian reprocessing. As was discussed in Section 1.1 it has been assumed that spent fuel will be shipped to an AFR 10 years after discharge from the reactor. To provide a complete shipment scenario in this report, it has been assumed that commercial reprocessing will begin in 1990.

Four possible locations were assumed for the AFR or reprocessing facilities:

1. Barnwell, South Carolina, Allied-General Nuclear Services (AGNS), 1500-MTHM capacity.
2. West Valley, New York, Nuclear Fuels Services (NFS), 750-MTHM capacity. (This facility is not expected to operate again.)
3. Oak Ridge, Tennessee, Exxon Nuclear, 2100-MTHM capacity. (This facility is projected.)
4. Morris, Illinois, General Electric, (GE).

The NFS facility in West Valley, New York, has been shut down for some time and is not expected to be reopened in the future. The GE facility in Morris, Illinois, has a backlog of 310 MTHM¹² stored spent fuel, but even though spent fuel is being stored at this site, no fuel is expected to be reprocessed at the Morris site. Therefore, the only reprocessing capacity available in 1990 is assumed to be from the 1500 MTHM AGNS facility in Barnwell, South Carolina. An additional 2100 MTHM of reprocessing capacity will be assumed to come on line in 1998 at a facility in East Tennessee.

The reprocessing plant is assumed to receive 10-year-old spent fuel, and after reprocessing, discharges seven classes of wastes:

(1) HLW (glass or calcine), (2) cladding hulls, (3) high-activity TRU, (4) TRU LLW, (5) non-TRU resins, (6) LLW, and (7) failed equipment. The reprocessing wastes would be sent either to a shallow-land burial or a deep geologic disposal facility depending on the waste type and transuranic (TRU) content. The waste volume projections and shipments are covered in more detail in Section 2.1.6.

1.2.7 Shallow-Land Burial Facilities

Three LLW burial sites now receive institutional waste and wastes from most of the fuel cycle facilities discussed in the previous sections. The Barnwell, South Carolina burial ground is operated by Chem-Nuclear Systems, Inc., and both the Richland, Washington, and Beatty, Nevada, sites are operated by Nuclear Engineering Company (NECO). The Sheffield, Illinois, site, previously operated by NECO, was closed in 1978. Earlier, the Maxey Flats, Kentucky, site operated by NECO and the West Valley, New York, site, operated by Nuclear Fuel Services, Inc., were also closed. The estimated volume of LLW from all sources¹³ that was buried at the sites open in 1978 is as follows:

<u>Burial Site</u>	<u>Volume Shipped (m³)</u>	<u>% of Total</u>
Sheffield, IL*	3,680	5
Barnwell, SC	63,140	75
Beatty, NV	8,780	10
Richland, WA	8,200	20

*The Sheffield site was closed in April 1978.

It is not known whether the above distribution (corrected for Sheffield) of waste volumes received by each site will continue in the future. For this reason, no distribution of LLW among the various shallow-land burial sites is assumed in this report.

The Richland and Beatty sites were closed by the governors of the respective states because of violations in the packaging regulations of waste packages received at the sites, but both have since been reopened. All three sites are now operating under much stricter regulations im-

posed by the governors of the three states. For instance, the Governor of South Carolina has limited the amount of LLW that may be buried each month at the Barnwell site. In 1978, over 2.2 million cubic feet of LLW buried at this site; the new limit of 200,000 ft³ per month that has been imposed for 1979 and subsequent years will have a significant impact since as shown in Section 2.1.5, the LLW generation rate is increasing rapidly.

Similar measures have not been taken yet to limit the quantities of waste received at the Beatty and Richland sites, but the remaining capacities of the two sites are limited. The commercial capacity of each of the three sites is estimated to be:¹⁴

<u>Location</u>	<u>Commercial Capacity (m³)</u>
Barnwell, South Carolina	2 x 10 ⁶ (7 x 10 ⁷ ft ³)
Richland, Washington	9 x 10 ⁵ (3.2 x 10 ⁷ ft ³)
Beatty, Nevada	7 x 10 ⁵ (2.5 x 10 ⁷ ft ³)

The operational lifetime of each burial site depends heavily on both the commercial capacity and the rate at which the waste is received, and hence, a move to reduce the amount of wastes that each site will be allowed to receive, as was done in South Carolina, may be implemented to extend a particular state's resources.

Results of this type of action would likely force the large generators of LLW, mainly LWRs and the institutional sector, to improve their volume reduction techniques to reduce the total volumes shipped each year. On the other hand, present legislation may result in the requirement that most wastes (including resins, filter sludges, and concentrated liquids from LWRs and liquid wastes from the institutional sector) be solidified before shipment. This requirement would result in shipment of larger total volumes from both LWRs and the institutional sector.

To give some indication of the present attitudes of the states towards the issue of LLW burial, the following excerpts from amendments to NECO's license at their Richland, Washington, burial site made by the State of Washington, Department of Social and Health Services,¹⁵ are presented:

CRITERION FOR WASTE TREATMENT, HANDLING
AND PACKAGING CONDITIONS

- o If wastes contain both toxic chemicals (including pathogenic or infectious materials) and radioactive materials, the hazard of each shall be evaluated independently. If the chemical hazard exceeds the radiological hazard, the waste shall not be buried at the licensee's Richland site, except as specifically approved by the Department of Social and Health Services.

This action might affect a sizable portion of waste coming from the institutional sector, specifically medical and research facilities.

- o After February 29, 1980, the licensee shall not receive waste containing transuranic elements. However, waste containing less than 10 nanocuries total transuranic nuclides per gram of waste is acceptable provided transuranic nuclides are essentially evenly distributed within a homogeneous waste form. This license condition does not authorize receipt or burial of components or equipment contaminated with transuranic nuclides.
- o After December 31, 1980, radioactive waste containing more than 1% oil by volume shall either be solidified, or absorbed with a quantity of absorbent material capable of absorbing twice the total volume of oil to be absorbed. The waste container shall be restricted to a DOT 17-H specification container or equivalent, and it shall be lined with a minimum 4 mil plastic liner which shall be sealed. Only absorbents approved by the Department shall be used.

This restriction could affect LWR and fuel fabrication facilities, which generate contaminated oil.

- o The licensee shall not receive packaged waste at the site unless it is in accordance with applicable NRC, DOT, and State regulations, and the conditions of this license, including the following:
 - Unless specified, the licensee shall not receive any liquid wastes. Solidified radioactive waste shall be certified by the generator to have no detectable free-standing liquids. No detectable free-standing liquid shall be defined as less than 1% liquid by volume until December 31, 1980. Effective January 1, 1981, this criterion shall be defined as trace quantities (not more than 0.5% or one gallon per container, whichever is less).

- Until December 31, 1982, liquid scintillation vials and fluids, and other organics with similar chemical properties, may be received and buried at the site providing the scintillation materials are packaged in sufficient absorbent material to absorb twice the total volume of liquid in the package. Waste containers shall be restricted to 17H containers or equivalent containers and shall be lined with a minimum 4 mil plastic liner.

Eventually, these restrictions will severely restrict the use of scintillation techniques by the institutional sector for medical and research purposes.

- Liquids and wet sludges (i.e., evaporator bottoms, concentrates, filter media) which have been solidified with one of the solidification media specified below, may be received:
 - i) Dow media
 - ii) Cement
 - iii) Urea-formaldehyde
 - iv) Asphalt
 - v) Delaware custom media
 - vi) Other solidification media which have been received by NRC and/or the Department.
- Ion exchange resins and filter media may be received in a dewatered form for transportation and subsequent burial, provided that they have been certified to contain no detectable free-standing liquids, as defined before, until June 30, 1981. After June 30, 1981, resins and filter media containing radioactive material having a total specific activity of $1 \mu\text{Ci}/\text{cm}^3$ or greater of materials with half-lives greater than 5 years must be stabilized by solidification.
- All packaged radioactive waste received at the site must meet, at a minimum, the water spray, free drop, compression, and penetration tests of 49 CFR 173.398 for Type A packages. Effective March 31, 1980, and except for overpacks which are removed prior to burial, cardboard, fiberboard, and paper packages are prohibited.

These selected amendments to NECO's license for the Richland burial site may not be representative of the requirements at the other two shallow-land burial sites. However, this trend toward stricter packaging and shipping regulations being advanced by NRC, DOT, and the various states is expected to continue in the future.

Future Considerations

As discussed previously, the available capacity for burial of LLW in the future is indeed limited at the three present sites. It is possible that, by expanding the capacity at the present sites, in conjunction with improved volume reduction practices implemented by the large waste generators, the three present sites may be adequate to handle the projected volumes of LLW from all expected sources through the year 2000.

There is a possibility that each state may be required to have its own shallow-land burial site for LLW, as has been urged by the NRC. Already, the states of Pennsylvania, North Carolina, and Virginia have expressed a willingness to study the possibility of having LLW burial sites. If this were to occur, it would drastically reduce the number of long-distance shipments of LLW from all around the United States to the three present sites. Such a move would have broad, economic and political ramifications for the generators and shippers of LLW throughout the United States.

1.2.8 Deep Geologic Disposal Facilities

Several geologic media have been studied by the DOE as possibilities for a suitable repository environment, including salt, shale, granite, and basalt. Although DOE has renewed R&D efforts in non-salt rock types, current indications point towards salt as being the most likely medium for the first commercial repository. Therefore, it has been assumed that, when the first commercial repository is opened, it will be located in salt somewhere in the Gulf Coast area, where most of the known large salt deposits are located.

Wastes Committed to Deep Geologic Disposal

Deep geologic repositories are intended to isolate hazardous, long-lived wastes from the earth's biosphere for extremely long periods of time. Deep geologic repositories will be capable of accepting spent fuel in shielded containers, or if a decision is made to reprocess commercial spent fuel again, the repository will be able to handle the waste products from reprocessing. These wastes will consist of solidified HLW, either in a calcine or glass form; cladding hulls; high-activity TRU wastes; and TRU LLW. TRU waste from MOX fuel fabrication operations will also be sent to the geologic repository.

Transportation Logistics

Several studies have considered the logistics of transporting the numerous types of waste to the repository.^{16,17} There is already a considerable backlog of commercial spent fuel at LWR sites across the United States. By the time a repository is opened, there will be a large enough backlog of spent fuel, reprocessed wastes, or other TRU waste to require a substantial transportation logistics program. This will be necessary to ensure that the repository can accommodate the large number of shipments which it could be expected to receive. The actual repository design will likely dictate the types and sizes of waste containers it will be capable of handling and the rate at which it can receive them.

1.3 INSTITUTIONAL WASTES

Radioactive wastes from the institutional sector originate from the use of radiopharmaceuticals and radioisotopes in hospitals, other medical facilities, and research facilities. Sources of these institutional wastes are spread across all 50 states, with the larger volumes coming from states with large populations (e.g., New York, Pennsylvania, California, Illinois).

Waste Characterization

The waste forms are generally classified as:

1. Dry, solid waste (e.g., used syringes, vials, test tubes, disposable labware, papers, gloves).
2. Absorbed liquids (i.e., aqueous and organic liquids dispersed in an absorbent medium, usually vermiculite).
3. Liquid scintillation vials.
4. Biological waste (e.g., animal carcasses, waste).

The wastes are usually placed in a 55-gal steel drum, with a polyethylene bag liner and a clamp-on lid. The dry, solid waste is often compacted, with a significant reduction in volume. Smaller 30-gal steel drums are also used, mainly for convenience of handling. The 30-gal drums are sometimes used in conjunction with a 55-gal drum for shipping absorbed liquid wastes. The 30-gal drum is partly filled with vermiculite or other absorbent material before being placed in the 55-gal drum, and the space around the 30-gal can is filled with extra vermiculite. The liquid waste is then poured into the 30-gal drum, which is then sealed, and a clamp-on lid is placed on the 55-gal drum for shipment. For purposes of projecting the number of shipments of institutional waste for 1980 to 2000, a shipment of forty 55-gal drums and ten 30-gal drums per truck was assumed. A packing efficiency of 70% also was assumed. These assumptions lead to a value of approximately 234 ft³ (6.63 m³) of waste per shipment. The results of these projections, in terms of projected volumes and number of shipments, are described in detail in Section 2.2.

1.4 DEFENSE TRANSURANIC WASTES

Defense programs in the United States that have generated and continue to generate TRU wastes are under the auspices of the Department of Energy. The sites at which most of this waste is generated, retrievably stored, and buried are as follows: Bettis, PA, Argonne Laboratory, IL, Mound Facility, OH, Oak Ridge, TN, Savannah River, GA, Los Alamos, NM, Rocky Flats, CO, Nevada Test Site, NV, Idaho Falls, ID, and Hanford, WA.

Defense Transuranic Waste Characterization

The TRU waste produced by the U.S. defense programs can be classified into four categories: currently produced waste, retrievably stored waste, buried waste, and decontamination and decommissioning (D&D) waste. TRU waste is defined as waste (other than the legally defined HLW) that contains more than 10 nCi of TRU per gram of waste. The currently produced and retrievably stored wastes are the best characterized categories of waste, and accurate information is available on the volumes of each. Information concerning buried TRU wastes is not well characterized; estimates of the volumes buried do exist, but they may be in error by a factor of 2. The defense TRU wastes are usually considered as either contact-handled (CH) or remotely-handled (RH) wastes, with the surface dose rate being the limiting factor on CH containers (usually <200 mrem/hr). Some of the more important characteristics of defense TRU waste can be summarized:

- o Scrap metal is the most common form.
- o Over 98% of the TRU waste volume in retrievable storage can be contact handled.
- o The most common waste containers for CH TRU waste are 55-gal drums and 4 by 4 by 7 ft, fiberglass-coated, plywood boxes (known as the Rocky Flats box), but various other containers have been used.

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16. D. Joy and B. Holcomb, "Logistics Models for the Transportation of Radioactive Waste and Spent Fuel," ORNL/TM-6192, March 1978.

17. L. Shappert, D. Joy, and M. Heiskell, "Radioactive Waste Transportation Systems Analysis and Program Plan," ORNL-5362, March 1978.

SECTION 2

SHIPMENTS OF NUCLEAR MATERIALS

Essentially all commodities that move from one facility to another in the nuclear fuel cycle are transported by commercial, exclusive-use vehicles (truck, rail, or barge). Because nuclear materials from the institutional sector, such as radiopharmaceuticals, isotopes for research, and source material, are usually carried in less than truckload (LTL) quantities as normal commodities, they will be omitted from this report. Nuclear materials from the defense sector are carried by exclusive-use vehicles, but will be omitted because of their classified nature. However, waste materials from both the institutional and defense sectors, which are transported in truckload quantities or by exclusive-use vehicles, will be enumerated in this section.

To estimate the mileages involved in transporting commodities between various facilities, point-to-point distances were calculated. Correction factors can then be applied to these point-to-point distances, depending on whether the shipments are by truck or rail. Frequently, correction factors of 1.26 and 1.33 have been applied to point-to-point distances for truck and rail transport, respectively.¹⁷ The point-to-point distances between certain facilities have been given in this report, and it is suggested that the above-mentioned correction factors be applied to each of the mileage values in this report to obtain more realistic figures for the mileages between facilities.

Of special interest for the carrier workshop was the nuclear material densities given below:

<u>Commodity</u>	<u>Density (kg/m³)</u>
Yellowcake (U ₃ O ₈)	1730
UF ₆	3090
Fuel Assemblies	3500
Calcine HLW	1300
Glass HLW	3000
Cladding Hulls	1600
UO ₂	2050
PuO ₂	2130
LLW	48 to 4420
Defense TRU Drums	714
Defense TRU Boxes	250 to 370

2.1 FUEL CYCLE FACILITIES

2.1.1 Shipments From Uranium Mine/Mill Facilities

Most of the active uranium mine/mill facilities are located in the western states of Wyoming, Colorado, and New Mexico with several facilities in Washington, Utah, and Texas. The major mine/mill locations and capacities are listed in Table 2.1. The product from the mill is shipped to one of two conversion facilities located in Oklahoma and Illinois. Since there are 30 to 40 mine/mill facilities, estimating the number of shipments from each mine/mill site to a conversion facility would be impractical. Therefore, geographic centroids were chosen for five locations in the states of Washington, Wyoming, Colorado, New Mexico, and Texas. The locations of these centroids in relation to the locations of the two conversion facilities are shown in Figure 2.1, and the mileages from the mine/mill centroids to the two conversion facilities are given in Table 2.2.

The uranium ore requirement for the period 1980 to 2000 was projected on a yearly basis. The average annual ore requirement per 1000 MWe of installed capacity was assumed to be 196,900 MT.¹ This value, which is a weighted average for a 30-year lifetime of a typical LWR plant, accounts for the initial core load and yearly refueling requirements. Based on the installed nuclear capacity projections of Section 1.2.5, the projected uranium ore requirements are presented in Table 2.3.

The projected U_3O_8 requirement for the period 1980 to 2000 was computed in a manner similar to the ore requirement. The average annual U_3O_8 requirement per 1000 MWe of installed capacity is 271.1 MT.¹ Assuming an average recovery rate for the typical mill of 92%, the projected U_3O_8 requirement is given in Table 2.4.

The total number of predicted shipments from the mine/mill centroids to the conversion facilities for 1980 to 2000 is also given in Table 2.4. The distribution of U_3O_8 shipped is assumed proportional to the UF_6 production rates at the two operating conversion facilities; i.e., 60% goes to Metropolis, Illinois and 40% goes to Gore, Oklahoma. The predicted shipments of yellowcake for 1980 to 2000 were based on the 1979 production rates for U_3O_8 (metric tons of ore per day) that are given in Table 2.1 for the specific sites. The production rates were

TABLE 2.1
ACTIVE MINE/MILL FACILITIES AND PRESENT CAPACITIES

Mine/Mill Site	Company	Capacity (MT ore/day) ¹
Grants, NM	Kerr McGee	6,350
Grants, NM	Anaconda	5,450
Grants, NM	United Nuclear-Homestake	3,200
Marquez, NM	Bokum	1,800
Cebolleta, NM	Sohio-Reserve	1,500
Church Rock, NM	United Nuclear	2,700
Gas Hills, WY	Pathfinder-Lucky Mc Uranium	1,800
Gas Hills, WY	Union Carbide	1,090
Gas Hills, WY	Federal American	860
Jeffrey City, WY	Western Nuclear	1,550
Powder River Basin, WY	Mono-Rocky Mt.	1,500
Powder River Basin, WY	Exxon	2,700
Shirly Basin, WY	Pathfinder	1,600
Shirly Basin, WY	Getty	1,350
Maybell, CO	Union Carbide	75
Uravan, CO	Union Carbide	1,200
Marshall Pass, CO	Homestake	450
Canon City, CO	Cotter	900
Moab, UT	Atlas	1,100
La Sal, UT	Rio Algam	700
Wellpinit, WA	Western Nuclear	1,800
Ford, WA	Dawn	350
Falls City, TX	Conoco	<u>1,600</u>
Totals		41,625

¹From Reference 15, "World Nuclear Fuel Cycle"

FIGURE 2.1 LOCATION OF MINE/MILL CENTROIDS AND CONVERSION FACILITIES

TABLE 2.2
MILEAGES FROM MINE/MILL CENTROIDS TO CONVERSION FACILITIES

Mine/Mill Centroids	Distance to Conversion Facilities	
	Metropolis, IL	Gore, OK
Wellpinit, WA	1651	1447
Casper, WY	1008	783
Aspen, CO	991	664
Grants, NM	1074	718
Falls City, TX	778	482

TABLE 2.3
PROJECTED URANIUM ORE REQUIREMENTS

Year	Uranium Ore (MT) ¹
1980	11,800,000
1985	19,500,000
1990	29,300,000
1995	35,250,000
2000	45,500,000

- ¹Assumptions:
- (1) Average Annual ore requirement per 1000 MWe of installed capacity is 196,900 MT.
 - (2) Ore requirement is sufficient to meet domestic demand only.
 - (3) Average U₃O₈ concentration in ore is 0.15%.

TABLE 2.4
PROJECTED NUMBER OF SHIPMENTS OF YELLOWCAKE
FROM MINE/MILL CENTROIDS TO CONVERSION FACILITIES

Year	Projected U ₃ O ₈ Requirement Shipped (MT U ₃ O ₈)	Number of Shipments ¹
1980	16,250	890
1985	26,850	1,475
1990	40,400	2,220
1995	48,500	2,665
2000	62,600	3,440

¹Based on 18.2 MT U₃O₈ per shipment, in fifty 55-gal drums.

summed for each grouping of mine/mill facilities (e.g., all the mines in New Mexico), and the total was assumed to be shipped from the centroid of that region to the conversion facilities. The projected number of shipments from each centroid is:

<u>Mine/Mill Centroid</u>	<u>% of Total Shipped from Centroid</u>
Wellpinit, Washington	5.2
Casper, Wyoming	30
Aspen, Colorado	10.5
Grants, New Mexico	50.5
Falls City, Texas	3.8

2.1.2 Shipments From Conversion Facilities

The two operating conversion facilities in the United States are located at Metropolis, Illinois (Allied Chemical), and Gore, Oklahoma (Kerr-McGee). The Kerr-McGee plant uses a wet process for converting U_3O_8 to UF_6 , whereas the Allied Chemical plant uses a dry process. Significant quantities of solid LLW which must be shipped off-site are generated only in the dry conversion process.

The locations of the two conversion facilities in relation to the enrichment plant and shallow-land LLW burial sites are illustrated in Figure 2.2. Mileages from the conversion facilities to the enrichment plants and LLW burial sites are given in Table 2.5.

The projected natural enriched UF_6 requirements for the period 1980 to 2000 have been calculated on the basis of the installed nuclear capacity projections of Section 1.2.5 and an average annual UF_6 requirement of 340 MT per 1000 MWe of installed capacity.¹ This value, which is a weighted average for an assumed 30-year lifetime of a typical LWR plant, accounts for the initial core load and yearly refueling requirements based on an assumed tail assay of about 0.25%. About 60% of the natural UF_6 is now produced by the dry conversion process. If this percentage is assumed to remain constant for the period 1980 to 2000, projections may be made for the amounts of UF_6 produced by the two conversion facilities as shown in Table 2.6.

The projected number of shipments of natural UF_6 for 1980 to 2000 from the two conversion facilities to the enrichment plants is given in

FIGURE 2.2 LOCATIONS OF CONVERSION, ENRICHMENT, AND SHALLOW-LAND BURIAL FACILITIES

TABLE 2.5
MILEAGES FROM CONVERSION TO ENRICHMENT FACILITIES AND LLW BURIAL

Enrichment	Distances from Conversion Facilities	
	Metropolis, IL	Gore, OK
Paducah, KY	8	377
Oak Ridge, TN	260	608
Portsmouth, OH	109	420
<u>Shallow-Land Burial¹</u>		
Barnwell, SC	494	-
Beatty, NV	1,541	-
Richland, WA	1,685	-

¹ Solid LLW is generated only from the dry process of uranium conversion at the Metropolis, Illinois, facility.

TABLE 2.6
ANNUAL QUANTITIES OF NATURAL UF₆ SHIPPED FROM CONVERSION FACILITIES

Year	Quantity of UF ₆ Shipped (MT UF ₆) ¹	
	Metropolis, IL	Gore, OK
1980	12,200	8,200
1985	20,200	13,500
1990	30,400	20,300
1995	36,500	24,400
2000	47,100	31,400

¹ Assumes 60% of UF₆ is produced by the dry conversion process at the Metropolis, Illinois plant.

Table 2.7 and is based on the data in Appendix A.6. The product of both plants is transported to enrichment plants as follows:² 20% to Paducah, 40% to Oak Ridge, and 40% to Portsmouth. Using this breakdown, the quantities of UF_6 shipped for enrichment is given in Table 2.8.

As stated in Section 1.2.2, LLW is produced only at the Metropolis plant at a rate of 0.45 m^3 per metric ton of uranium as UF_6 . Thus the quantity of waste can be calculated, and using the shipping package data in Appendix A.1.3, the number of shipments of LLW to a shallow-land burial site is given in Table 2.9.

2.1.3 Shipments From Enrichment Facilities

The enriched UF_6 requirement and the enrichment capacity in separative work units (SWU) needed to supply 1000 MWe of installed nuclear capacity have been estimated to be 58 MT and 0.216×10^6 SWU, respectively.¹ These numbers represent a weighted average of the initial core loading and subsequent reload cores for a reference LWR, resulting in an average enrichment of 3%.

The demand for enriched UF_6 by the domestic nuclear industry to supply the projected future generating capacity is given for the period 1980 to 2000 in Table 2.10. The actual production by the U.S. enrichment industry will probably be higher than the projected numbers, since some enriched uranium is shipped to foreign countries. It has been assumed that about 20% of the enriched UF_6 will be fabricated into fuel assemblies, which will be shipped to overseas interests. Although the United States also sells enriched uranium to overseas interests, these sales have declined over the last several years. For this report, overseas shipments of enriched UF_6 have been neglected, and only shipments of fabricated fuel to overseas interests are considered.

The three government-owned and contractor-operated gaseous diffusion enrichment plants are located at Paducah, Kentucky, Oak Ridge, Tennessee, and Portsmouth, Ohio. The combined capacity of the three plants in 1979 was expected to be 20.9×10^6 SWU.⁴ Estimates of the projected capacities of the diffusion plants with the CIP/CUP expansion and uprating programs in effect for the period 1980 to 1990 are shown in Table 2.11. The added enrichment capacity beginning in 1986 as a result of the planned construction of a new gaseous centrifuge enrichment facility at the Portsmouth, Ohio site, has been estimated (Table 2.12).

TABLE 2.7
NUMBER OF SHIPMENTS OF NATURAL UF₆
FROM CONVERSION FACILITIES TO ENRICHMENT FACILITIES

Year	Number of Shipments by Mode					
	Mode 1 (28%) ¹		Mode 2 (39%) ²		Mode 3 (33%) ³	
	<u>IL</u>	<u>OK</u>	<u>IL</u>	<u>OK</u>	<u>IL</u>	<u>OK</u>
1980	180	121	380	256	160	108
1985	300	200	630	420	266	178
1990	448	300	948	633	400	268
1995	538	360	1140	761	482	322
2000	694	463	1470	980	622	415

¹Mode 1 uses 48X cylinders (9.5-MT capacity each) by truck; 2 cylinders per shipment.

²Mode 2 uses 48Y cylinders (12.5-MT capacity each) by truck; 1 cylinder per shipment.

³Mode 3 uses 48Y cylinders (12.5-MT capacity each) by rail; 4 cylinders per shipment.

TABLE 2.8
QUANTITIES OF NATURAL UF₆ SHIPPED FOR ENRICHMENT

Year	Quantities of UF ₆ Shipped to Enrichment (MT UF ₆) ¹		
	Paducah, KY	Oak Ridge, TN	Portsmouth, OH
1980	4,100	8,150	8,150
1985	6,700	13,500	13,500
1990	10,100	20,300	20,300
1995	12,200	24,350	24,350
2000	15,700	31,400	31,400

¹Assumes that 20% of total available UF₆ goes to Paducah, 40% goes to Oak Ridge, and 40% goes to Portsmouth.

TABLE 2.9
PROJECTED QUANTITIES AND NUMBER OF SHIPMENTS OF LLW FROM
CONVERSION FACILITY TO SHALLOW-LAND BURIAL SITES

Year	Quantity Shipped ¹		Number of Shipments ²
	(m ³)	(MT)	
1980	3,700	8,200	357
1985	6,100	13,500	587
1990	9,200	20,400	887
1995	11,100	24,600	1070
2000	14,300	31,700	1378

¹Significant quantities of solid LLW are generated and shipped from the Metropolis, Illinois, site only. The average density of ash waste is assumed to be 2.22 MT/m³ (2.22 gm/cm³).

²Based on fifty 55-gal drums per shipment, or 23 MT/shipment.

TABLE 2.10
ENRICHED UF₆ SHIPPED TO MEET TOTAL FABRICATION NEEDS

Year	Installed Nuclear Capacity (GWe)	Enrichment Capacity Needed (10 ⁶ SWU) ¹	Enriched UF ₆ Shipped to Meet Total Fabrication Needs (MT UF ₆) ²
1980	59.9	12.9	4,690
1985	99.0	21.4	7,760
1990	149.0	32.2	11,670
1995	179.0	38.6	14,015
2000	231.0	49.9	18,095

¹Assumes that 0.216×10^6 SWU is needed for 1000 MWe of installed capacity; 0.25% tails assay.

²This amount of enriched UF₆ is sufficient to supply the total industry production of fabricated UO₂ fuel given in Table 2.18.

TABLE 2.11
U.S. DIFFUSION ENRICHMENT CAPACITY

Year	Enrichment Capacity (10^6 SWU) ¹
1978	18.7
1979	20.9
1980	22.4
1981	23.1
1982	23.4
1983	23.4
1984	25.4
1985-1990	27.4

¹Assumes 0.25% tails in FY 78 and 79, 0.23% thereafter.

TABLE 2.12
U.S. CENTRIFUGE ENRICHMENT CAPACITY

Year	Enrichment Capacity (10^6 SWU) ¹
1986	0.55
1987	3.30
1988	6.60
1989	8.80

¹Assumes 0.25% tails in FY 78 and 79, 0.23% thereafter.

Examination of the total enrichment capacity projected for 1990 shows that the value of 36.2×10^6 SWU is still sufficient to meet the domestic demand for enriched UF_6 . However, sometime after 1990, demand will exceed the capacity, necessitating further expansion of existing enrichment facilities or construction of new plants. The locations of the enrichment facilities in relation to the fuel fabrication facilities are illustrated in Figure 2.3. Mileages from the enrichment facilities to the fuel fabrication facilities are given in Table 2.13.

The Paducah facility enriches uranium to about 0.96% before shipping it to either Portsmouth or Oak Ridge for further enrichment. The Paducah facility receives about 20% of the natural UF_6 from the conversion plants and, after partial enrichment, ships half to Oak Ridge and half to Portsmouth.² The projected quantity and number of shipments of slightly enriched UF_6 from the Paducah facility to Oak Ridge and Portsmouth are given in Table 2.14. The mileages between enrichment plants are given in Table 2.13. After the uranium is enriched to between two and four percent U-235 at the Portsmouth and Oak Ridge sites, the product is shipped to the fuel fabrication facilities. The shipments of enriched UF_6 that will be shipped to each fuel fabrication facility for 1980 to 2000 is based on the market shares, as reflected in 1976 deliveries to these plants from enrichment facilities.³ Thus, the breakdown assumed for this report is:

<u>Fabrication Plant</u>	<u>Percent of Total UF_6 Shipped to Facility</u>
Wilmington, North Carolina	35
Apollo, Pennsylvania	7
Richland, Washington	7
Columbia, South Carolina	40
Hematite, Missouri	7
Erwin, Tennessee*	4

*Uses highly enriched uranium for military purposes, which has generally not been considered in this report.

The projected quantity and number of shipments of UF_6 to fuel fabrication facilities are given in Tables 2.15 and 2.16. Half of the UF_6 is shipped from Oak Ridge and half is shipped from Portsmouth.³

FIGURE 2.3 LOCATIONS OF ENRICHMENT AND FUEL FABRICATION FACILITIES

TABLE 2.13
MILEAGES FROM ENRICHMENT FACILITIES
TO FUEL FABRICATION FACILITIES

Fabrication Facilities	Distances from Enrichment Facilities	
	Oak Ridge, TN	Portsmouth, OH
Richland, WA	1936	1902
Apollo, PA	406	223
Wilmington, NC	379	419
Columbia, SC	230	345
Hematite, MO	374	406
Paducah, KY ¹	252	327
Erwin, TN	110	180
	<u>Windsor, CT</u>	<u>Lynchburg, VA</u>
Hematite, MO*	974	-
Apollo, PA*	-	219

¹The Paducah, Kentucky, enrichment facility sends slightly enriched uranium to Oak Ridge and Portsmouth.

*Enriched UF₆ is shipped to Hematite, Missouri, and Apollo, Pennsylvania, sites for conversion to UO₂ powder, and is then shipped to Windsor, Connecticut, or Lynchburg, Virginia, for fabrication into fuel assemblies.

TABLE 2.14
PROJECTED NUMBER OF SHIPMENTS BETWEEN ENRICHMENT PLANTS

Year	Quantity Shipped (MT UF ₆)	Number of Shipments ¹	
		Mode 1 ²	Mode 2 ³
1980	2590	83	27
1985	4240	136	45
1990	6390	205	67
1995	7720	247	82
2000	9930	318	105

¹Half of the given shipments go to Oak Ridge and half go to Portsmouth. See Table 2.13 for mileages between enrichment plants. The total number of shipments is the sum of Mode 1 and Mode 2.

²Mode 1 is by rail (80%) in 48Y containers, 12.5 MT UF₆/container, 4 cylinders/shipment.

³Mode 2 is by truck (20%) in 48X containers, 9.5 MT UF₆/container, 2 cylinders/shipment.

TABLE 2.15
ENRICHED UF₆ QUANTITIES SHIPPED TO FUEL FABRICATION FACILITIES

Year	Shipments to Individual Facilities (MT UF ₆)					
	PA	MO	NC	SC	WA	TN ¹
1980	330	330	1,640	1,880	330	190
1985	580	580	2,720	3,100	580	190
1990	910	910	4,085	4,670	910	190
1995	1,100	1,100	4,910	5,610	1,100	190
2000	1,450	1,450	6,330	7,240	1,450	190

¹The amount of UF₆ sent to the Erwin, Tennessee for military use is assumed to remain constant over the period 1980 to 2000.

TABLE 2.16

PROJECTED NUMBER OF SHIPMENTS OF ENRICHED UF₆ TO FUEL FABRICATION FACILITIES

Year	Number of Shipments to Each Fabrication Plant ¹					
	Apollo, PA (7%)	Hematite, MO (7%)	Wilmington, NC (35%)	Columbia, SC (40%)	Richland, WA (7%)	Erwin, TN ² (4%)
1980	29	29	144	165	29	17
1985	51	51	239	272	51	17
1990	80	80	358	410	80	17
1995	97	97	431	492	97	17
2000	127	127	555	635	127	17

¹Based on 11.4 MT/shipment in a 30B cylinder, with 5 cylinders per shipment. Half of the stated shipments for any given year originate from the Oak Ridge, Tennessee facility and half from the Portsmouth, Ohio enrichment facility.

²The number of shipments to the Erwin, Tennessee, site is assumed to remain constant for the period 1980 to 2000.

³Based on the allocation of enriched UF₆ among the various fuel fabrication facilities in Reference 3.

The LLW generated from the enrichment process is buried onsite. In the future, when the gaseous centrifuge facility begins operation, the contaminated equipment, process waste, and failed centrifuge machines are also expected to be buried onsite.

2.1.4 Shipments From Fuel Fabrication Facilities

Seven facilities in the United States are involved in the conversion of enriched UF_6 to UO_2 powder, and/or fabrication of fuel assemblies from UO_2 powder. The Hematite, Missouri and Apollo, Pennsylvania facilities convert enriched UF_6 to UO_2 powder and ship it to Windsor, Connecticut and Lynchburg, Virginia, respectively, where the UO_2 powder is fabricated into fuel assemblies. The other facilities perform both the UF_6 - UO_2 conversion and fuel fabrication operations at the same location. These facilities are located at Richland, Washington, Wilmington, North Carolina, and Columbia, South Carolina. The locations of these facilities in relation to the weighted centroids for pressurized water reactors (PWRs) and boiling water reactors (BWRs) in the six U.S. regions are illustrated in Figures 2.4 and 2.5, respectively.. Mileages from the fuel fabrication facilities to the PWR and BWR weighted centroids are given in Table 2.17. There is very little difference between the BWR, PWR, and LWR centroids. The latter is the result of combining the first two and is used in this report.

Fuel Fabrication Requirements and Shipment Projections

In any future projections of fuel fabrication data, the U.S. domestic demand and the actual industry production must be considered. For instance, the total industry production of the five fuel fabrication facilities in 1978 was estimated to be 2645 MTU.⁵ This estimated production was sufficient to support about 70 GWe of installed generating capacity. However, the actual generating capacity (nuclear) in 1978 was only about 50 GWe in the United States. This large production capacity is required for several reasons. First, uranium production and fuel fabrication capacity must be available ahead of the actual schedule for fuel delivery to the power plant. This time delay is necessary to allow for (1) delivery of fuel to the plant, (2) accumulation of the required quantity of fuel for the initial core

FIGURE 2.4 LOCATIONS OF FUEL FABRICATION FACILITIES IN RELATION TO PWR WEIGHTED CENTROIDS

**FIGURE 2.5 LOCATIONS OF FUEL FABRICATION FACILITIES IN RELATION TO
BWR WEIGHTED CENTROIDS**

TABLE 2.17

MILEAGES FROM THE FUEL FABRICATION FACILITIES TO THE BWR AND PWR WEIGHTED CENTROIDS

Region	Distances from Fuel Fabrication Facility				
	Richland, WA*	Columbia, SC*	Windsor, CT	Wilmington, NC	Lynchburg, VA
1 BWR Centroid	2213	597	-	-	-
PWR Centroid	2274	-	67	535	394
2 BWR Centroid	1655	618	-	-	-
PWR Centroid	1685	-	668	633	456
3 BWR Centroid	1960	209	-	-	-
PWR Centroid	2104	-	718	231	259
4 BWR Centroid	1277	905	-	-	-
PWR Centroid	1259	-	1073	1064	874
5 BWR Centroid	1643	720	-	-	-
PWR Centroid	1598	-	1393	1000	968
6 BWR Centroid	128	2263	-	-	-
PWR Centroid	445	-	2066	2259	2121

*BWR fuel assemblies are only fabricated at the Richland and Columbia sites.

loading or refueling, and (3) new plant low-power testing and startup. Also, several of the U.S. fuel fabricators sell fuel to overseas interests.

To make forecasts for the domestic demand and industry production for the period 1980 to 2000, several assumptions were made. The amount of uranium necessary as fabricated UO_2 fuel to supply 1000 MWe annually of installed capacity was assumed to be 44.5 MT UO_2 .¹ Therefore, the projected domestic demand for any year is the product of the installed nuclear capacity in that year and the factor 44.5 MT UO_2 /GWe. The estimated industry production (Table 2.18) is assumed to be 1.35 times the domestic demand, in order to compensate for the necessary lead times and foreign sales. To meet the future demand for fabricated LWR fuel, whether it be UO_2 or MOX fuel, the existing facilities will have to expand their capacities, and some new MOX fabrication facilities may need to be built in the future. Westinghouse recently announced that it would build a fuel fabrication plant in Prattville, Alabama (in addition to the Westinghouse plant in ~~Columbia~~, ^{South} Carolina). Since this report assumes that present fuel fabrication facilities will expand their capacity to meet future requirements, an error in the mileage difference between these two plants will result in the shipments from the enrichment facilities and in shipments to PWRs.

To estimate the actual number of PWR and BWR fuel assemblies that are fabricated and shipped each year, several assumptions must be made. First, we assume that there is a 2:1 PWR/BWR mix in the U.S. and for U.S. foreign sales. The fraction of the core that is replaced during refueling each year is assumed to be one-third for a PWR and one-fourth for a BWR. The number of fuel assemblies for a PWR core is assumed to be 174 and to remain constant from 1980 through 2000. For the BWR, we assumed that there are 714 fuel assemblies per core through 1982, after which there will be 625 fuel assemblies per core until the year 2000. The basis for these assumptions may be found in Appendix C, Section C.2.

The projected number of BWR and PWR fuel assemblies fabricated and the number of shipments for 1980 to 2000 are given in Tables 2.18 and 2.19. It was assumed that 80% of the total industry production of LWR fuel assemblies was shipped to domestic reactors to meet installed capacity projections and necessary lead times, and 20% of LWR fabricated fuel was shipped to overseas interests.

TABLE 2.18
NUMBER OF UO₂ FUEL ASSEMBLIES FABRICATED

Year	Industry Production (MT UO ₂)	Fuel Assemblies Fabricated ¹		
		PWR	BWR	TOTAL
1980	3,600	4,850	7,450	12,300
1985	5,950	8,400	12,900	21,300
1990	8,950	12,650	19,450	32,100
1995	10,750	15,200	23,350	38,550
2000	13,880	19,600	30,200	49,800

¹ Assumes total industry production is 35% over and above domestic demand: 20% for foreign sales, 15% to compensate for lead time.

TABLE 2.19
PROJECTED NUMBER OF SHIPMENTS OF LWR FUEL
ASSEMBLIES TO LWR CENTROIDS

Year	Fuel Assemblies		Number of Shipments	
	PWR	BWR	PWR ¹	BWR ²
1980	3,880	5,960	324	166
1985	6,720	10,320	560	287
1990	10,120	15,560	844	432
1995	12,160	18,680	1,014	519
2000	15,680	24,160	1,307	672

¹Two PWR UO₂ fuel assemblies per container, 6 containers per truck.

²Two BWR UO₂ fuel assemblies per container, 18 containers per truck.

Fuel shipped overseas leaves from ports at either Baltimore, Maryland or Norfolk, Virginia, and the basis for the distribution of U.S. shipments is based on the UF₆ receipts by fuel fabricators and the regional electricity production by reactors. The percentage distribution of UF₆ receipt (and thus the percentage distribution of fabricated fuel assemblies) is:

<u>Facility</u>	<u>% of Total PWR Shipments</u>	<u>% of Total BWR Shipments</u>
Columbia, SC	-	90
Richland, WA	9	10
Windsor, CT	14	-
Lynchburg, VA	14	-
Wilmington, NC	63	-

The first facility manufactures and ships only BWR fuel assemblies; whereas, the last three facilities manufacture and ship only PWR fuel assemblies.

The number of BWR fuel assemblies which are shipped is based on the generating capacity (MWe produced by BWRs) of each region in the year 2000. The BWR generating capacity distribution for the six regions is:

<u>Region</u>	<u>Percent of Total BWR Generating Capacity in the Year 2000</u>
1	28
2	23
3	25
4	4
5	13
6	7

Therefore, the projected number of shipments of BWR fuel assemblies for any given year which originates at the Columbia or Richland locations and go to any of the six centroids may be determined by using both of the percentage distributions given above. For example, the projected number of shipments for 1980 from the Columbia facility will be 90% of the 166 shipments (from Table 2.19) of BWR fuel assemblies or 150 shipments, and 28% of these 150 shipments will go to region 1, 23% to region 2, and so on.

The fuel fabrication facilities which manufacture PWR fuel are located at Wilmington, North Carolina, Windsor, Connecticut, Lynchburg, Virginia, and Richland, Washington. The number of PWR fuel assemblies which are shipped is also based on the generating capacity (MWe produced by PWRs) of each region. The PWR generating capacity distribution for the six regions is:

<u>Region</u>	<u>Percent of Total PWR Generating Capacity in the Year 2000</u>
1	19
2	22
3	35
4	1
5	8
6	15

Therefore, the projected number of shipments of PWR fuel assemblies for any given year which originates at any of the four PWR fuel fabrication facilities and go to any of the six centroids may be determined by using the regional percentage breakdowns for generating capacity and the breakdowns for percent of the total PWR shipments originating at each facility, given above. For example, the projected number of shipments for 1980 from the Wilmington facility will be 63% of the 324 shipments (from Table 2.19) of PWR fuel assemblies shipped that year (or 204 shipments); and 19% of those 204 shipments will go to region 1, 22% to region 2, and so on.

It was assumed that 20% of the commercial LWR fuel assemblies fabricated are shipped to overseas interests from either the Baltimore, Maryland, or Norfolk, Virginia ports. The predicted number of BWR and PWR fuel assemblies shipped to overseas interests for 1980 to 2000 is given in Table 2.20. The shipments of UO_2 fuel assemblies from the various fabrication facilities to the ports for overseas shipment follow the same percentage breakdowns given before. For instance, BWR fuel shipments to the east coast ports of Baltimore, Maryland or Norfolk, Virginia from either the Columbia or Richland fabrication facilities will be as follows. For 1980, 90% of the 42 BWR fuel shipments (from Table 2.20), or 38 shipments, will go from the Columbia facility to

TABLE 2.20
PROJECTED NUMBER OF SHIPMENTS OF LWR FUEL ASSEMBLIES
SHIPPED TO OVERSEAS INTERESTS FROM EAST COAST PORTS¹

Year	Number of Fuel Assemblies		Number of Shipments	
	PWR	BWR	PWR ²	BWR ³
1980	970	1490	81	42
1985	1680	2580	140	72
1990	2530	3890	211	108
1995	3040	4670	254	130
2000	3920	6040	327	168

¹Shipments of fresh LWR UO₂ fuel to overseas interests are assumed to be shipped from ports in Baltimore, Maryland, and Norfolk, Virginia. Half of the fuel shipped goes out of each port.

²Two PWR UO₂ Fuel assemblies sent per container; 6 containers per truck to port.

³Two BWR UO₂ Fuel assemblies sent per container; 18 containers per truck to port.

either the Norfolk or Baltimore port. It is assumed that 50% of the shipments go to each port. The same breakdown will apply for PWR fuel shipments. For instance, in 1980 63% of the 81 PWR fuel shipments, or 51 shipments, will go from the Wilmington facility to the Norfolk or Maryland port, again assuming a 50/50 split between each port, and so on for each fabrication facility.

MOX Fuel Fabrication

Reprocessing of commercial spent fuel is assumed to begin in 1990 (as discussed in Section 1.1) and recycled uranium and plutonium are assumed to be available for MOX fuel fabrication by 1991. The projected number of MOX fuel assemblies fabricated and the number of shipments to the LWR regions for 1991 and 2000 are given in Table 2.21. (The effect of MOX fuel shipments is to decrease the number of shipments given in Table 2.19. Clearly if reprocessing of spent fuel does not occur, then MOX fuel shipments would not occur either.) The shipments of MOX fuel assemblies from the fabrication facilities to the LWR controids also follow the percentage breakdowns given before for UO₂ fuel shipments. That is, the number of BWR MOX fuel shipments given in Table 2.21 which originate from either Columbia or Richland will be 90% and 10% of the 41 shipments for 1980, respectively. Then 28% of the shipments from each fabrication facility will go to region 1, 23% to region 2, and so on. The number of PWR MOX fuel shipments originating from either the Wilmington, Lynchburg, Windsor, or Richland facility will be 63%, 14%, 14%, and 9% of the 33 ~~shipments~~ ^{shipments} for 1980, respectively. Likewise, 19% of the shipments will go from each facility to region 1, 22% to region 2, and so on.

Fuel Fabrication Waste Characterization

The pelletizing and fuel assembly fabrication process does not produce any solid waste directly other than that produced from recovering UO₂. The primary sources of solid wastes are noncombustible and combustible trash, filters from ventilation systems, and filter cakes from some liquid waste treatment systems. A representative sample of the waste from all fuel fabrication plants indicates that 85% of the total trash volume is combustible.⁵ Items generally found in the combustible and noncombustible waste are:

TABLE 2.21
PROJECTED NUMBER OF SHIPMENTS OF MOX FUEL
ASSEMBLIES TO LWR REGIONS

Year	MOX Fuel Assemblies Fabricated ³		Number of Shipments	
	PWR	BWR	PWR ¹	BWR ²
1991	260	656	33	41
1995	260	656	33	41
1999	628	1581	79	99
2000	628	1581	79	99

¹Two PWR UO₂ fuel assemblies in a special all-metal container,
4 containers per legal-weight truck.

²Four BWR UO₂ fuel assemblies in a special all-metal container,
4 containers per legal-weight truck.

³The projections of Table 2.19 are decreased by these amounts if MOX
fuel is shipped.

Combustible Trash

Shoe covers
Paper wipes
Plastic gloves
Coveralls
Waste paper
Filter components
Plastic bags
Wood (from crates)
Oil

Noncombustible Trash

Worn-out equipment
Piping
Fire brick
Wire
Metal
Ceramic scrap
Glassware
Metal pails
Insulation
Tools

Several fuel fabrication facilities incinerate their combustible waste to concentrate any uranium contamination. The concentrated waste is then ready for uranium recovery, if economically feasible. Filter sludges from the filtration of various liquid waste streams at the plants are either processed through scrap recovery, if warranted by the uranium concentration, or packaged for burial if the uranium content is too low. Prefilters and HEPA filters are treated like filter sludges, depending on the uranium contamination. Some plants with incinerators disassemble the filters and burn the combustible components. In most instances, the filters are packaged and shipped for disposal. Also, oil that is contaminated with uranium from the rotary press operation is either shipped offsite for burial or stored onsite until economical methods of UO_2 recovery are found.

Estimates indicate that a typical overall production rate of LLW from a UO_2 fuel fabrication facility is about 80 ft³ (2.26 m³) per MTU fabricated.⁵ Reference 6 indicates that the amount of LLW generated from a MOX plant will increase by about 65% over the amount generated from the traditional UO_2 fabrication plant. Therefore, the total amount of waste from the new generation MOX fuel fabrication plant will be 132 ft³/MTHM (3.74 m³/MTHM), and will be assumed to be all TRU-LLW. Knowing the amount of fuel fabricated each year, the amount of TRU LLW shipped from the fabrication facilities can then be determined.

The projected amounts of LLW and TRU LLW from UO_2 and MOX fuel fabrication, respectively, and the number of shipments from the fabrication facilities are presented in the following tables. Tables 2.22 and 2.23 indicate the projected volumes and number of shipments of LLW and TRU LLW to shallow-land burial and deep geologic disposal, respectively. The LLW generated as shown in Table 2.23 is in lieu of some of the waste generation shown in Table 2.22.

The number of shipments of LLW and TRU LLW that originate from the various fuel fabrication facilities and that are shipped to shallow-land burial and deep geologic disposal, respectively, is based on the amounts of enriched UF_6 each facility receives. The percentages of total waste originating at each facility are as follows:

Wilmington, North Carolina	- 35%
Columbia, South Carolina	- 40%
Lynchburg, Virginia	- 8%
Windsor, Connecticut	- 8%
Richland, Washington	- 9%

Table 2.24 indicates the mileages from the UO_2 /MOX fuel fabrication facilities to the shallow-land burial and assumed deep geologic disposal sites. The locations of the fuel fabrication facilities in relation to either shallow-land LLW burial or assumed deep geologic disposal sites are illustrated in Figures 2.6 and 2.7, respectively. (No distribution of LLW among the various shallow-land burial sites is assumed in this study.)

2.1.5 Shipments From Light Water Reactors

There are two basic types of LWRs now operating in the United States--BWRs and PWRs. The present installed generating capacity of nuclear plants is represented by about a 2:1 PWR/BWR mix, and this ratio will be assumed to remain essentially the same for the period from 1980 to 2000 considered in this report. The installed nuclear capacity projections chosen for this report, which were based on projections made by the Department of Energy in May 1979, represent a low growth case for the period 1980 to 2000. These projections¹⁶ are given in Table 2.25 and Figure 2.8; the rationale for their selection is detailed in Appendix C.

TABLE 2.22
PROJECTED QUANTITIES AND NUMBER OF SHIPMENTS OF LLW
FROM FUEL FABRICATION FACILITIES TO SHALLOW-LAND BURIAL

Year	Volume Shipped (m ³) ¹	Number of Shipments ²
1980	8,300	480
1985	12,500	722
1990	17,700	1023
1995	20,800	1203
2000	25,800	1491

¹Based on 2.26 m³ of waste per MT UO₂ fabricated.

²Based on 17.3 m³/shipment; shipments will be in 55-gal drums, transported by truck. Shipments originate from the fabrication facilities as follows: Wilmington, NC--35%; Columbia, SC--40%; Lynchburg, VA--8%; Windsor, CT--8%; and Richland, WA--9%.

TABLE 2.23
PROJECTED QUANTITIES AND NUMBER OF SHIPMENTS TO TRU-LLW
FROM MOX FUEL FABRICATION FACILITIES TO GEOLOGIC DISPOSAL

Year	Volume Shipped (m ³) ^{1,3}	Number of Shipments ²
1991	900	108
1995	900	108
1998	2200	264
2000	2200	264

¹Based on 3.74 m³ of waste per MT of MOX fabricated.

²Based on 8.35 m³ (295 ft³) of waste per shipment. waste will be transported in 55-gal drums in a Super Tiger and carried by truck. Shipments originate from the fabrication facilities as follows: Wilmington, NC--35%; Lynchburg, VA--8%; Richland, WA--9%; Columbia, SC--40%; and Windsor, CT--8%.

³For every 3.74 m³ of waste generated from MOX fuel fabrication, 2.26 m³ less waste is generated and shipped than shown in Table 2.22.

TABLE 2.24

MILEAGES FROM FUEL FABRICATION FACILITIES TO LOW-LEVEL WASTE BURIAL/DISPOSAL

Fuel Fabrication Facilities	Distances to Low-Level Burial Sites			Distances to Assumed Deep Geologic Disposal Region
	Richland, WA	Beatty, NV	Barnwell, SC	
Richland, WA	-	660	2179	1578
Windsor, CT	2302	2354	761	1381
Lynchburg, VA	2129	2057	314	967
Wilmington, NC	2304	2175	210	1004
Columbia, SC	2166	2009	56	827

FIGURE 2.6 LOCATIONS OF FUEL FABRICATION AND SHALLOW-LAND BURIAL FACILITIES

FIGURE 2.7 LOCATION OF MOX FUEL FABRICATION FACILITIES IN RELATION TO ASSUMED GEOLOGIC REPOSITORY REGION

TABLE 2.25
PROJECTIONS OF INSTALLED U.S. NUCLEAR CAPACITY

Year ¹	Capacity (MWe) ²				
	Additional PWR	Additional BWR	Total PWR	Total BWR	Total ³ LWR
1965	175	326	175	326	501
1966	---	---	175	326	501
1967	---	---	175	326	501
1968	1,011	---	1,186	326	1,512
1969	---	1,278	1,186	1,604	2,790
1970	987	1,352	2,173	2,956	5,129
1971	1,405	1,336	3,578	4,292	7,870
1972	2,728	2,728	6,306	7,076	13,872
1973	5,478	---	11,784	7,076	18,860
1974	5,276	4,520	17,060	11,596	28,656
1975	3,645	3,464	20,705	15,060	35,765
1976	4,010	---	24,715	15,060	43,225
1977	3,449	1,857	28,164	16,917	45,081
1978	3,820	786	31,984	17,703	49,687
1979	---	---	31,984	17,703	49,687
1980	8,200	2,000	40,184	19,703	59,900
1985	25,900	13,200	66,100	32,900	99,000
1990	34,700	15,300	100,800	48,200	149,000
1995	20,000	10,000	120,800	58,200	179,000
2000	34,700	17,300	155,500	75,500	231,000

¹Data through 1978 are actual data.

²Based on DOE 1979 Low-growth case for nuclear power given in Reference 16 and discussed in Appendix C. See Section 1.1.2.

³Does not include Hanford N (860 MW) or Indian Point 1 (265 MW) since they will not produce commercial spent fuel or LLW.

FIGURE 2.8
PROJECTED INSTALLED U.S.
NUCLEAR CAPACITY

LWRs that are now operating, under construction, or planned through the year 2000 are illustrated in Figure 2.9. As discussed in Section 1.2, the United States was divided into six regions, based on Regional Electric Reliability Council areas, to simplify the process of quantifying shipments with LWRs all over the United States to other facilities in the fuel cycle. For convenience in estimating distances over which commodities must be transported into and out of specific LWR locations, centroids for each region were determined. These centroids represent a weighted average of all the LWR plants by size (MWe) in each region. As a result, great circle distances from the centroid of any region to any other specific sites in the fuel cycle (e.g., LLW burial sites) may be determined. In this way, LWR shipments are expressed from regions rather than from specific sites. This regional breakdown and the locations of the LWR centroids of the six regions are illustrated in Figure 2.10.

Spent Fuel and Other Reactor Components

Spent fuel discharged from LWRs will either go to an away-from-reactor (AFR) spent fuel storage facility or to a deep geologic repository. If the spent fuel is to be reprocessed, it may first go to a spent fuel storage facility. Whether or not spent fuel is reprocessed, if AFRs are utilized, they will be assumed to be located at or near the same sites as the assumed reprocessing plants as discussed in Section 1.2.6. The locations of the reprocessing facilities and the AFRs in relation to the reactor centroids are illustrated in Figure 2.11. In any case, either spent fuel or reprocessed waste will be shipped eventually to a deep geologic repository. Figure 2.12 illustrates the locations of the reactor centroids and AFR/reprocessing facilities in relation to the assumed geologic repository region. Mileages from the LWR centroids to the AFR/reprocessing facilities, or deep geologic repository region are given in Table 2.26.

A PWR and a BWR differ considerably in the quantities of spent fuel discharged and LLW produced. The spent fuel generation rate and projected shipping schedule for PWRs and BWRs are detailed in Appendix C, Sections C.2 and C.3. Table 2.27 presents the projected amounts of spent fuel discharged from PWRs and BWRs for the period 1980 to 2000, in

**FIGURE 2.9 SITES FOR LIGHT WATER REACTORS CURRENTLY OPERATING,
UNDER CONSTRUCTION, OR PLANNED**

FIGURE 2.10 LOCATIONS OF LIGHT WATER REACTOR WEIGHTED CENTROIDS BY REGION

FIGURE 1-12

× LWR CENTROIDS
○ AFR/REPROCESSING FACILITY

FIGURE 2.11 LOCATIONS OF LWR CENTROIDS IN RELATION TO ASSUMED
AFR / REPROCESSING FACILITIES

FIGURE 2.12 LOCATIONS OF LWR CENTROIDS AND ASSUMED AFR / REPROCESSING FACILITIES IN RELATION TO ASSUMED GEOLOGIC REPOSITORY REGION

TABLE 2.26

MILEAGES FROM LWR CENTROIDS TO ASSUMED AFR SPENT FUEL STORAGE,
REPROCESSING FACILITIES, AND DEEP GEOLOGIC REPOSITORY REGION

LWR Centroid	Distances to AFR/Reprocessing Facilities				Distances to Deep Geologic Repository Region
	Barnwell, SC	Morris, IL	West Valley, NY	Oak Ridge, TN	
Region 1	677	741	245	652	1301
Region 2	621	122	390	387	788
Region 3	118	564	578	120	573
Region 4	948	296	773	696	712
Region 5	756	687	1094	623	*
Region 6	2127	1581	2064	1899	1434

*The centroid for Region 5 is located within the region where a deep geologic repository is assumed to be.

TABLE 2.27
ESTIMATED SPENT FUEL DISCHARGE

Year	Number of PWR FA Discharged	Cumulative PWR FA	PWR MTHM Discharged	Cumulative MTHM, PWR	Number of BWR FAs Discharged	Cumulative BWR FA	BWR MTHM Discharged	Cumulative MTHM, BWR	Cumulative MTHM, LWR
1967	13	13	5	5	74	74	10	10	15
1968	13	26	5	10	74	148	10	20	30
1969	13	39	5	15	74	222	10	30	45
1970	88	127	32	47	74	296	10	40	87
1971	88	215	32	79	364	660	46	86	165
1972	161	376	58	137	673	1,330	85	171	308
1973	265	641	96	233	976	2,310	123	294	527
1974	467	1,110	169	402	1,610	3,920	202	496	898
1975	872	1,980	315	717	1,610	5,530	202	698	1,420
1976	1,270	3,250	459	1,180	2,640	8,170	332	1,030	2,210
1977	1,530	4,780	553	1,730	3,430	11,600	431	1,460	3,190
1978	1,830	6,610	662	2,390	3,430	15,030	431	1,890	4,280
1979	2,090	8,690	755	3,150	3,850	18,900	483	2,380	5,530
1980	2,370	11,060	854	4,000	3,990	22,900	506	2,880	6,880
1981	2,370	13,430	854	4,850	3,990	26,900	506	3,390	8,240
1982	2,850	16,300	1,070	5,920	4,350	31,209	563	3,950	9,870
1987	4,350	35,000	1,770	13,370	6,530	59,700	941	7,900	21,300
1990	5,560	50,470	2,380	19,780	7,960	82,150	1,270	10,100	29,900
1992	6,360	62,800	2,700	25,000	8,920	99,500	1,380	13,900	38,900
1997	7,520	98,100	3,230	40,100	10,500	149,000	1,660	21,700	61,800
2000	8,730	123,000	3,790	50,900	13,100	206,000	1,960	27,200	78,100

number of fuel assemblies (FA) and metric tons of heavy metal (MTHM) discharged, in annual and cumulative amounts. Figures 2.13 and 2.14 show the projected cumulative discharge and shipping schedules for PWR and BWR fuel assemblies, respectively.

Shipments of spent LWR fuel from the reactor centroids have been projected, assuming the first spent fuel is shipped in 1985. Since spent fuel is assumed to have been cooled for ten years before shipment, the first fuel shipped in 1985 will be assemblies accumulated through 1975. After 1985, the annual number shipped is the annual number put into storage ten years earlier. The projected number of fuel assemblies and the number of shipments of spent fuel from LWR centroids are given in Table 2.28. The number of spent fuel shipments which originate from each centroid is based on the generating capacity of BWRs and PWRs in each region, respectively, which are as follows:

<u>Region</u>	<u>% of Total PWR Generating Capacity</u>	<u>% of Total BWR Generating Capacity</u>
1	19	28
2	22	23
3	35	25
4	1	4
5	8	13
6	15	7

This results in 19% of the shipments of PWR spent fuel shipped by rail or truck originating in region 1, 22% from region 2, and so on. Likewise for BWR spent fuel shipments, 28% are shipped by rail and truck from region 1, 23% from region 2, etc. The shipments of BWR and PWR spent fuel beginning in 1985 are assumed to be sent to AFR storage at either Barnwell, South Carolina, Morris, Illinois, or West Valley New York. If fuel reprocessing begins in 1990, spent fuel is assumed to be shipped only to the AGNS reprocessing facility in Barnwell, South Carolina. Then in 1998 if additional reprocessing capacity comes on line, shipments of spent fuel will go to both the Barnwell facility and the assumed East Tennessee reprocessing facility.

FIGURE 2.13
PROJECTED DISCHARGE AND SHIPPING
SCHEDULE FOR PWR FUEL ASSEMBLIES

FIGURE 2.14
PROJECTED DISCHARGE AND SHIPPING SCHEDULE
FOR BWR FUEL ASSEMBLIES

TABLE 2.28
PROJECTED NUMBER OF SHIPMENTS OF SPENT FUEL
ASSEMBLIES FROM LWR CENTROIDS

Year	Fuel Assemblies Shipped Annually ¹			Number of Shipments by Mode ²			
	PWR	BWR	Total	Truck ³		Rail	
				PWR	BWR	PWR	BWR
1985	1,980	5,530	7,510	990	1383	124 ⁴	139 ⁴
1990	2,370	3,390	6,360	1067	898	163	110
1995	3,750	5,658	9,408	1500	1132	250 ⁵	148 ⁵
2000	5,560	7,960	13,520	1668	1194	390 ⁶	223 ⁶

¹Assumes a 10-year delay in shipping spent fuel; that is, fuel assemblies shipped in 1985 will be the number of assemblies accumulated by 1975. Subsequent to 1985, the number shipped is the annual number put into storage 10 years earlier.

²The percentage of shipments by mode is given in Table A.7.

³One PWR assembly or two BWR assemblies per cask.

⁴Weighted average of 4 IF 300 and 2 NLI 10/24 casks gives eight PWR or twenty BWR fuel assemblies per cask.

⁵Based on 9 PWR or 23 BWR fuel assemblies per cask.

⁶Based on 10 PWR or 25 BWR fuel assemblies per cask.

Other reactor components, such as PWR control rods, BWR control blades, and BWR channel boxes, are periodically removed from the reactor core and shipped for burial. The total number of these types of materials that are shipped from 1980 through 2000 is insignificant in comparison with the amounts of spent fuel shipped. These items are detailed in Appendix C, Section C.4.

LWR Wastes

The quantities of LLW shipped from BWRs and PWRs differ significantly. BWRs generally produce about twice as much LLW per year as do PWRs. The greater amount of LLW from BWRs results mainly from the greater amount of spent resins, concentrated contaminated liquids, and filter wastes produced by BWR plants. The LLW generated at all LWRs will be routinely shipped to shallow-land burial sites; locations of the sites in relation to the reactor centroids are illustrated in Figure 2.15. Mileages from the LWR centroids to the shallow-land burial sites are given in Table 2.29. (No distribution of LLW among the various shallow-land burial sites is assumed in this report.)

Two basic types of reactor coolant cleanup systems are used in BWR plants: (1) the deep-bed condensate polishing system (CPS) and (2) the precoat-filter CPS. About 75% of the BWRs now in operation use the deep-bed CPS, and 25% use the precoat-filter CPS.⁵ For PWR plants, about 50% of the coolant cleanup systems operate with a condensate polishing system, and 50% operate without such a system.⁵

The LLW from the two types of PWR and BWR plants can be broken down into five types of waste:

1. Spent resins.
2. Concentrated liquids.
3. Precoat filter sludge (BWR) and cartridge filters (PWR).
4. Compactible trash.
5. Noncompactible trash.

The percentage breakdowns of each of these waste categories from the respective types of PWR and BWR plants are given in Appendix A, Section A.1.1 and in Table A.1.

Several recent studies^{5,7} have considered the shipments of LLW from LWRs. Reactor waste data for the period 1960 to 1977 were compiled in

FIGURE 2.15 LOCATIONS OF LWR CENTROIDS IN RELATION TO SHALLOW-LAND BURIAL SITES

TABLE 2.29
MILEAGES FROM LWR CENTROIDS TO LLW BURIAL SITES

Centroid	Distances to LLW Burial Sites		
	Richland, WA	Beatty, NV	Barnwell, SC
Region 1	2250	2282	677
Region 2	1674	1663	621
Region 3	2068	1747	118
Region 4	1269	1278	948
Region 5	1617	1300	756
Region 6	350	322	2123

Reference 7, and graphs were presented of reactor waste generation rates in terms of volume generated per unit thermal power output per unit time ($\text{m}^3/\text{Mwt-hr}$). Other data in Reference 7 indicate the annual and cumulative number of waste shipments from PWRs and BWRs (m^3/yr), activity levels per unit volume shipped (Ci/m^3), and activity generated per unit thermal power output per unit time ($\text{Ci}/\text{Mwt-hr}$). For the purposes of this report, the waste generation rate data in $\text{m}^3/\text{Mwt-hr}$ were used because of the larger data base.

Reference 5 contained a detailed summary of surveys of 30 LWR power plants for the period 1971 to 1977. Eighteen PWR plants, both with and without a CPS, and twelve BWR plants, with either a deep-bed CPS or a precoat-filter CPS, were surveyed to determine average waste generation rates in $\text{ft}^3/\text{MWe-yr}$. These waste generation rates were used in Reference 5 in conjunction with projected increases in the electrical generating capacity of nuclear power plants to determine annual waste volumes through 2000. The effect on waste volume of (1) a broad application of current advanced volume-reduction systems and (2) pending requirements that all wastes be solidified before shipment were determined also in Reference 5. The waste generation rate projections for these different alternatives are summarized in Appendix B, Table B.1.

The ranges of waste generation rates for BWRs and PWRs presented in Reference 7 were chosen to make waste volume projections for this report. Waste generation rates for the period 1972 to 1977 varied over the following ranges:

PWR: 2 to $5 \times 10^{-5} \text{ m}^3/\text{Mwt-hr}$;

BWR: 5 to $8 \times 10^{-5} \text{ m}^3/\text{Mwt-hr}$.

With the installed nuclear capacity projections of Table 2.25, projections of LWR waste volumes can be made for the period 1980 to 2000. Three projections will be made: (1) a low estimate, (2) a high estimate, and (3) a best estimate. These generation rates are used in conjunction with the assumptions: (1) a 33% thermal efficiency for both PWRs and BWRs, and (2) a 60% capacity factor for low projection, 65% capacity factor for best-estimate projection, and a 70% capacity factor for high projection.

The ranges of waste generation rates from Reference 7 which will be used for the three projections are as follows:

PWR: $2 \times 10^{-5} \text{ m}^3/\text{Mwt-hr}$ for low projection,
 $3.5 \times 10^{-5} \text{ m}^3/\text{Mwt-hr}$ for best estimate projection,
 $5 \times 10^{-5} \text{ m}^3/\text{Mwt-hr}$ for high projection.

BWR: $5 \times 10^{-5} \text{ m}^3/\text{Mwt-hr}$ for low projection,
 $6.5 \times 10^{-5} \text{ m}^3/\text{Mwt-hr}$ for best-estimate projection,
 $8 \times 10^{-5} \text{ m}^3/\text{Mwt-hr}$ for high projection

The resulting waste volume projections are presented in Table 2.30 and are based on the continuation of present waste volume reduction and solidification practices. Waste volumes could be reduced by 5% per year by the greater use of waste reduction techniques that are currently available.⁵ Such a reduction would result in a net 64% decrease in the total waste shipped by the year 2000. The waste volume projections, with an assumed 5% reduction per year, are given in Table 2.31. Figure 2.16 illustrates the difference in these waste generation rates for both the continuation of present volume reduction and solidification practice and the introduction of 5% per year reduction in waste volume beginning in 1980.

Shipments of LLW from reactor centroids, projected for 1980 to 2000, are given in Table 2.32. The projected number of shipments which originate from each BWR or PWR centroid is based on the BWR and PWR generating capacity in each region, respectively. These breakdowns are based on the generating capacity of BWR and PWRs in each region which were given earlier in this subsection. Therefore, 19% of the shipments by the three modes originate from PWRs in region 1, 22% from region 2, etc. Likewise for BWRs, 28% of the shipments by the three modes originate from region 1, 23% from region 2, etc.

Figure 2.17 shows the effect of improving waste volume reduction practices by 5% per year on the number of shipments of LLW. It may be overly optimistic to assume that waste volumes will continue to decrease consistently by 5% per year for the next twenty years. Perhaps it would be more realistic to assume a reduction of 10% for the first ten years

TABLE 2.30

WASTE VOLUME PROJECTIONS FROM LWRs WITH CURRENT VOLUME REDUCTION

Year	Low Projection (m ³ /yr)			Best Estimate (m ³ /yr)			High Projection (m ³ /yr)		
	PWR	BWR	Total	PWR	BWR	Total	PWR	BWR	Total
1979	10,200	14,100	24,300	19,300	19,800	39,100	29,700	26,300	56,000
1980	12,800	15,700	28,500	24,300	22,100	46,400	37,300	29,300	66,600
1985	21,100	26,200	47,300	39,900	36,900	76,800	61,400	48,900	110,300
1990	32,100	38,400	70,500	60,900	54,100	115,000	93,650	71,650	165,300
1995	38,500	46,300	84,800	72,900	65,300	138,200	112,200	86,500	198,700
2000	49,500	60,100	109,600	93,900	84,700	178,600	144,500	112,200	256,700

TABLE 2.31

WASTE VOLUME PROJECTIONS FROM LWRs WITH IMPROVED VOLUME REDUCTION

Year	Low Projection ¹ (m ³ /yr)			Best Estimate ¹ (m ³ /yr)			High Projection ¹ (m ³ /yr)		
	PWR	BWR	Total	PWR	BWR	Total	PWR	BWR	Total
1979	10,200	14,100	24,300	19,300	19,800	39,100	29,700	26,300	56,000
1980	12,200	14,900	27,100	23,100	21,000	44,100	35,500	27,800	63,300
1985	16,300	20,300	36,600	30,900	28,500	59,400	47,500	37,800	85,300
1990	19,200	23,000	42,200	36,500	32,400	68,900	56,100	42,900	99,000
1995	17,800	21,400	39,200	33,800	30,300	64,100	52,000	40,100	92,100
2000	17,700	21,500	39,200	33,700	30,700	64,000	51,800	40,200	92,000

¹Beginning in 1980, a 5% per year reduction in waste volume will occur as a result of increased use of volume reduction techniques. This will result in a net 64% reduction in total waste shipped by the year 2000.

FIGURE 2.16 LWR WASTE VOLUME PROJECTIONS

TABLE 2.32
PROJECTED NUMBER OF SHIPMENTS OF LLW FROM LWR REGIONS
TO SHALLOW-LAND BURIAL SITES¹

Year	Number of Shipments by Mode ²							
	PWR				BWR			
	Mode 1	Mode 2	Mode 3	Total	Mode 1	Mode 2	Mode 3	Total
1980	858	258	180	1296	219	648	1015	1882
1985	1409	423	296	2128	365	1082	1694	3141
1990	2150	645	452	3247	535	1585	2483	4603
1995	2574	772	541	3887	646	1914	2997	5557
2000	3315	995	696	5006	838	2482	3887	7207

¹Assumes continuation of current volume reduction and solidification practice for the period 1980 to 2000, best-estimate case.

²Mode 1 is by shielded truck, carrying 55-gal drums and 4- by 4- by 8-ft boxes.

Mode 2 is by regular truck, carrying 55-gal drums and 4- by 4- by 8-ft boxes.

Mode 3 is by regular truck, carrying 300-ft³ cask.

FIGURE 2.17 BEST ESTIMATE PROJECTION OF NUMBER OF SHIPMENTS OF LLW FROM LWR REGIONS TO COMMERCIAL BURIAL SITES

and 5% for the next ten years, or to assume some other reduction scenario. In any event, after 2000 it would be highly unlikely for waste volumes to continue to be reduced by 5% per year. Nevertheless, the 5% per year waste volume reduction factor is useful to illustrate the dramatic effect that fuller utilization of currently available volume reduction systems could have on the amount of wastes to be shipped in the future. The projection used in this report, however, will be based on the continuation of current practices.

2.1.6 Shipments from Reprocessing Facilities

As was discussed in Section 1.1, commercial reprocessing of LWR fuel is assumed to begin in 1990 to provide a complete shipment scenario for this report. At that time the only reprocessing capacity is assumed to be provided by the Allied-General Nuclear Services (AGNS) plant in Barnwell, South Carolina. The reprocessing capacity is estimated to be 1500 MTHM in 1990. In 1998, an additional 2100 MTHM of reprocessing capacity is expected to come on line at a location in East Tennessee. The projections of reprocessing capacity, 10-year backlog of spent fuel available, and cumulative spent fuel reprocessed for the period 1990 to 2000 are given in Table 2.33.

Reprocessing Wastes

Numerous waste forms will be generated from the reprocessing of spent fuel; these wastes will be shipped to either the deep geologic repository region or LLW shallow-land burial sites. The waste forms will include HLW, cladding hulls, high-activity TRU wastes, TRU LLW, non-TRU LLW, and failed equipment. The first four categories of waste are assumed to be shipped to a deep geologic repository, whereas, the last two categories are assumed to be shipped to LLW shallow-land burial sites. The assumed locations of the reprocessing facilities in relation to the LLW shallow-land burial sites and geologic repository region are illustrated in Figures 2.18 and 2.19, respectively. Mileages from the reprocessing facilities to the LLW shallow-land burial sites and the geologic repository region are given in Table 2.34. (No distribution of LLW among the various shallow-land burial sites is assumed in this report.)

TABLE 2.33
METRIC TONS OF HEAVY METAL ASSUMED REPROCESSED

Year	10-Year- Old Backlog	Amount of 10-Year Old Backlog Generated	Amount Reprocessed	Cumulative Amount Reprocessed	Backlog at End of Year
1990	5,530	1,360	1,500	1,500	5,390
1991	5,390	1,360	1,500	3,000	5,250
1992	5,250	1,630	1,500	4,500	5,380
1993	5,380	1,850	1,500	6,000	5,730
1994	5,730	2,070	1,500	7,500	6,300
1995	6,300	2,280	1,500	9,000	7,080
1996	7,080	2,500	1,500	10,500	8,080
1997	8,080	2,710	1,500	12,000	9,290
1998	9,290	2,980	3,600	15,600	8,670
1999	8,670	3,250	3,600	19,200	8,320
2000	8,320	3,530	3,600	22,800	8,250

FIGURE 2.18 ASSUMED LOCATIONS OF REPROCESSING FACILITIES IN RELATION TO SHALLOW-LAND BURIAL SITES

FIGURE 2.19 LOCATIONS OF ASSUMED REPROCESSING FACILITIES IN RELATION TO ASSUMED GEOLOGIC REPOSITORY REGION

TABLE 2.34

MILEAGES FROM ASSUMED REPROCESSING FACILITIES TO LLW
SHALLOW-LAND BURIAL SITES AND ASSUMED GEOLOGIC REPOSITORY REGION

Burial Locations	Distances from Reprocessing Facilities	
	Barnwell, SC	East Tennessee Facility
Richland, WA	2179	1936
Beatty, NV	2060	1780
Barnwell, SC	-	252
Gulf Coast Region	807	779

The types of shipping containers used to transport these types of wastes are detailed in Appendix A, Sections A.1.2, and A.3.2. The quantities of the wastes produced from reprocessing a reference amount of spent fuel are discussed in Appendix D, Section D.2, and are summarized here in Table 2.35. Using these waste volume generation rates, the projected amounts of reprocessing wastes shipped for the period 1990 to 2000 can be calculated. These volumes are presented in Table 2.36, and the projected number of shipments is given in Tables 2.37 and 2.38. Up to 1998, all shipments will originate at the Barnwell facility. Beginning in 1998, when the East Tennessee reprocessing facility is assumed to come on line, 42% of the given shipments in the two aforementioned tables will originate from the Barnwell facility, and 58% will originate from the East Tennessee facility.

Reprocessed UF_6 and PuO_2

Uranium and plutonium extracted from the assumed reprocessing of spent fuel will be shipped to an enrichment facility and an MOX fuel fabrication facility, respectively as UF_6 and PuO_2 . According to Table D.3 in Appendix D, there are about 957 kg of uranium and 8.7 kg of plutonium (fissile + other Pu) per metric ton of heavy metal reprocessed. Therefore, there will be 1435 MTU (2123 MT UF_6) and 13 MT Pu (14.8 MT PuO_2) available for shipment to MOX fuel fabrication facilities from 1991 through 1998. In 1998, when an additional 2100 MTHM of reprocessing capacity is added, there will be 3445 MTU (5095 MT UF_6) and 31.3 MT Pu (35.6 MT PuO_2) available for MOX fuel fabrication.

Special safeguards must be implemented for shipping reprocessed PuO_2 . Containers filled with 28 kg of PuO_2 are placed in a special overpack; eight overpacks are then transported in a special sabotage-resistant, legal-weight truck, escorted by armed guards. The PuO_2 shipment package is discussed further in Appendix A, Section A.5.

Reprocessed plutonium will be shipped to MOX fuel fabrication; the projected number of such shipments for 1991 to 2000 is given in Table 2.39. The percentage of the PuO_2 shipments given in Table 2.39 which go to each of the MOX fuel fabrication facilities is assumed to be as follows:

TABLE 2.35
REPROCESSING WASTE VOLUMES

Waste Type	NFS ¹		AGNS ¹		Exxon ¹		Y/OWI	DEIS	Value Chosen For Report
	Generated (ft ³)	Shipped (ft ³)	Generated (ft ³)	Shipped (ft ³)	Generated (ft ³)	Shipped (ft ³)	(ft ³)	(ft ³)	(ft ³)
HLW ²	5,600	5,600	3,000-5,250	3,000-5,250	3,600	3,600	2,250-4,500	3,900	4,000
Hulls ⁷	18,400	14,000	30,000	30,000	22,500	22,500	17,700	17,800	20,000
High-Activity Wastes	9,600	8,600	10,960	1,840	1,960	1,960	Note 3	Note 3	2,000
LLW TRU	35,000	3,500	62,900	9,160	61,400	14,100	57,600	50,700	15,000
Non-TRU Resins	62,730	57,200	---	---	4,300	7,100 ⁴	---	32,100	25,000
LLW ⁵	73,000	23,700	71,170	36,580	82,100	23,960	---	34,900	30,000
Failed Equipment	20,720	31,000 ⁶	---	---	930	1,300 ⁶	9,200	30,500	20,000

¹Based on 1500 MTHM.

²When two volumes are given for HLW, the lower value is for calcine waste (81 lb/ft³) and the higher value is for glass waste (187 lb/ft³).

³ILW volume is included in this LLW TRU.

⁴No explanation is given for the increase.

⁵Includes combustible, noncombustible, and compactible.

⁶Volume increase is due to cementing of the waste.

⁷Density is 100 lb/ft³ assuming 20% theoretical density for uncompacted hulls and an equal volume of sand, leaving 60% void space.

TABLE 2.36

PROJECTED REPROCESSING WASTE VOLUMES SHIPPED FOR DISPOSAL

Year	HLW (m ³)	Cladding Hulls (m ³)	High- Activity Wastes (m ³)	TRU LLW (m ³)	Non-TRU Resins (m ³)	LLW (m ³)	Failed Equipment (m ³)
1990	115	570	60	425	700	850	570
1992	115	570	60	425	700	850	570
1994	115	570	60	425	700	850	570
1996	115	570	60	425	700	850	570
1998	275	1,370	145	1,020	1,680	2,040	1,370
2000	275	1,370	145	1,020	1,680	2,040	1,370

Based on average estimates of waste generation rates presented in Table 2.21, assuming 1500 MTHM reprocessing capacity from 1990 to 1998 and 3600 MTHM reprocessing capacity from 1998 to 2000.

TABLE 2.37
PROJECTED NUMBER OF SHIPMENTS FOR REPROCESSING
WASTE VOLUMES TO ASSUMED GEOLOGIC DISPOSAL REGION

Year	Number of Shipments by Waste Category			
	HLW ¹	Cladding Hulls ²	High Activity ³ TRU-Waste	TRU LLW ⁴
1990	107	318	19	36
1992	107	318	19	36
1994	107	318	19	36
1996	107	318	19	36
1998 ⁵	255	762	46	86
2000	255	762	46	86

¹Shipped by rail in a shielded cask containing 6 canisters.

²Shipped by rail, 3 casks with three 55-gal drums/cask on a railcar.

³Shipped by truck, holding one Super Tiger and one Half Super Tiger, with a total of 15 shielded 55-gal drums.

⁴Shipped by truck, holding one Super Tiger and one Half Super Tiger, with a total of 60 55-gal drums.

⁵Until 1998, 100% of waste comes from Barnwell, SC; during and after 1998, 42% comes from Barnwell and 58% comes from East Tennessee.

TABLE 2.38
PROJECTED NUMBER OF SHIPMENTS FOR REPROCESSING
WASTE VOLUMES TO SHALLOW-LAND BURIAL

Year	Number of Shipments by Waste Category	
	Non-TRU LLW ¹	Failed Equipment ²
1990	90	33
1992	90	33
1994	90	33
1996	90	33
1998	215 ³	78 ³
2000	215	78

¹Includes non-TRU resins and combustible, compactible and noncompactible non-TRU trash shipped in 55-gal drums by truck.

²Failed equipment may be cemented in drums before shipping to meet non-TRU classification (<10 nCi per gram of waste).

³Until 1998, all non-TRU waste originates at Barnwell, SC; during and after 1998, 42% originates at Barnwell, and 58% originates at the East Tennessee location.

TABLE 2.39

PROJECTED NUMBER OF SHIPMENTS OF REPROCESSED PuO_2 FROM ASSUMED
REPROCESSING FACILITIES TO MOX FUEL FABRICATION FACILITIES

Year	Amount Shipped (MT PuO_2)	Number of Shipments ¹
1991	14.8	66
1995	14.8	66
1999 ²	35.6	159
2000	35.6	159

¹Based on 28 kg PuO_2 per container, with 8 containers shipped in a special truck, for a net 0.224 MT/shipment.

²Until 1998, all shipments of reprocessed PuO_2 originate at Barnwell, SC; during and after 1998, 42% originates at Barnwell, and 58% originates at the East Tennessee site.

Wilmington, North Carolina	- 35%
Columbia, South Carolina	- 40%
Lynchburg, Virginia	- 8%
Windsor, Connecticut	- 8%
Richland, Washington	- 9%

Mileages from the reprocessing facilities to the MOX fuel fabrication facilities are given in Table 2.40. The location of the assumed reprocessing facilities in relation to the MOX fuel fabrication facilities is illustrated in Figure 2.20.

Reprocessed uranium will be shipped to the enrichment facilities as UF_6 for enrichment before fabrication. The projected number of shipments of reprocessed uranium shipped from the reprocessing facilities to the enrichment facilities is given in Table 2.41. The percentage of the reprocessed uranium shipments which go to the enrichment facilities is assumed to be as follows:

Paducah, Kentucky	- 20%
Oak Ridge, Tennessee	- 40%
Portsmouth, Ohio	- 40%

The mileages from the reprocessing facilities to the enrichment facilities are given in Table 2.42 and the location of the reprocessing facilities to the enrichment facilities is illustrated in Figure 2.21.

TABLE 2.40
MILEAGES FROM ASSUMED REPROCESSING FACILITIES TO
MOX FUEL FABRICATION FACILITIES

MOX Fuel Fabrication Facility	Distances from Reprocessing Facilities	
	Barnwell, SC	East Tennessee Facility
Richland, WA	2179	1936
Windsor, CT	761	742
Lynchburg, VA	314	372
Wilmington, NC	210	141
Columbia, SC	56	175

FIGURE 2.20 LOCATIONS OF ASSUMED REPROCESSING AND MOX FUEL FABRICATION FACILITIES

TABLE 2.41
PROJECTED NUMBER OF SHIPMENTS OF UF₆ FROM
ASSUMED REPROCESSING FACILITIES TO ENRICHMENT FACILITIES

Year	Amount Shipped (MT UF ₆)	Number of Shipments ¹
1991	2123	85
1995	2123	85
1999	5095 ²	204 ²
2000	5095	204

¹Based on shipments in 48Y cylinders by rail, with 4 cylinders per shipment, or 25 MT UF₆/shipment.

²Until 1998, 100% of reprocessed UF₆ comes from Barnwell, SC; during and after 1998, 42% comes from Barnwell, and 58% comes from an East Tennessee location.

TABLE 2.42
MILEAGES FROM ASSUMED REPROCESSING FACILITIES
TO ENRICHMENT FACILITIES

Enrichment Facility	Distance from Reprocessing Facility	
	Barnwell, SC	East Tennessee
Oak Ridge, TN	252	-
Paducah, KY	502	252
Portsmouth, OH	400	260

FIGURE 2.21 LOCATIONS OF ASSUMED REPROCESSING AND ENRICHMENT FACILITIES

2.2 SHIPMENTS OF INSTITUTIONAL WASTES

Wastes from the institutional sector are generated at locations throughout the United States, with the largest generators being located in the states and regions that have the heaviest populations. All institutional wastes are shipped to shallow-land LLW burial sites, located at Barnwell, South Carolina, Beatty, Nevada, and Richland, Washington.

The percentage of the total institutional waste volume shipped each year by region in 1978 is as follows:⁸

Region 1 - Northeast	28%
Region 2 - East Central	17%
Region 3 - South	17%
Region 4 - North Central	9%
Region 5 - South Central	14%
Region 6 - West	14%

The amount of institutional LLW shipped during the period 1972 to 1977 indicates that the annual increase in waste volume shipped has been about 20%.⁹ In 1978, 21,300 m³ of LLW from the institutional sector was shipped for burial.⁸ The typical composition of this waste was:

Biological waste	10%
Adsorbed liquids	12%
Dry solid waste	35%
Liquid scintillation vials	43%

For future projections of institutional waste shipments these percentage breakdowns will be assumed to apply. Table 2.43 and Figure 2.22 show the medium projection of the amount of waste shipped, for which the 20% per year increase in the 1978 waste volume shipped is assumed to continue for the period 1980 to 2000. A low estimate (i.e., a 15% increase per year over the 1978 volume shipped) and a high estimate (a 25% increase/year) are also presented in Table 2.43 and Figure 2.22. If a 5% per year reduction in waste volume resulting from improvements in waste reduction technology is assumed to occur beginning

TABLE 2.43

INSTITUTIONAL WASTE PROJECTIONS WITH CURRENT VOLUME REDUCTION

Year	Low- Projection Waste Volume (m ³) ¹	Medium- Projection Waste Volume (m ³) ²	High- Projection Waste Volume (m ³) ³
1979	24,400	25,400	26,500
1980	27,600	29,700	31,800
1985	43,500	50,900	58,300
1990	59,400	72,100	84,800
1995	75,400	93,300	111,300
2000	91,300	114,500	137,800

¹Assumes a 15% per year increase over the 1978 waste volume shipped.

²Assumes a 20% per year increase over the 1978 waste volume shipped.

³Assumes a 25% per year increase over the 1978 waste volume shipped.

FIGURE 2.22 INSTITUTIONAL WASTE PROJECTIONS

in 1980, the net reduction in total waste shipped by the year 2000 will be 64%. The results of this potential improvement are presented in Table 2.44 and Figure 2.22.

Based on the medium projection from Table 2.43, the amounts of waste and the projected number of shipments for institutional wastes are given in Table 2.45. Figure 2.23 illustrates the percentage of the total institutional waste that is shipped from each region in relation to the LLW shallow-land burial sites.

TABLE 2.44

INSTITUTIONAL WASTE PROJECTIONS WITH IMPROVED WASTE VOLUME REDUCTION

Year	Low- Projection Waste Volume (m ³) ¹	Medium- Projection Waste Volume (m ³) ¹	High- Projection Waste Volume (m ³) ¹
1979	24,400	25,400	26,500
1980	26,200	28,200	30,200
1985	33,700	39,400	45,100
1990	35,600	43,100	50,800
1995	34,900	43,200	51,600
2000	32,700	41,000	49,400

¹ Assumes a 5% per year decrease in the 1978 waste volume resulting from improvements in waste volume reduction technology beginning in 1980.

TABLE 2.45
PROJECTED NUMBER OF SHIPMENTS OF INSTITUTIONAL
LLW TO SHALLOW-LAND BURIAL

Year	Amount Shipped (m ³) ¹	Number of Shipments ²
1980	29,700	4,480
1985	50,900	7,679
1990	72,100	10,877
1995	93,300	14,075
2000	114,500	17,273

¹Based on the medium projection from Table 2.43.

²Based on forty 55-gal drums and ten 30-gal drums per shipment in an exclusive-use truck, with a packing efficiency of 0.7. This results in 6.63 m³/shipment.

FIGURE 2.23 PERCENTAGES OF INSTITUTIONAL LOW-LEVEL WASTE GENERATED BY REGION IN RELATION TO SHALLOW-LAND BURIAL SITES

2.3 SHIPMENTS OF DEFENSE TRANSURANIC WASTES

Defense programs in the United States that have generated and continue to generate TRU wastes are located at several sites (Figure 2.24). The defense TRU wastes are assumed to be transported predominately by rail, as has been done in the past. TRU defense wastes generated at the Bettis, Pennsylvania site, the Mound Facility in Ohio, the Argonne, Illinois lab, and the Rocky Flats, Colorado site are assumed to be shipped for storage at the Idaho National Engineering Laboratory (INEL) in Idaho Falls.

The projected amounts of defense TRU wastes and the number of shipments are based on data of generation rates in Table 2.46. The estimated waste generation rates in Table 2.46 are based on the estimated rates of accumulation between 1978 and 1985 and on actual quantities adjusted to reflect yearly production, produced during FY 76-76A.^{10,11} The projections listed in that table are through 1985, but will be assumed to remain constant through 2000. The projected number of shipments are given in Table 2.47. Mileages from the waste generation sites to the Idaho Falls storage site are given in Table 2.48.

Note that, in Table 2.46, the generation rates of CH TRU wastes listed for the period 1978 to 1985 at the Idaho Falls site are actually estimates of the amounts of CH TRU waste that will be shipped to Idaho from such generation locations as Rocky Flats, Mound Lab, Argonne, and Bettis. The various CH containers are detailed in Appendix A, Section A.8.

FIGURE 2.24 LOCATIONS OF DOE FACILITIES THAT GENERATE AND/OR STORE DEFENSE TRU WASTES

TABLE 2.46

QUANTITIES OF DEFENSE TRU WASTE AND PROJECTED GENERATION RATES

Location	Backlog Quantities as of 1/1/78 (ft ³)			Generation Rates (ft ³ /yr)		
	Retrievably Stored		Buried	CH		RH
	Contact Handled	Remote Handled		1978-85 Estimate	FY76-76A Survey	1978-85 Estimate
Idaho Falls, ID	1,200,000	300	2,100,000	120,000 ¹	0	2,000
Hanford, WA	250,000	2,900	5,500,000	75,000	43,000	700
Savannah River, SC	60,000	0	1,100,000	5,600	5,600	0
Los Alamos, NM	50,000	0	600,000	20,900	9,400	1,100
Oak Ridge, TN	10,000	26,500	200,000	1,300	3,100	3,000
Nevada Test Site, NV	10,000	0	0	4,200	0	0
Rocky Flats, CO	0	0	0	---	71,200	---
Mound Lab, OH	0	0	0	---	10,600	---
Argonne National Lab, IL	0	0	0	---	3,800	---
Bettis, PA	0	0	0	---	3,000	---
Others	0	0	0	---	3,000	---
SubTotal	1,580,000	29,700	9,500,000	227,000	152,700	6,800
Total	11.1 x 10 ⁶ ft ³					

¹This quantity is the estimated amount of CH TRU waste that will be shipped to Idaho from Rocky Flats, Mound Lab, Argonne, and Bettis. Very little CH TRU waste is actually generated at Idaho.

TABLE 2.47
PROJECTED NUMBER OF SHIPMENTS OF
DEFENSE TRU WASTES TO IDAHO FALLS

Generation Location	Number of Shipments by Year				
	1980	1985	1990	1995	2000
Bettis, PA ¹	10	10	10	10	10
Argonne, IL ²	8	8	8	8	8
Mound Facility, OH ³	12	12	12	12	12
Rocky Flats, CO ³	80	80	80	80	80

¹Based on shipments in Super Tigers by truck.

²Based on shipments in Poly Panthers by truck.

³Based on shipments in ATMX railcars.

TABLE 2.48
MILEAGES FROM DEFENSE TRU GENERATION LOCATIONS TO IDAHO FALLS

Defense TRU Locations	Idaho Falls
Bettis, Pennsylvania	1713
Mound Facility, Ohio	1512
Argonne Laboratory, Illinois	1270
Rocky Flats, Colorado	517

2.4 RADIOACTIVE MATERIAL CATEGORIES AND TRANSPORTATION EQUIPMENT

This section defines the categories of radioactive materials and the equipment used to transport them. The primary packaging is emphasized, with some discussion of the transportation mode. The packages are transportable by truck, rail, or marine modes unless the license explicitly restricts the type of modes. In this report, it is assumed that all truck shipments are below the legal weight limits, and all rail shipments are unrestricted (<263,000 lb) unless otherwise specified.

Radioactive wastes are generated at all facilities and include an assortment of materials with a wide range of contamination levels. For the purposes of this study, these wastes will be classified as LLW, HLW, or cladding waste. Cladding waste includes chopped sections of Zircaloy tubing, stainless steel, and Inconel fuel assembly hardware contaminated with activation products. HLW results from the fission product stream that is generated when spent fuel is reprocessed. Cladding waste and HLW are produced only in the event of spent fuel reprocessing. All other wastes are classified as LLW.

Generally, the materials requiring transportation are unique to a particular facility discussed in Sections 2.1 through 2.3. Low-level waste is a notable exception since it is generated at most facilities. The materials discussed below are related to the facility descriptions, as shown in Table 2.49.

There are five general classifications for packages, depending on the type and radioactivity of specific radionuclides contained. The Department of Transportation (DOT) regulations specify "limited quantities" of radioactive material which are exempt from the DOT packaging, marking, and labeling requirements. Such "limited quantity" shipments are permitted in the U.S. mail. A classification of "low specific activity material" (LSA) applies to material having a low level of activity per unit mass and includes thorium and uranium ores, tritiated water having a specific activity less than 5 millicuries per milliliter, and materials having less than the activity specified in DOT regulations (49 CFR 173).

The next larger quantity class is "Type A." Packages containing Type A quantities must conform to DOT package specification (49 CFR 173) for Type A packages which include a series of tests designed to simulate

TABLE 2.49
ORIGIN OF RADIOACTIVE MATERIAL SHIPMENTS

Material Transported	Origin	Section Number of Descriptive Material		
		Facility	Package Description	Supplemental Information
Low-Level Waste	Conversion thru Reprocessing	2.1.2 thru 2.1.6	2.4.1	A.1
Yellowcake	Mill	2.1.1	2.1.1	A.7
UF ₆	Conversion Enrichment Reprocessing	2.1.2 2.1.3 2.1.6	2.4.2	A.6
Fresh Fuel	Fabrication	2.1.4	2.4.3	A.4
Spent Fuel	Reactor	2.1.5	2.4.4	A.2
High-Level Waste	Reprocessing	2.1.6	2.4.5	A.3
Cladding Hulls Waste	Reprocessing	2.1.6	2.4.6	A.3
UO ₂	Conversion/ Fabrication	2.1.4	A.5	A.5
PuO ₂	Reprocessing	2.1.6	2.4.7	A.5
Institutional Waste	Institutions	2.2	2.4.1	---
Defense TRU Waste	Defense Facilities	2.3	2.4.8	A.8
TRU Waste	Fabrication Reprocessing	2.1.2 thru 2.1.6	2.4.1	A.1
Intermediate-Level Waste	Conversion thru Reprocessing	2.1.2 thru 2.1.6	2.4.1	A.1

a normal accident, for example, a package falling off the tailgate of a truck during an unloading sequence. These tests include a drop of 1.2 m (48 in.) onto an unyielding surface, a puncture test, a stacking test, an internal pressure test, and a water spray test. Shipments not exceeding Type A quantity limits and which conform to the DOT regulations are exempted from the NRC requirements discussed in the next paragraph.

Shipments containing greater than Type A quantities of radionuclides are termed either "Type B" or "large quantity" shipments. Large quantity shipments contain greater than the Type B quantity limits. These shipments must conform to NRC requirements in 10 CFR Part 71 as well as to the DOT requirements. The packages used for these shipments also must conform to testing requirements for hypothetical accident conditions, as well as to testing requirements for routine transport conditions. The tests include a drop test from 9 m (30 ft), a fire test of 800°C (1475°F) for 3 minutes, a drop test of 1 m (40 in.) onto a 6 in. diameter unyielding pin, and a water submersion test for fissile material. These sequential tests are designed to simulate a severe hypothetical accident.

2.4.1 Low-Level Waste

LLW includes resins and filters from liquid cleanup systems at reactors, AFR storage facilities, and fuel storage pools in reprocessing facilities; HEPA filters; various radioactive trash from all facilities (e.g., failed or obsolete equipment, plastic bags, gloves, and other protective clothing); and miscellaneous combustible and noncombustible trash. The waste is generally shipped in 210-liter (55-gal) drums, in plywood boxes, or in disposable metal containers (liner) inside a reusable shield.

Defense-related wastes contaminated with more than 10 nCi per gram of waste are classified as TRU LLW. Some of the commercial waste is contaminated with TRU elements, and a similar definition for commercial waste can be expected. Non-TRU LLW are disposed of by shallow-land burial, whereas TRU LLW are assumed to be put in a deep geologic disposal facility. In general, wastes from reactors, mills, UF₆ conversion, and uranium enrichment plants are non-TRU. Waste from MOX

fuel fabrication facilities is almost entirely TRU-contaminated, as are about 70% (by volume) of reprocessing facility wastes. Reactor wastes associated with leaking fuel assemblies may be classified as TRU wastes in the future.

If radioactivity levels exceed values such that the wastes must be shielded during handling or must be handled remotely, then the LLW are further classified as high-activity LLW, intermediate-level waste (ILW), or RH waste (vs. CH waste). Thus, LLW could be designated as LLW, TRU LLW, ILW, TRU ILW, RH TRU, etc. Generally, the RH/CH designation is used only for defense wastes, where the RH designation is for wastes having dose rates in excess of 200 mrem/hr at the surface of the RH container.¹² Wastes that require shielding are sometimes called ILW if the surface dose rate is greater than 10 mrem/hr; however, in other cases¹³ the threshold for special shielding is 50 mrem/hr.

Various transport packages are used for LLW, and one consideration when selecting a package is the amount of shielding required. Because the threshold for shielding varies, we have generally avoided using special nomenclature for LLW in this report. We have used the following designations:

1. A regular truck van is used if the radioactivity levels outside the van meet regulations.
2. A shielded van (a regular truck trailer lined with steel plates) is used if the radioactivity levels require the equivalent of about 0.5 in. of lead (package surface radiation levels [0.02 - 1 rem/hr]).
3. If designations 1 and 2 cannot be used, an LLW package is used which incorporates the required shielding (see Table 2.50).
4. A special designation of "high activity" is used for TRU LLW from reprocessing plants that require a relatively highly shielded package (see Section A.1.2).

According to Reference 12, RH defense wastes are stored where they are generated. Therefore, since only CH wastes are transported, the RH/CH distinction is not important for this report. Defense waste packages are discussed further in Section 2.4.8 and Appendix A.8.

A detailed discussion of transport package classifications is beyond the scope of this report. As discussed earlier, DOT regulations are applicable to packages containing up to Type A quantities of radionuclides and the NRC licenses packages containing greater than Type A, (i.e., Type B) quantities of radionuclides. As detailed in Section A.1, most of the LLW is placed in 210-liter (55-gal) drums or boxes. The drums usually meet Type A specifications, but boxes may only meet a less-restrictive specification--low specific activity (LSA). In either case, the drums and boxes are shipped in regular trailers or shielded vans, as tabulated in Section 2.1 and detailed in Section A.1.

The remainder of the LLW is shipped in shielded transport packages, and Table 2.50 lists 15 of the approximately 50 different packages available. The variety of available packages permits a more economical package selection, depending on waste volume, form, and activity. The transport package will contain a number of 210-liter drums or a disposable steel liner, which usually contains dewatered resins.

Figure 2.25 shows one of the large-volume, lightly-shielded packages on a truck trailer, and Figure 2.26 shows two heavily-shielded packages on a truck trailer. Figure 2.27 shows a package that is loaded from the side using a powered loading tray. Figure 2.28 shows the Super Tiger package that is assumed in this study to be used for TRU-contaminated LLW. Some defense TRU wastes are shipped in Super Tigers and in the Poly Panther package shown in Figure 2.29.

2.4.2 Uranium Hexafluoride

Uranium hexafluoride is a highly reactive material, which can rapidly combine chemically with water, most organic compounds, and other metals. UF_6 does not react with oxygen, nitrogen, or dry air, and it is sufficiently inert with aluminum, copper, Monel, and nickel that they can be used in a UF_6 environment without excessive corrosion. At room temperature, UF_6 is a white, volatile solid. The UF_6 is placed in its shipping container under pressure as a liquid at about 90°C (200°F), after which it is cooled to room temperature and solidified before shipment.

TABLE 2.50

TYPICAL SHIELDED TRANSPORT PACKAGES FOR LLW

Package Designation	Contents Classification Type	NRC Certification Number	Shielding (in.)	210-liter (55-gal) Drum Capacity	Liner Capacity (ft ³)	Radiation Level (R/hr)	Contents Maximum Container Empty Weight (lb)	Payload Weight (lb)
CNS 1-13C	B	9081	5.7 ¹	1	13	1,000	20,950	5,000
CNS 6-80-2	A	9111	5.0 ¹	4	85	500	44,000	7,500
CNS 7-100	A	9113	3.5 ¹	7	87	150	35,000	7,000
CNS 8-120 (LN-50-100)	B	6601	4.5 ¹	8	126	250	58,000	12,000
CNS 14-195H	A	9094	2.75 ¹	14	200	25	39,650	16,850
CNS 21-300	A	9096	1.5 ¹	21	322	5	30,200	27,250
HN-100 Series 2	A	9079	1.75 Pb 1.25 Steel	14	170	15	33,800	14,000
HN-200	B	6574	3.75 Pb 1.25 Steel	3	80	800	37,325	7,400
HN-300	A	9092	3.75 Steel	12	140	5	35,000	8,000
HN-600	A	9080	2.75 Pb 1.5 Steel	7	80	100	35,000	13,000
Super Tiger	B	6400	0.4 Steel	42	575	NA ²	15,000	30,000
Half Super Tiger Mode A	B	6679	0.4 Steel	18	284	NA ²	8,000	16,000
Half Super Tiger Mode B	B	6679	NA ²	NA ²	NA ²	NA ²	45,000	3,000
Poly Panther	B	6272	0.4 Steel	NA ²	120	NA ²	3,500	3,000
NECO B3	B	6058	0.4 Steel 6 Pb	1	13	NA ²	20,500	9,000

¹Equivalent lead thickness.²Not available.

FIGURE 2.25 A LARGE-VOLUME, LIGHTLY-SHIELDED PACKAGE

FIGURE 2.26 HEAVILY-SHIELDED WASTE PACKAGES

FIGURE 2.27 SIDE-LOADED WASTE PACKAGE WITH RETRACTABLE LOADING TRAY

PAYLOAD LIMIT: 30,000 LBS.
EMPTY WEIGHT: 15,000 LBS.

FIGURE 2.28 THE SUPER TIGER PACKAGE

FIGURE 2.29 THE POLY PANTHER PACKAGE

Three containers are generally used for shipping UF_6 in the LWR fuel cycle: the 30B cylinder containing 2.5 tons,* the 48X cylinder containing 10 tons,* and the 48Y cylinder containing 14 tons.* Two 10-ton cylinders, one 14-ton cylinder, or five 2.5 ton cylinders can be transported on a truck trailer. Four 10-ton cylinders, four 14-ton cylinders, or sixteen 2.5 ton cylinders can be transported on a railroad flatcar. Four 48X (10-ton) cylinders are shown on a railcar in Figure 2.30.

Cylinders containing UF_6 enriched to greater than 1.0 wt% ^{235}U must be shipped in protective outer packages (called overpacks) to ensure criticality prevention and to help protect the cylinders from accident environments. Usually, such shipments constitute a Type B quantity of radioactive material under NRC regulations, and Type B protective overpacks for the 2.5- and 10-ton cylinders have been designed to satisfy the accident test criteria of 10 CFR 71 (DOT Specification 21 PF-3 and 21 PF-1, respectively). These overpacks are boxes or cylinders with about 6 in. of foam between steel plates. Neoprene pads or rubber cradles inside the inner steel liner cushion the UF_6 cylinder. Figure 2.31 shows five 30B cylinders in their overpacks and ready for truck transport.

2.4.3 Fresh Fuel

Fresh fuel assemblies are usually enclosed in a plastic bag and shipped in a container that supports the fuel assembly along its entire length (sometimes called a strongback). Typically, two fuel assemblies are packaged within one container. Containers for PWR fuel are about 5.3 m long and 1.2 m in diameter and weigh about 4800 kg when loaded. Six PWR containers (12 fuel assemblies) are typically shipped on a truck trailer by using simple tiedown techniques. BWR containers are about 0.8 m square by 5.3 m long and weigh up to 1270 kg when loaded. Eighteen containers (36 fuel assemblies) are typically shipped on a truck trailer. Figure 2.32 shows a PWR fresh fuel shipment.

*The "2½-ton" cylinder has a nominal capacity of 2.28 metric tons; however, the nomenclature is common practice. The same is true for the "10-ton" (9.5 MT) and "14-ton" (12.5 MT) cylinders.

FIGURE 2.30 FOUR 10-TON UF_6 CYLINDERS

FIGURE 2.31 ENRICHED UF_6 CYLINDERS IN OVERPACKS

FIGURE 2.32 FRESH FUEL SHIPMENT

MOX fresh fuel packages are expected to resemble the PWR containers because of safeguards requirements. Also, a special, sabotage-resistant truck will likely be required to meet evolving regulations. The transport of this type of fuel assembly is not assumed to begin until about 1991.

2.4.4 Spent Fuel

Spent fuel contains uranium, plutonium, other TRU radionuclides, and highly radioactive fission products. The radioactive decay processes of these materials also generate a large amount of decay heat. The spent fuel assemblies are usually stored at the reactor for at least 120 days to allow radioactivity and heat generation levels to decrease before transport. After 120 days, the typical LWR spent fuel assembly contains about 2×10^6 Ci and generates about 8.4 kW of heat. Casks are licensed for spent fuel that has been cooled for as short as 120 to 180 days; however, the present practice is to let the spent fuel cool much longer--5 to 10 years. After 10 years, the radioactivity level would be lower by a factor of 10, and the heat generation rate would be lower by a factor of more than 20.

Spent fuel shipping casks are designed with a thick layer of steel, lead, or depleted uranium for gamma shielding and with a water or solid hydrocarbon layer for neutron shielding. Steel liners provide structural strength and additional gamma shielding. Heat removal is usually accomplished by natural convection and conduction inside the cask and by natural convection and radiation from numerous fins on the exterior of the cask. Although not required for safety, mechanical heat removal systems are sometimes provided to reduce the time required to cool the cask and contents before unloading and thereby reduce shipping costs. All these factors make spent fuel shipping casks massive.

Spent LWR fuel has been shipped in the United States for many years, and several types of shipping casks have been designed. Table 2.51 lists information about casks now available or proposed for domestic use, and Section A.2 contains descriptions of several additional proposed casks. Figure 2.33 shows the IF 300 cask loaded on a railcar, and Figure 2.34 shows a spent fuel cask on a truck trailer. Figure 2.35 shows two barge roll-on/roll-off transferral processes.

TABLE 2.51

LICENSED OR PROPOSED SHIPPING CASKS FOR CURRENT-GENERATION LWR SPENT FUEL

Cask Designation	Number of Assemblies		Loaded (Empty) Cask Weight (MT)	Usual Transport Mode ¹	Shielding		Cavity Coolant	Maximum Heat Removal (kW)	Status (NRC Certificate Number)
	PWR	BWR			Gamma	Neutron			
NAC-1 (NFS-4)	1	2	23 ² (22)	Truck	Lead and steel	Borated water and antifreeze	Water ⁷	11.5	Licensed (6698)
NLI 1/2	1	2	22 (21)	Truck	Lead, uranium, and steel	Water and antifreeze	Helium	10.6	Licensed (9010)
TN-8	3		36 (33)	Truck ³	Lead and steel	Borated solid resin	Air	35.5	Licensed (9015)
TN-9		7	36 (33)	Truck ³	Lead and steel	Borated solid resin	Air	24.4	Licensed (9016)
TN-12	12	32	98 (90)	Rail	Steel	Borated solid resin	Air	120	Licensed in Europe only
IF-300	7	18	63 ⁴ (53)	Rail ⁵	Uranium and steel	Water and antifreeze	Water or air	76 ⁶	Licensed (9001)
NLI 10/24	10	24	88 (80)	Rail	Lead, uranium, and steel	Water and antifreeze	Helium	97 ⁸	Licensed (9023)
NAC-3	12	32	100 ⁹ (90)	Rail	Steel	Water and antifreeze	Water or air	100 ⁹	SAR submitted

¹Barge transport permissible unless explicitly ruled out by license.

²Excludes special trailer weighing 11 MT.

³Overweight permit required.

⁴Excludes 16-MT skid.

⁵Truck shipment for short distances with overweight permit.

⁶Licensed decay heat load is 62 kW.

⁷Air permissible if heat load less than 2.5 kW.

⁸Licensed decay heat load is 70 kW.

⁹Nominal value.

FIGURE 2.33 SPENT FUEL ON A RAILCAR

FIGURE 2.34 SPENT FUEL CASK ON A TRAILER

HEAVY HAUL PROCESS

FLOATING BRIDGE PROCESS

FIGURE 2.35 TWO BARGE ROLL ON / ROLL OFF TRANSFERRAL PROCESSES

About 50% of the reactors now operating or under construction do not have rail sidings, thus precluding the use of rail casks at these sites except by over-weight truck transport to a railhead. The other factors influencing the choice of rail, barge, or truck transport are largely economic ones: the cask payload, the loading and unloading time, the travel time, and the cask availability. Rail shipments have the payload and loading/unloading time advantages, but the present shorter truck travel times at least partly compensate for these advantages. Barge transport may be a viable alternative for many situations. Utilities have purchased both rail and truck casks as the best means for their particular situation. Existing receiving facilities are designed for specific cask types, and extensive truck shipments may restrict operations to less than full design capacity because of limited overhead crane capacity.

2.4.5 High-Level Waste

HLW is the primary waste generated when spent fuel is reprocessed. The waste will be solidified in borosilicate glass in stainless steel containers and will include essentially 100% of the fission products from the fuel, excluding noble gases, tritium, iodine, and bromine, essentially 100% of the transplutonic actinides from the spent fuel; and about 0.5% of the uranium and plutonium originally in the fuel.

HLW is currently not being commercially produced. Casks designed specifically for shipping solidified HLW have not been built; however, they are expected to resemble the casks now available for shipment of spent fuel. Because of the higher payload per shipment, rail shipment will probably be used exclusively. Two options have been proposed: an unrestricted (<263,000 lb) rail cask weighing about 75 MT or a restricted rail cask weighing about 160 MT. As discussed in Section A.3.1, the 75 MT rail cask will be used as the reference HLW cask, but barge and truck transport are technically feasible.

2.4.6 Cladding Waste

Cladding waste is the term denoting solid residues from fuel reprocessing operations in which fuel bundles have been sheared into short lengths and the fuel pellets have been leached from the cladding

with acid. The residues include short lengths of fuel cladding with some residual fuel, end fittings, fuel support grids, assorted springs, spacer elements, and fuel-bundle support rods. The radioactivity of cladding wastes arises both from neutron-induced isotopes and from the fission products and actinides present in the small amount of fuel that remains with the cladding.

Casks designed specifically for rail or truck shipment of cladding wastes have not been built. These casks are expected to resemble casks now available for shipment of spent fuel, but should be somewhat simpler in design because heat removal requirements would be reduced. Casks would require no neutron shielding and only a few inches of gamma shielding. Heat loads are low enough that cooling fins would probably not be required. The maximum disposable container dimensions are not yet established, but will be dictated by requirements of the Federal repository handling equipment. Various disposable container sizes have been proposed, which to a certain extent depend on whether the hulls are noncompacted, mechanically compacted, or compacted by melting.

Both a rail cask and a truck cask have been proposed for cladding waste. The rail cask would weigh about 75 MT and transport about 1.6 m^3 of waste. Recently, a 25 MT cask was proposed that would transport about 0.6 m^3 of waste. One cask could be transported on a legal-weight truck, three on an unrestricted railcar, and more on a barge. Figure 2.36 shows a cask similar to the proposed cladding waste cask. Additional details are provided in Section A.3.2.

2.4.7 Plutonium Dioxide

Plutonium is separated from the spent fuel at the reprocessing facility and converted to PuO_2 powder before being shipped. Plutonium has been transported for many years in various forms and containers for research and weapons programs. The most common is the 6M package, consisting of a 5-liter steel drum with a 12.7-cm inner vessel of schedule 80 steel pipe. The contents are limited to 4.4 kg because of a package heat dissipation limit of 10 W.

Figure 2.37 shows a PuO_2 overpack (the PPP-1M) that has been designed for commercial scale operations to reduce handling requirements and thereby reduce occupational doses as well as costs.¹⁴ The PuO_2 -

FIGURE 2.36 CASK SIMILAR TO CLADDING WASTE CASK

FIGURE 2.37 PLUTONIUM OXIDE OVERPACK (PPP-IM)

filled containers (28 kg of PuO_2) are put into the overpack, which is 0.44 m in diameter and 1.6 m long. Neutron and gamma shielding are provided by lead and a proprietary solid organic material. The design includes both a primary and a secondary pressure vessel, in accordance with current NRC regulations. The overpack has a gross weight of 0.82 MT and for safeguards purposes has been designed so that no lifting lugs are required. Special handling equipment is required to load and unload the overpack.

Figure 2.38 shows one concept¹⁴ for transporting the overpacks to meet safeguards requirements. Eight overpacks are transported in a penetration- and accident-resistant material (PARM) developed by Sandia Laboratories.

2.4.8 Defense TRU Waste

As discussed in Section 2.4.1, only CH TRU wastes are transported. Most of this waste is placed in fiberglass-reinforced, plywood boxes or 210-liter drums and transported in the ATMX railcar, but some is transported by truck in a Super Tiger or a Poly Tiger overpack (Section 2.4.1). Mode distribution details are given in Section A.8.

FIGURE 2.38 VAULT CONCEPT FOR PuO_2 TRANSPORT WITH TOP-PLUG LOADING

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APPENDIX A
PACKAGE SELECTION AND SHIPMENT FREQUENCY CONVERSION

For most of the wastes described in Section 2, numerous package sizes or types are commonly used--too many, in fact, to be considered in the projections of Section 1. This appendix describes the process used to select representative packages for each waste category. The LLW package sizes and types, which are the most numerous, are discussed first. Spent fuel casks are discussed second for both truck and rail modes, followed by HLW and cladding waste casks, fresh fuel, UO_2 , PuO_2 , UF_6 , U_3O_8 , and defense wastes.

The waste volume generation rates for each facility are presented in Section 2 in units of cubic meters per year or cubic meters per megawatt. This appendix also shows the derivation of the conversion from waste volume to the number of shipments of a specific type. The conversion factors are used in Section 2.

All truck shipments are legal weight unless specified as overweight, and all rail shipments are unrestricted unless specified as restricted.

A.1 LOW-LEVEL WASTE

As discussed in Section 2.4.1, numerous different packages are used to transport LLW. The variety allows selection of the package size and type that will most economically accommodate the form, activity, and volume of waste to be transported. To be useful in the projections of waste shipments, however, the number of packages must be reduced to a more manageable, but representative, number. The process used for reducing the number of packages is described in the following sections. Because the process for choosing reactor LLW packages is the most complex, it is discussed first to simplify subsequent discussions of LLW from other facilities.

A.1.1 Reactor LLW

A recent report¹ lists the annual LLW volumes and transport packages from 46 reactors at 36 sites for 1971 through 1977. The annual waste volumes varied significantly among various reactors of the same type and from year to year for the same reactor. Generally, the 1977 data were used unless there was a substantial difference from the preceding years, in which case an estimated average was used. Reference 1 presents data for four reactor categories: (1) BWR with a deep-bed CPS, (2) BWR with a precoat-filter CPS (3) PWR with a CPS, and (4) PWR without a CPS.

A second source² was used to determine the fraction of the 210-liter drums that are shipped in shielded vans rather than regular, unshielded trucks. Generally, Reference 2 could be used to verify the conclusions drawn from the data in Reference 1.

Package Size

Twenty-two package sizes were listed in Reference 1 and in some cases, more than one package size was listed for a given volume of waste. For noncompacted trash, an additional number of boxes and crates of various sizes were identified. As a first step in reducing the number to be considered, the package sizes were weighted by the annual volume of waste shipped in that particular package within each waste type and reactor category. Where more than one package size was indicated, the waste volume was assumed to be evenly distributed among

the indicated sizes. For each waste type and reactor category, the two or three package sizes used most often are given in Table A.1. As a result of this first step, the number of package sizes was reduced from 22 to 12. Of the package sizes omitted, the highest percentage usage which was neglected is given in the last column to illustrate the potential error.

The 12 package sizes appearing in Table A.1 are still too many sizes for our purpose. The second column of Table A.1 gives the percentage of the total waste volume for a BWR or a PWR, and these percentages show that some waste types are much more prevalent than others. Therefore, a reduction in the number of package sizes was considered on another basis--by weighting the package size percentage usage (column 5 of Table A.1) by the waste volume percentage (column 2 of Table A.1). The result is shown in Table A.2 as Grouping No. 1, where some packages of similar sizes were combined at little loss of information.

Seven package sizes are still too cumbersome; therefore, several regroupings were tried. The 210-liter (55-gal) drums and the boxes are shipped in vans and were grouped, as were the 1.1- to 5.2-m³ sizes and the 5.7- to 8.5-m³ sizes. The results are given in Table A.2 as Grouping No. 2. Grouping No. 3 at the bottom of Table A.2 is the result of grouping the 1.1 and 1.4-m³ casks with the boxes and 210-liter drums and grouping the remaining casks together. This last grouping seemed to be a reasonable way to group the package sizes.

Because the cask type and waste volume can vary significantly even from year to year for the same reactor, the data used as the primary contributors to Tables A.1 and A.2 were examined to see whether anomalies were influencing the results. About half of the BWR large cask contribution resulted from the large percentage (23%) of the wastes attributed to concentrated liquid wastes from units with a deep-bed CPS. The data of Reference 1 indicate that 54% of these wastes were transported in 8.5-m³ packages, 17% in 5.7-m³ packages, and 21% in 2.4-m³ packages. Although owners of two of the six reactors reported that 210-liter packages were used, they provided no waste volume information. A zero contribution was used for that package size in our calculations; therefore, the larger casks may not be as prevalent as indicated.

TABLE A.1
SUMMARY OF PACKAGE SIZES BY REACTOR AND WASTE TYPE

Waste Type	Volume ¹ Percent		Reactor Type	Package Size (m ³)	Percent Usage	Highest % Neglected
	BWR	PWR				
Deep Bed Resin (Density Range: 482-1526 kg/m ³)	8.5		BWR DB CPS	0.21 8.5	40 30	10
	0.4		BWR PF CPS	0.21 4.8	50 50	0
		2.8	PWR w/o CPS	0.21 4.8 2.8	36 20 18	7
		1.0	PWR w/ CPS	0.21 4.8 2.8	33 28 17	11
Concentrated Liquid (Density Range: 643-2008 kg/m ³)	23		BWR DB CPS	8.5 2.4 5.7	54 21 17	4
	1.1		BWR PF CPS	0.21	100	0
		12	PWR w/o CPS	0.21 4.2	44 39	6
		14	PWR w/ CPS	1.1 1.4	73 16	9
Filter Wastes (Sludges) (Density Range: 562-2409 kg/m ³)	10		BWR DB CPS	8.5 0.21 5.2 6.1	28 27 22 22	0.2
	14		BWR PF CPS	0.21 2.3 4.8	68 16 16	0
		1.2	PWR w/o CPS	0.21	89	2
		1.2	PWR w/ CPS	0.21 0.21 4.2	42 26 15	9

TABLE A.1 (Continued)

Waste Type	Volume ¹ - Percent		Reactor Type	Package Size (m ³)	Percent Usage	Highest % Neglected
	BWR	PWR				
Compactible Trash	28		BWR	Typically 210-liter drums used		
(Density Range: 96-1205 kg/m ³)		44	PWR	Only 210- and 332-liter drums reported		
Non-Compactible Trash	14		BWR	210 liter drums and 1.22- by ₂ 1.22- by 2.44 m boxes frequently used ²		
(Density Range: 48-4417 kg/m ³)		24	PWR	Typically 210-liter drums and 1.22- by 1.22- by 2.44 m boxes used ²		

¹Within the BWR or PWR category.

²Assume a 50/50 distribution.

TABLE A.2
SUMMARY OF PACKAGE SIZES BY REACTOR TYPE

Package Type	Reactor Type	
	BWR	PWR
<u>Grouping No. 1</u>		
210 liter	55%	67%
(1.1, 1.4 m ³)	0	14%
(2.3, 2.4, 2.8 m ³)	8%	0
(4.3, 4.8, 5.2 m ³)	5%	6%
(5.7, 6.1 m ³)	6%	0
(8.5 m ³)	19%	0
Box	7%	13%
<u>Grouping No. 2</u>		
Van-transported	62%	80%
Small and Medium Casks	13%	20%
Large Casks	25%	0
<u>Grouping No. 3</u>		
Van-transported	62%	94%
Casks	38%	6%

The PWR concentrated liquid waste has about the same total percentage contribution (23%) as does the BWR waste, but most of the waste is carried in package sizes lumped with the 210-liter package. Interestingly, the contribution of the 4.3-m³ package size to Grouping No. 3 of Table A.2 from this waste category constitutes 5 of the 6% of the total waste transported by cask. No anomalies are apparent, but this preference by PWR owners to use smaller packages for this predominant waste category helps explain the results of Table A.2.

Shielded Transport Vehicle Requirements

Reference 1 also contained information on whether the package was shielded. Data on the contact and 3-ft (0.914 m) dose rate was also provided. These data were not as useful as the data from Reference 2, which included the 1978 LLW shipment data for 6 of the 36 sites of Reference 1. In comparing the two references, we found that the shielding data in Reference 1 were not consistent from utility to utility (i.e., the questionnaire may have been interpreted differently). Therefore, Reference 2 was relied on for shielding requirements for the van-transported packages. Three PWR and three BWR sites were considered in Reference 2, and these will be designated below as PWR-1, PWR-2, etc.

For PWR-1, 96% of the waste was shipped in vans (79% shielded and 17% unshielded), and 4% was shipped in casks. For PWR-2, 87% was shipped in vans (70% shielded and 17% unshielded), 12% was shipped in intermediate-sized casks, and 1% was shipped in large casks. The data for PWR-3 appeared anomalous in that the 1978 waste volume was ten times as great as the 1971-1977 trend given in Reference 1; therefore, the data for PWR-3 were not used here. Averaging the data from PWR-1 and PWR-2 results in a value of 0.81 for the fraction of the PWR van-transported packages that must be shielded. Of interest is that 78% of the PWR-3 waste was transported in 8.5-m³ packages, but except for this last case, the PWR package size data of Reference 2 agree reasonably well with the third grouping of Table A.2, which is based on Reference 1.

The BWR-1 site shipped 76% of the LLW in regular vans and 24% in casks; no shielded vans were used. For the BWR-2 site, 90% of the LLW was shipped by vans (76% shielded and 14% unshielded), and 10% was

shipped in casks. In the BWR-3 case, 51% of the LLW was shipped in vans (14% shielded and 37% unshielded), and 49% was shipped in casks. Variation in the BWR data is greater than that in the PWR data, making selection of a shielding fraction difficult. Reference 2 suggested average values of 56% by van (11% shielded and 45% unshielded) and 44% by cask, which is reasonably consistent with the values of Table A.2. Therefore, the inferred value of 0.20 is used below for the fraction of the BWR van-transported packages that must be shielded.

Shipment Size

The conversion used to obtain the number of shipments for a given volume of waste is discussed below first for 210-liter drums and then for the large-volume casks. The amount of waste, in cubic meters, contained in the 210-liter drums and the boxes and transported in a regular or shielded van depends on many factors, including the void spaces left in the drums and boxes, truck size, payload weight, waste density, truck scheduling, and amount of on-site storage. The container inventory for Chem Nuclear Inc. lists a shielded van with a capacity of 75 210-liter drums (about 15.6 m³), a total volume of 76.4 m³, and a payload weight of 11,820 kg, and Reference 1 contains data on the package void space and the waste density; from this information, one could attempt to calculate a shipment capacity. However, the data of Reference 2 indicate a range of 5.2 to 26.4 m³ for the average shielded van shipment and 5.3 to 43 m³ for the average regular van shipment. This large variation indicates that other factors dominate. Using the data of Reference 2 and weighting each site equally yields an average shielded van shipment size of about 12 m³ for PWRs and 20.5 m³ for BWRs. It is not clear why the cubic feet per shipment varies as indicated, but instead of selecting an arbitrary value, the calculated values are used below.

The cask sizes in Table A.2 range from small, heavily-shielded ones with a tare-to-payload weight ratio as high as 4 to the larger, lighter-shielded ones with a tare-to-payload weight ratio of slightly less than 1. The variation between these two extremes is nonlinear with cask size. The BWR data indicate that about half of the shipments are in the 8.5 m³ range, whereas the PWR data indicate a middle range of

about 4.8 m³. To better illustrate the range of shipments that a carrier could expect, the larger cask was selected, even though the number of shipments calculated will be somewhat low for BWRs and even lower for PWRs. Since only 6% of the PWR shipments are affected, the apparent reduction in the number of PWR shipments is considered acceptable.

Table A.3 shows the package and shipment sizes selected for this study. The shipments per m³ is the quotient of the waste fraction and the volume per shipment and can be multiplied by the reactor LLW volume generation rate to obtain the number of shipments of the appropriate type. Note that, since the BWR/PWR ratio is held constant in this study, the BWR and PWR waste volume generation rates of Section 2.1.5 could be combined, and the number of shipments per cubic foot of waste in Table A.3 could be combined with no loss of information as to the number and type of shipments of reactor LLW.

A.1.2 Reprocessing LLW

The data for LLW volumes from commercial reprocessing plants presented in Section 2.1.6 are for (1) the NFS plant³ proposed for mid-1970 startup and is presumably based on their operational experience from 1966 to 1972; (2) the AGNS plant,^{4,5} designed in the early 1970s; and (3) the Exxon plant,⁶ designed in the mid- to late-1970s. Generally, the NFS wastes were packaged in 210-liter drums. Some TRU wastes with a relatively high activity were packaged in 1.27-m³ steel canisters and shipped in spent fuel casks.

AGNS LLW were planned to be shipped largely in 210-liter drums, with some 114-liter and some 303-liter drums being used. The high-activity TRU wastes were to be shipped with a 0.78-cm-thick steel overpack.

Exxon LLW were to be shipped in 210-liter drums. The high-activity TRU wastes were to be shipped in a 55 MT rail cask, containing nine 210 liter drums.

In all of the above examples, TRU wastes were shipped either in a highly-shielded cask, in a Super Tiger, or in a Half Super Tiger. (Super Tiger containers were discussed in Section 2.4.1.) A Super Tiger can hold 42 210-liter drums or ten 210-liter drums with the AGNS steel

TABLE A.3

PACKAGE AND SHIPMENT SIZES SELECTED FOR REACTOR LLW

Package	Vehicle	Waste Fraction		Volume per Shipment		Number of Shipments per m ³ of Reactor LLW	
		BWR	PWR	BWR	PWR	BWR	PWR
210-liter drums and 1.22- by 1.22- by 2.44-m boxes	Shielded Van	0.12	0.76	12 m ³	20.5 m ³	1.0×10^{-2}	3.7×10^{-2}
210-liter drums and 1.22- by 1.22- by 2.44-m boxes	Enclosed Truck	0.50	0.18	17 m ³	17 m ³	2.9×10^{-2}	1.1×10^{-2}
8.5 m ³ cask ¹	Truck	0.38	0.06	8 m ³	8 m ³	4.8×10^{-2}	7.5×10^{-3}

¹Five percent void assumed.

overpack. A Half Super Tiger can hold 18 210-liter drums or five 210-liter drums with the AGNS steel overpack. Three Super Tigers can be shipped on a railcar, and one Super Tiger and one Half Super Tiger can be shipped on a truck trailer.

The reprocessing LLW package requirements can be expressed as two distinct package types: 210-liter drums (which are shipped in a Super Tiger if TRU-contaminated) and a highly shielded package for high-activity TRU wastes. The highly shielded packages could be a spent fuel rail cask containing a specially sized package as in the NFS case; an overpack for a 210-liter drum, which is then shipped by truck in a Super Tiger, as in the AGNS case; or a special rail cask containing 210-liter drums, as in the Exxon case. Many other possibilities are feasible such as heavily-shielded, large-volume casks for the TRU-contaminated resins (since most of the high-activity TRU waste is resins) and 210-liter drums with appropriate shielding for the remainder.

The highly-shielded TRU wastes from the NFS and Exxon facilities were projected for rail transport, but also could be shipped by truck at some reduction in payload. The HLW and the cladding hulls waste also resulting from reprocessing operations are assumed to be shipped by rail to the deep geological repository; therefore, it is commonly assumed that the TRU wastes would also be shipped by rail since the destination is the same. Reference 5 points out that truck transport costs are probably less, but that institutional factors may govern the choice between rail and truck. In addition, Reference 5 states that fleet equipment requirements are substantially less for truck-transported TRU waste. The truck-transported option will be used in this report as the most probable mode for reprocessing LLW (TRU or non-TRU) because of the probable reduced cost and lower fleet requirements.

The number of shipments per cubic foot of waste can be calculated, as shown in Table A.4, by using the Exxon data of Appendix D for the fraction of waste in each category; using the AGNS approach for TRU waste truck transport; assuming 90 drums of non-TRU waste per truck; and assuming 5% void space in each drum (50% in the case of failed equipment).

TABLE A.4
PACKAGE AND SHIPMENT SIZES SELECTED FOR REPROCESSING LLW

Waste Type	Package	Vehicle	Waste Fraction	Waste Volume Per Shipment (m ³)	Number of Shipments per m ³ of LLW
High-activity TRU	Shielded 210-liter drum and Super Tiger	Truck	0.04	3	1.3×10^{-2}
TRU	210-liter drum and Super Tiger	Truck	0.29	11.9	2.4×10^{-2}
Non-TRU	210-liter drum	Enclosed Truck	0.67	17.4	3.9×10^{-2}

A.1.3 Fuel Fabrication and Conversion LLW

No Recycle

Without plutonium recycle, none of the LLW from fuel fabrication facilities is TRU contaminated. Therefore the wastes from such facilities are packaged in 210-liter drums, 0.056m³ filter boxes, and 1.22-by 1.22-by 2.44-m³ wooden boxes; an average shipment contains 17.3 m³ (Reference 2). This value is assumed to include void/packing fractions. These wastes are transported by truck without special shielding. These results are shown in Table A.5.

Plutonium Recycle

With plutonium recycle, all LLW are assumed to be TRU contaminated and would be treated the same as TRU wastes from reprocessing facilities (i.e., packaged in 210-liter drums and transported by truck in Super Tiger containers). One Super Tiger per truck trailer is assumed because of the lower waste generation rate at fabrication facilities than at reprocessing facilities. The number of shipments per cubic foot of waste is then 42/60 of that for TRU reprocessing wastes, as shown in Table A.5.

Conversion

The ash resulting from the dry process for converting U₃O₈ to UF₆ is assumed to be transported in 210-liter drums in a truck without special shielding, as are the non-recycle fuel fabrication wastes.

TABLE A.5
PACKAGE AND SHIPMENT SIZES SELECTED FOR FABRICATION AND CONVERSION

Waste Type	Package	Vehicle	Waste Fraction	Waste Volume Per Shipment (m ³)	Shipments per m ³
Fabrication and Conversion Non-TRU LLW	210-liter drum	Enclosed Truck	1.0	17.3	5.8×10^{-2}
Pu Recycle, TRU	210-liter drum and Super Tiger	Truck	1.0	8.4	1.2×10^{-1}

A.2 SPENT FUEL

The cask fleet description is detailed in Table A.6 and discussed in Section 2.4.4. These casks are for current-generation fuel, (i.e., licensed to carry spent fuel cooled as short as 120 to 180 days), whereas the present practice is to let the spent fuel cool 5 to 10 years. Because Pu recycle is assumed to start in 1990, and spent fuel will continue to cool for at least 5 years before shipping, the need for modifying these casks to accommodate Pu recycle spent fuel assemblies need not be discussed here.

Several companies have announced plans to develop new casks. Nuclear Assurance Corporation⁷ plans to build the NAC-2 rail cask, which will be a 80-MT cask capable of carrying 7 PWR or 21 BWR fuel assemblies. It will be a lighter version of the NAC-3 cask. The shielding material will be steel, and either a wet or a dry cavity cooling medium can be used. An overweight truck cask design is also being considered.

Exxon Nuclear Company⁸ has announced plans to build rail and legal-weight truck casks, which will carry 12 PWR/28 BWR and 2 PWR/4 BWR fuel assemblies, respectively. The initial design is based on 120-day-cooled fuel and uranium shielding, but a 5-year-cooled fuel design and steel shielding have not been ruled out. The design is not being pursued at this time.

Edlow International⁹ is interested in a project to design and license a new generation of rail and legal-weight truck casks, which will be based on 5-year-cooled fuel. The casks would be capable of carrying 12 PWR/32 BWR and 2 PWR/4 BWR fuel assemblies, respectively. The rail cask would weigh 95 MT and would be transported on an unrestricted weight basis.

The NAC-1 and NLI 1/2 casks can transport 1 PWR or 2 BWR fuel assemblies. The TN truck casks will not be considered in computing the expected number of spent fuel shipments because they require an over-weight permit and because they are seldom used in the United States at this time¹⁰. There are four IF-300 casks and two NLI 10/24 rail casks, and a weighted average of the two capacities results in an average capacity of 8 PWR/20 BWR fuel assemblies. (NAC defined an average of 8 PWR/21 BWR for a rail cask in Reference 11.) The average

TABLE A.6
LICENSED OR PROPOSED SHIPPING CASKS FOR CURRENT-GENERATION LWR SPENT FUEL

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Cask Designation	Number of Assemblies		Loaded (Empty) Cask Weight (MT)	Usual Transport Mode ¹	Shielding		Cavity Coolant	Maximum Heat Removal (kW)	Status (NRC Certificate Number)
	PWR	BWR			Gamma	Neutron			
NAC-1 (NFS-4)	1	2	23 (22)	Truck	Lead and steel	Borated water and antifreeze	Water ⁷	11.5	Licensed (6698)
NLI 1/2	1	2	22 (21)	Truck	Lead, uranium, and steel	Water and antifreeze	Helium	10.6	Licensed (9010)
TN-8	3		36 (33)	Truck ³	Lead and steel	Borated solid resin	Air	35.5	Licensed (9015)
TN-9		7	36 (33)	Truck ³	Lead and steel	Borated solid resin	Air	24.4	Licensed (9016)
TN-12	12	32	98 (90)	Rail	Steel	Borated solid resin	Air	120	Licensed in Europe only
IF-300	7	18	63 ⁴ (53)	Rail ⁵	Uranium and steel	Water and antifreeze	Water or air	76 ⁶	Licensed (9001)
NLI 10/24	10	24	88 (80)	Rail	Lead, uranium, and steel	Water and antifreeze	Helium	97 ⁸	Licensed (9023)
NAC-3	12	32	100 ⁹ (90)	Rail	Steel	Water and antifreeze	Water or air	100 ⁹	SAR submitted

¹Barge transport permissible unless explicitly ruled out by license.

²Excludes special trailer weight 11 MT.

³Overweight permit required.

⁴Excludes 16-MT skid.

⁵Truck shipment for short distances with overweight permit.

⁶Licensed decay heat load is 62 kW.

⁶Licensed decay heat load is 62 kW.

⁷Air permissible if heat load is less than 2.5 kW.

⁸Licensed decay heat load is 70 kW.

⁹Nominal value.

capacity of an unrestricted rail cask is assumed to increase, as shown in Table A.7 due to the introduction of 12/32 casks. Most of the spent fuel to be shipped between 1980 and 2000 will be cooled 5 to 10 years, and the introduction of a 12/32 rail cask whose design is based on longer-cooled fuel is quite likely in this time span. To the one significant figure used, the gradual introduction of new-generation truck casks does not impact Table A.7.

Also shown in Table A.7 is the assumed distribution between unrestricted rail and legal-weight truck shipments. Initially, a 50/50 split (in number of fuel assemblies, not number of shipments) is assumed since this seems to be the current assumption. The split is assumed to approach 70 rail/30 truck in the year 2000 as a result of introduction of the new-generation rail casks and the preference of some receiving facilities for rail casks. (Due to crane capacity, AGNS cannot operate at full capacity unless a high percentage of the spent fuel assemblies are received by rail casks.)

Barge transport of spent nuclear fuel may be a viable alternative to rail and truck transport for reactors located on navigable waterways. Intermodal transport, using a combination of barge and overland (rail or truck) transport, is a possible alternative for 80% of the reactors projected to be operational by 1985.¹² As indicated on Table A.6, licensed spent fuel casks are considered licensed for the barge mode unless the NRC certification explicitly limits the mode to truck and/or rail.¹³ The capacity values given in Table A.7 are based on the usual assumption of one cask per railcar or one rail cask per barge. Other arrangements are also possible: more than one rail cask per barge, and roll-on/roll-off systems using existing rail or truck casks or specially designed casks. Intermodal transport by barge is more costly than either rail or truck transport because of the high cask rental charges incurred during the long transit time required. Although it is a viable alternative, barge transport of spent nuclear fuel is not projected to impact the mode distribution of Table A.7. Future institutional and improved economic factors may result in a significant volume of traffic for this mode.

TABLE A.7
SPENT FUEL CASK SHIPMENT SIZES

Year	Fuel Assembly Capacity		Mode Distribution Fraction	
	Truck	Rail/Barge (PWR/BWR)	Truck	Rail
1980	1/2	8/20	0.50	0.50
1985	1/2	8/20	0.50	0.50
1990	1/2	8/20	0.45	0.55
1995	1/2	9/23	0.40	0.60
2000	1/2	10/25	0.30	0.70

A.3 HIGH-LEVEL AND CLADDING WASTES

Unlike LLW and spent fuel, there are no built and licensed casks to choose between for either HLW or cladding wastes. There are, however, several conceptual designs, which vary substantially in the cask size assumed and in the size and number of containers transported in the cask. The larger the diameter of the canister, the larger the payload per shipment for the same cask diameter; however, it is the waste repository conditions that will govern the choice of canister diameter and length. In any case, rail shipment is normally assumed for HLW and cladding waste because of the higher payload per shipment, and the expected rail facilities at both the reprocessing and the geologic disposal facilities. Barge transport of both HLW and cladding waste casks is a technically feasible alternative. Recently, a cladding waste cask was proposed¹⁴ which could be transported one cask on a legal-weight truck, three casks on a railcar on an unrestricted basis, or a number of casks on a barge. A truck-transported HLW cask is technically feasible also.

A.3.1 High-Level Waste

Two distinct cask types were recently proposed for transporting HLW. The AGNS-type cask⁵ is an unrestricted rail cask weighing about 75 MT. A range of canister and cask sizes was investigated, and the baseline cask chosen will transport 2 m³ of waste in six stainless steel canisters, 30.5 cm in diameter and 4.4 m long. The PNL-type cask¹⁵ is a restricted rail cask, weighing 100 MT empty and about 160 MT gross, including a six-axle railcar. Nine canisters, 30.5 cm in diameter and 3 m long, could be transported.

The PNL cask exceeds the weight limit for unrestricted travel; therefore, as done consistently in this report, the restricted cask will not be considered as a basis for projections. The AGNS cask will be used, but the assumed cask and canister length will be shorter to be consistent with the technical support documents for the commercial waste management EIS.¹⁶ The overall length of the canister is 3 m with an active length of 2.4 m; thus, the active volume is 0.18 m³ per canister, or 1.0 m³ of waste per shipment. The resulting shipment size parameters are given in Table A.8.

TABLE A.8
HIGH-LEVEL AND CLADDING WASTE SHIPMENT SIZES

Waste Type	Package	Mode	Waste Volume per Shipment (m ³)	Shipments per m ³
High-Level Waste	Cask with 6 canisters	Rail	1.0	1
Cladding Waste	3 casks with 3 210-liter drums each	Rail	1.8	5.5 x 10 ⁻¹

A.3.2 Cladding Waste

Two distinct cask types were also recently proposed for transporting cladding wastes. The first is an unrestricted rail cask, weighing about 75 MT. Reference 5 investigated a number of cask and canister sizes and chose a baseline canister size of 112 cm in diameter and 2.28 m long; two canisters are shipped end-to-end in a cask. Other reports¹⁷ have generally assumed a canister 30.5 cm in diameter and 3.0 m long in a cask about the same size as the cask in Reference 5. An active length of 2.4 m will be assumed, as was the case for HLW. A 75-MT cladding waste cask could transport nine 30.5 cm canisters because of the reduced shielding requirements compared with an HLW cask; thus, 1.6 m^3 of waste would be contained in each shipment.

Reference 14 describes a legal-weight truck cask, weighing about 25 MT, which can be shipped three to a railcar without exceeding the limits for unrestricted travel. Three 210 liter drums would be transported in each cask. Assuming a 95% volume utilization, about 0.6 m^3 and 1.8 m^3 of waste could be transported on a legal-weight truck and unrestricted railcar, respectively. More than three casks could be transported by barge.

The conceptual cask of Reference 14 was chosen for this study because it reflects the latest thinking in optimizing the transportation costs, it will transport a relatively large payload, and it is not likely to be unacceptable at a geologic repository since TRU LLW wastes are also shipped in the same container--the 210-liter drum. The shipment size parameters are given in Table A.8, where it has been assumed that rail transport of cladding waste casks is used exclusively.

A.4 FRESH FUEL

Fresh fuel assemblies are usually enclosed in a plastic or polyethylene sheath and positioned within an inner metal container or a metal fuel assembly cradle. Two packaged PWR fuel assemblies are usually placed in a metal outer container, and six PWR containers (12 fuel assemblies) can be carried on a legal-weight truck. Two packaged BWR fuel assemblies are usually placed in a wooden or aluminum box, and 18 BWR containers (36 fuel assemblies) can be carried on a legal-weight truck. Shipment parameters are given in Table A.9.

Both types of fresh fuel containers have been licensed for MOX fuel. To meet present safeguards requirements, however, two PWR or four BWR MOX fuel assemblies will be assumed to be packaged in an all-metal container similar to the PWR container described above, and four containers will be assumed to be carried in a special legal-weight transporter.¹⁸ Shipment parameters are given in Table A.9.

A.5 URANIUM AND PLUTONIUM DIOXIDES

A.5.1 Uranium Dioxide

Natural UO_2 can be shipped in 210-liter drums, and forty drums can be shipped on a legal-weight, enclosed trailer. Each drum will hold about 430 kg of UO_2 , for a total shipment payload weight of 17.2 MT of UO_2 .¹⁸ Shipment parameters are given in Table A.10.

A.5.2 Plutonium Dioxide

As discussed in Section 2.4.7, special safeguards requirements are required for PuO_2 shipments. Containers filled with 28 kg of PuO_2 are placed in a special overpack²³, which serves as a neutron and gamma shield as well as a sabotage barrier. Eight overpacks are transported in a special legal-weight transporter escorted by armed guards. The net payload is 0.224 MT PuO_2 (Table A.10).

TABLE A.9
FRESH FUEL SHIPMENT SIZES

Fuel Type	Fuel Assemblies per Package	Mode ¹	Fuel Elements per Shipment
BWR UO ₂ Fuel	2	Truck	36
PWR UO ₂ Fuel	2	Truck	12
BWR MOX Fuel	4	Special Truck	16
PWR MOX Fuel	2	Special Truck	8

¹All trucks are legal weight.

TABLE A.10
URANIUM AND PLUTONIUM DIOXIDE SHIPMENT SIZES

Shipment	Amount per Container (MT)	Container and Mode	Amount per Shipment (MT)
UO ₂	0.43	40 210-liter drums per En- closed Truck	17.2
PuO ₂	0.028	8 Overpacks per Special Truck	0.224

A.6 URANIUM HEXAFLUORIDE

Containers for UF_6 were described in Section 2.4.2; the purpose of this section is to discuss the shipment parameters for each transportation leg. The parameters for each fuel cycle transportation link are given in Table A.11.

Conversion to Enrichment

About 28% of the natural UF_6 is shipped in 48X cylinders, and 72% is shipped in 48Y cylinders.¹⁸ Two 48X cylinders or one 48Y cylinder can be transported per truck, and four 48X cylinders or four 48Y cylinders can be transported per railcar. All 48X cylinders are shipped by truck, whereas 54% of the 48Y cylinders are shipped by truck and 46% are shipped by rail.¹⁸

Between Enrichment Plants

Shipment from the Paducah facility to the Oak Ridge and Portsmouth facilities are by rail in 48Y cylinders.¹⁶ Shipments from the Oak Ridge facility to the Portsmouth facility are by truck in 48X cylinders.

Enrichment to Fabrication

Because of its higher enrichment, UF_6 is usually shipped to the fabrication plant by truck in a 30B cylinder.¹⁶ Five cylinders, each within a protective overpack, are shipped in a legal-weight truck trailer.

Reprocessing to Enrichment

For this study, the uranium product from the reprocessing facility is assumed to be shipped to the enrichment plant as UF_6 . Other options are shipment to the fuel fabrication facility as UO_2 or as MOX. All the recycle UF_6 is assumed to be shipped by rail in 48Y cylinders.

A.7 NATURAL URANIUM CONCENTRATE

Natural uranium concentrate (yellow cake), U_3O_8 , is usually shipped in 210-gal drums containing about 364 kg of U_3O_8 each.¹⁹ Fifty drums are usually shipped in an enclosed trailer, for a net weight of 18,180 kg (18.2 MT) (Table A.12).

TABLE A.11
URANIUM HEXAFLUORIDE SHIPMENT SIZES

Fuel Cycle Step	Cylinder Size per MT (net)	Mode	Cylinder and Mode Fraction	Cylinders Shipment	MT per Shipment
Conversion to Enrichment	48X/9.5	Truck	0.28	2	19
	48Y/12.5	Truck	0.39	1	12.5
	48Y/12.5	Rail	0.33	4	25
Between Enrichment Plants	48Y/12.5	Rail	0.8	4	25
	48X/9.5	Truck	0.2	2	19
Enrichment to Fabrication	30B/2.28	Truck	1.0	5	11.4
Reprocessing to Enrichment	48Y/12.5	Rail	1.0	4	25

TABLE A.12
NATURAL URANIUM CONCENTRATE SHIPMENT SIZE

Material Shipped	Containers per Shipment	Mode	MT per Shipment
U ₃ O ₈	50 210-liter drums	Enclosed Truck	18.2

A.8 DEFENSE TRU WASTE

Defense TRU waste is usually divided into two categories: contact-handled (CH) waste, which has a surface dose rate less than 200 mrem/hr and remote-handled (RH) waste, which ^{has} a higher surface dose rate. RH waste is stored at the same site at which it is generated, but CH waste is generated at sites without storage facilities and requires transportation. The three most common waste packages for CH TRU waste are 1.22- by 1.22- by 2.44-m, fiberglass-coated plywood boxes (43%); random-sized, fiberglass-coated, plywood boxes (24%); and 210 liter drums (25%).²⁰ About half of the drums weigh less than 90 kg and the other half weigh more than 180 kg, giving an average weight of 150 kg. About 80% of the boxes weigh between 910 and 1360 kg, with an average of 1282 kg per box.

Three methods are predominantly used to transport CH TRU waste: ATMX railcars, Super Tigers, and Poly Panthers.²¹ (Super Tiger and Poly Panther packages are described in Section 2.4.1.) The two ATMX Series 500 railcars have a 2.7- by 2.7- by 15.3-m cargo space and a useful payload capacity of about 55 MT.⁵ Typically, 140 210-liter drums are transported per shipment,²¹ although space exists for up to 216 drums.⁵ The ten ATMX Series 600 railcars have an interior divided into three bays, each measuring 4.8 (length) by 7.6 (width) by 1.9 (height) m.²¹ A typical load consists of 128 210-liter drums, although space exists for up to 192 drums. Because of the dimensions, only 1.22- by 1.22- by 2.44-ft boxes can be transported in the 500 Series car, but up to 24 boxes can be transported in the 600 Series car. To use the space more effectively, a combination of pelletized drums and boxes are usually used, especially in the 500 Series car.

Wastes generated at Mound Lab in Ohio and Rocky Flats in Colorado are assumed to be shipped in ATMX railcars, wastes generated at Argonne National Lab in Illinois are assumed to be shipped by truck in Poly Panthers, and other wastes are assumed to be shipped by truck in Super Tigers.²⁰⁻²² Using the waste volume distribution data in References 21 and 22 results in 89% shipment by ATMX railcar, 4% by Poly Panther, and 7% by Super Tiger.

Assuming a typical truck shipment of 1 Super Tiger containing only 210-liter drums or 5 Poly Panthers containing 2.8 m³ of waste each

results in the values of Table A.13. The ATMX shipment volume was a weighted-average between the typical 500 and 600 Series shipments.

TABLE A.13
DEFENSE TRU WASTE SHIPMENT SIZE

Package	Mode	Mode Fraction	m ³ per Shipment	Shipments per m ³
ATMX	Rail	0.89	25.5	3.5×10^{-2}
Super Tiger	Truck	0.04	8.5	4.7×10^{-3}
Five Poly Panthers	Truck	0.07	14.2	4.9×10^{-3}

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APPENDIX B

COMPARISON OF LWR WASTE PROJECTIONS

As discussed in Section 2.1.5, two recent documents were relied heavily upon in making waste volume projections for LWRs for this report.^{1,2} The data presented in Reference 1 was found to be more suitable for making the type of projections necessary for this report for the period 1980 to 2000. However, it is felt that comparison of two different sets of waste generation rate projections would be enlightening. Since the data of Reference 1 are discussed in Section 2.1.5, only the information from Reference 2 will be summarized here.

Reference 2 determined an average waste generation rate from surveys of 18 PWR and 12 BWR reactor sites for 1971 through 1977. Three cases were presented in Reference 2. The first case considered the waste volumes that might be generated by an average LWR plant if the wastes were not treated or solidified before shipment. For this case, 75% of the BWR plants were assumed to use a deep-bed CPS, and the other 25% were assumed to use a precoat-filter CPS. Half of the PWR plants had a CPS, and half did not. Therefore, a weighted average was calculated for the waste generation rate for BWRs in this first case, and a simple linear average was calculated for PWR plants.

The second case considered the waste volumes that would be generated if all wastes, except compactible and non-compactible trash, were solidified before shipping. Again, weighted-average and linear-average waste generation rates were calculated for BWR and PWR plants, respectively.

The third case considered the volumes of waste that might be generated if present volume reduction and solidification practices continued for the period 1980 to 2000. This case will be shown to coincide very closely to the "best estimate" projection made from the data in Reference 1.

These three cases are summarized in Table B.1. By multiplying the weighted-average and linear-average waste generation rates for BWRs and PWRs, respectively, given in Table B.1, by the nuclear capacity projections discussed in Section 2.1.5, waste volumes shipped from LWRs

TABLE B.1

PROJECTED WASTE GENERATION RATES FROM LWRs

Case	BWR Waste Volumes ¹ (m ³ /MWe-year)			PWR Waste Volumes ¹ (m ³ /MWe-year)		
	Deep-Bed CPS	Precoat CPS	Avg ²	W/O CPS	W/ CPS	Avg.
Average plant with untreated wastes ³	0.967	0.566	0.868	0.473	0.487	0.479
All waste, except compactible and noncompactible trash is solidified	1.42	0.741	1.25	0.608	0.608	0.608
Continuation of current volume reduction and solidification practices	1.29	0.671	1.14	0.602	0.597	0.599

¹Reference 2.²Assumes that 75% of the BWRs are deep-bed plants and 25% are precoat-filter plants.³Untreated means no solidification or volume reduction.

can be estimated for 1980 to 2000. The total projected LWR wastes shipped for cases 1, 2, and 3 are presented in Tables B.2, B.3, and B.4, respectively. Figure B.1 shows the waste volume projections for the three cases.

The results of case 3, for which present volume reduction and solidification practices were assumed to continue for the period 1980 to 2000, and the results of the best-estimate projection from Section 2.1.5, which also made the same assumptions on waste management practices, are very similar. Projections for the volume of waste to be shipped in the year 2000 are 179,800 m³ according to Reference 2 and 178,600 m³ according to Reference 1; these values agree to within 0.5%. This comparison is shown in Table B.5.

TABLE B.2
PROJECTED WASTE VOLUMES FOR CASE 1 (UNTREATED) FROM LWRs

Year	Waste Volume Shipped ¹ (m ³ /year)		
	PWR	BWR	Total
1979	15,400	15,400	30,800
1980	19,300	17,100	36,400
1985	31,700	28,600	60,300
1990	48,400	41,900	90,300
1995	58,000	50,600	108,600
2000	74,650	65,650	140,300

¹Average LWR with untreated wastes.

TABLE B.3
PROJECTED WASTE VOLUMES FOR CASE 2 (PARTIALLY TREATED) FROM LWRs

Year	Waste Volume Shipped ¹ (m ³ /year)		
	PWR	BWR	Total
1979	19,500	22,100	41,600
1980	24,500	24,700	49,200
1985	40,250	41,200	81,450
1990	61,400	60,350	121,750
1995	73,600	72,900	146,500
2000	94,700	94,500	189,200

¹ Assumes that all waste, except compactible and non-compactible trash, is solidified before shipment.

TABLE B.4
PROJECTED WASTE VOLUMES FOR CASE 3 (COMPACTED AND
SOLIDIFIED) FROM LWRs

Year	Waste Volume Shipped ¹ (m ³ /year)		
	PWR	BWR	Total
1979	19,200	20,260	39,470
1980	24,100	22,500	46,600
1985	39,700	37,650	77,350
1990	60,500	55,160	115,660
1995	72,500	66,600	139,100
2000	93,400	86,400	179,800

¹A continuation of current volume reduction and solidification practices is assumed to continue for the period 1980 to 2000.

FIGURE B.1
PROJECTED WASTE VOLUMES FOR CASES
1,2,3, FOR LWRs

TABLE B.5
COMPARISON OF WASTE VOLUME PROJECTIONS

Year	Reference 1 Best Estimate Projection ¹ (m ³)	Reference 2 Case 3 Projection ¹ (m ³)
1979	39,100	39,500
1980	46,400	46,600
1985	76,800	77,350
1990	115,000	115,660
1995	138,200	139,100
2000	178,600	179,800

¹Both projections assume a continuation of current volume reduction and solidification practices for the period 1980 to 2000.

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APPENDIX C
PROJECTION OF INSTALLED NUCLEAR CAPACITY AND
SPENT FUEL AND CONTROL ROD SHIPMENTS

Appendix C describes the methods used to determine the number of spent fuel assemblies and control rods shipped through the year 2000. The method involves four basic steps: (1) projections of installed nuclear capacity as a function of time, (2) estimations of the spent fuel discharged as a function of the installed capacity, (3) determination of spent fuel shipping requirements, and (4) determination of the shipment requirement for other reactor materials such as control rods.

C.1 PROJECTION OF INSTALLED NUCLEAR CAPACITY*

Data on the installed nuclear capacity for the past is readily available from utility surveys published in trade journals such as Electrical World (e.g., the January 15, 1979, issue) or Nuclear News (every August issue). Projections of future capacity are not quite so straightforward, since several organizations make projections using different sets of assumptions. The most frequent source of projections are the DOE (and its predecessors such as the ERDA and the FEA), the utilities, and the NRC.

All future projections can be characterized by two time regions. The first region of the projection, extending over about 10 years, is based on existing installed capacity and on utility expectations of additional installed capacity. (In some projections, the forecasting agency may anticipate some delays in the utility plans.) Since all additional installed capacity for the next 10 years is already under construction or planned, this is an accurate projection. Beyond this 10-year projection is the second region of projection, which is determined by assumptions in total electrical power growth, the fraction

*For this report, the Hanford-N reactor and the Indian Point-1 reactor were not included in the data base, since they will not generate commercial spent fuel.

of increased power growth to be contributed by nuclear power, and the type of nuclear power plant to supply the growth. Table C.1 shows the results of various projections by utilities, ERDA, FEA, DOE, and NRC.

Several points can be made from the projections. The first is that, as a result of the current slowdowns in the addition of nuclear power plants, the latest projections show a decrease in the installed capacity of nuclear power. Projections in 1973 and 1974 by the AEC were for over 1000 GW(e) of installed nuclear capacity in the year 2000, whereas the 1979 DOE forecast projects only 250 GW(e) for the year 2000. Projections for the year 2000 have shown a four-fold decrease in the last 5 years, which makes the projections extremely uncertain. A second factor is that the various projections provided by the different agencies differ for comparable years, with NRC projections generally being the lowest and DOE projections generally being the highest.

For purposes of this report, the DOE 1979 low-case projection¹ was used because of the recent trend of lower projections and in anticipation of lower projections following the Three Mile Island accident. The breakdown between PWR and BWR reactors in the DOE scenario was based on the methodology in Reference 1. This methodology used existing LWR plans for additional capacity through 1987 and assumes a 2:1 PWR/BWR split for additional capacity. (BWRs constitute 30% of all reactors committed as of January 1979.) The results of this calculation, shown in Table C.2 and Figure C.1, form the basis for the report.

TABLE C.1
PROJECTIONS OF INSTALLED NUCLEAR CAPACITY

Source	Year of Projection	INSTALLED CAPACITY (GWe)					Notes
		1980	1985	1990	1995	2000	
NRC	1976	68	105	186	285	383	From GESMO hearings
Utilities ¹	1977	76	155	185	---	---	4
ERDA, High	1977	68	146	251	370	510	From Ref. 2
ERDA, Low	1977	61	128	196	285	380	From Ref. 2
FEA	1977	---	113	---	---	---	
Utilities ²	1978	71	137	170	---	---	5
Utilities ³	1979	64	126	163	---	---	6
DOE, High	1979	---	118	175	225	280	From Ref. 1
DOE, Low	1979	---	100	150	180	232	From Ref. 1

¹As reported in the August 1977 issue of Nuclear News.

²As reported in the January 1979 issue of Electrical World.

³As reported in the August 1979 issue of Nuclear News.

⁴The 1990 value is the 1987 value; therefore, it is low for 1990.

⁵The 1990 value is the 1988 value; therefore, it is low for 1990.

⁶The 1990 value is the 1989 value; therefore, it is low for 1990.

TABLE C.2
INSTALLED NUCLEAR POWER CAPACITY

Year ^{2,3}	Additional PWR (MWe)	Additional BWR (MWe)	Total PWR (MWe)	Total BWR (MWe)	Total LWR ¹ (MWe)
1965	175	326	175	326	501
1966	---	---	175	326	501
1967	---	---	175	326	501
1968	1,011	---	1,186	326	1,512
1969	---	1,278	1,186	1,604	2,790
1970	987	1,352	2,173	2,956	5,512
1971	1,405	1,336	3,578	4,292	7,870
1972	2,728	2,728	6,306	7,076	13,872
1973	5,478	---	11,784	7,076	18,860
1974	5,276	4,520	17,060	11,596	28,860
1975	3,645	3,464	20,705	15,060	35,765
1976	4,010	---	24,715	15,060	43,225
1977	3,449	1,857	28,164	16,917	45,081
1978	3,820	786	31,984	17,703	49,678
1979	---	---	31,984	17,703	49,678
1980	8,200	2,000	40,184	19,703	59,900
1985	25,900	31,200	66,100	32,900	99,000
1990	34,700	15,300	100,800	48,200	149,000
1995	20,000	10,000	120,800	58,200	179,000
2000	34,700	17,300	155,500	75,500	231,000

¹Does not include Hanford N (860 Mw) or Indian Point 1 (265 Mw) reactors since they will not produce commercial spent fuel or LLW.

²Data through 1976 is actual data.

³Just prior to publication of this report, a new DOE nuclear growth protection was made which resulted in 125,000 MWe in 1985, 167,400 MWe in 1995, and 180,000 MWe in 2000. See Section 1.1.2.

C.2 SPENT FUEL GENERATION RATE

By keeping a yearly total of all the spent fuel generated by each operating reactor, a running total of spent fuel assemblies generated can be obtained (see, for instance, the Nuclear Assurance Corporation report).² The amount of spent fuel to be discharged for up to 10 years in the future can also be reasonably estimated by knowing the total utility construction plans and the core sizes of reactors under construction.

Since such detailed calculations are beyond the scope of this report and would still not cover the time period from 1990 to 2000, a different approach was adopted, which used the installed capacity curves generated earlier. This approach was to estimate the core sizes of PWRs and BWRs as a function of time and to estimate that 1/3 of a PWR core or 1/4 of a BWR core is discharged at refueling. Two assumptions were also used. First, refueling was assumed to occur on a yearly basis rather than after the fuel achieves a specific burn-up level. This assumption is consistent with current utility practice, which attempts to minimize peak-load unit usage (e.g., gas turbines) by performing reactor refueling and maintenance at periods of low electricity demand (e.g., during the spring and fall). A utility is apt to refuel in the fall even if the burn-up level will not be achieved until the winter, because of the low cost of uranium fuel relative to oil or coal. A second assumption was that new reactors did not discharge spent fuel until the second year of operation.³

By using these two assumptions and the capacity projection curves, the size of reactor cores as a function of time and output must be determined. To obtain these correlations, the core size data and output per fuel assembly from References 4 and 5 were used. Since the core size and output are influenced by design and regulatory conditions during the design of the reactor, the time period of interest for these calculations was the time period after an NRC construction permit was applied for. This period was converted into a useful number for spent fuel discharge by assuming 10 years from a construction permit application to operation (or 12 years from an application to discharge of spent fuel).³ The BWR data showed a gradual increase in power generation per fuel assembly and, thus, a corresponding decrease in the

number of fuel assemblies required to produce a given amount of electricity. The PWR data showed a fairly constant power generation per fuel assembly until 1967 construction permit applications (1979 startup). The average power generation rates are given below.

<u>Start-Up Date</u>	<u>BWRs</u>	
	<u>Avg. Power per Fuel Assembly (MWe)</u>	<u>Core Size for 1000 MWe (fuel assemblies)</u>
Through 1977	1.10	970
1978-1982	1.40	714
After 1982	1.60	625

<u>Start-Up Date</u>	<u>PWRs</u>	
	<u>Avg. Power per Fuel Assembly (MWe)</u>	<u>Core Size for 1000 MWe (fuel assemblies)</u>
Through 1979	4.50	222
After 1979	5.75	174

*Assuming 10 years from construction permit applications to startup.

The final key piece of information regarding spent fuel is the amount of heavy metal, in metric tons, discharged per 1000 MW(e). For this report the total core loading of heavy metal was assumed to remain constant (i.e., the power generation rate per fuel assembly has increased at the same rate that the MTHM per fuel assembly has increased). This assumption is good since the changes in fuel assembly design have been dictated by thermal-hydraulic considerations rather than by reactor physics considerations; the net effect has led to more fuel pins per fuel assembly. The following assumptions for PWRs and BWRs, where the metric tons of heavy metal per fuel assembly value is based on the current fuel,³ were used:

	<u>PWR</u>	<u>BWR</u>
MWt/MTHM	37.5	25.9
Burnup, MWd/MTHM	33,000	27,500
MTHM/Fuel assembly	0.461	0.183

Combining this information with the core size information and the installed capacity projections leads to the spent fuel discharge information in Table C.3.

Several checks were performed on the data in Table C.3. The standard assumptions above can be used to estimate the core sizes for PWRs and BWRs (assuming 3000 MWt = 1000 MWe):

$$\text{For PWRs: } N_{SA} = \frac{3000 \text{ MWt}}{(37.5 \text{ MWt/MTHM})(0.46 \text{ MTHM/FA})} = 174 \text{ FA}$$

$$\text{For BWRs: } N_{SA} = \frac{3000}{(25.9)(0.183)} = 633 \text{ FA}$$

These results compare favorably with the fuel assembly values of 174 and 625 derived earlier.

A second check is to compare known values for accumulated metric tons of heavy metal with the estimated values. Two values for the accumulated values were found. Reference 4 gives a value of 2342 MTHM in 1976 vs. the estimate of 2210 (a difference of 6%). Reference 5 gives a value of 4400 MTHM in 1978, compared with our estimate of 4280 (a 2.8% difference).

Another comparison can be made with the DOE estimates of spent fuel storage requirements (References 6 and 7). Some difficulty is encountered in comparing the values directly since the utility installed capacity estimates for the DOE references are 10-30% higher than those used in this report (e.g., the DOE capacity values are 167.5 and 181.6 GWE in 1988 and 1993, respectively.), and the DOE projections are discontinued in the year 1993. It is not surprising, therefore, that the DOE estimates of discharged spent fuel are approximately 25% higher than the estimates ^{given} ~~present~~ in this report. A more meaningful comparison

TABLE C.3
ESTIMATED SPENT FUEL DISCHARGE

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Year	Number of PWR FA Discharged	Total PWR FA	PWR, MTHM Discharged	Total MTHM, PWR	Number of BWR FA Discharged	Total BWR FA	BWR, MTHM Discharged	Total MTHM, BWR	Total MTHM, LWR
1967	13	13	5	5	74	74	10	10	15
1968	13	26	5	10	74	148	10	20	30
1969	13	39	5	15	74	222	10	30	45
1970	88	127	32	47	74	296	10	40	87
1971	88	215	32	79	364	660	46	86	165
1972	161	376	58	137	673	1,330	85	171	308
1973	265	641	96	233	976	2,310	123	294	527
1974	467	1,110	169	402	1,610	3,920	202	496	898
1975	872	1,980	315	717	1,610	5,530	202	698	1,420
1976	1,270	3,250	459	1,180	2,640	8,170	332	1,030	2,210
1977	1,530	4,780	553	1,730	3,430	11,600	431	1,460	3,190
1978	1,830	6,610	662	2,390	3,430	15,030	431	1,890	4,280
1979	2,090	8,690	755	3,150	3,850	18,900	483	2,380	5,530
1980	2,370	11,060	854	4,000	3,990	22,900	506	2,880	6,880
1981	2,370	13,430	854	4,850	3,990	26,900	506	3,390	8,240
1982	2,850	16,300	1,070	5,920	4,350	31,209	563	3,950	9,870
1987	4,350	35,000	1,770	13,370	6,530	59,700	941	7,900	21,300
1990	5,560	50,470	2,380	19,780	7,960	82,150	1,270	10,100	29,900
1992	6,360	62,800	2,700	25,000	8,920	99,500	1,380	13,900	38,900
1979	7,520	98,100	3,230	40,100	10,500	149,000	1,660	21,700	61,800
2000	8,730	123,000	3,790	50,900	13,100	206,000	1,960	24,200	78,100

of the two sets of data is to compare the amount of spent fuel discharged per reactor year of operation. Using the MTU/assembly values from this report, the following discharge values can be obtained (in MTU/reactor-year):

	<u>PWR</u>	<u>BWR</u>	<u>2:1 PWR to BWR Mix</u>
Report Estimate	26.7	29.0	27.4
DOE Estimate	24.8	33.4	27.6

Although the PWR and BWR values are different by approximately 10%, the "mix" values are almost identical. There is, therefore, a good agreement with the DOE values for spent fuel discharged per reactor year.

Although the estimates in this report agree with the actual data and estimates in the references, there is no guarantee that they will hold for the future. Design improvements, accidents, and regulatory changes can all affect the discharge of spent fuel. There is a large economic incentive to increase fuel burnup levels to the range of 50,000 MWd/MTHM to allow for 18-month refueling. Arkansas Power and Light has begun testing at higher burnup levels, and TVA is attempting 18-month refueling intervals at its Browns Ferry reactors. These trends will tend to decrease the discharge of spent fuel by about 1/3. A second change may result from accidents or regulatory changes. Obviously, neither reactor at Three Mile Island will discharge spent fuel for several years at least. Also, NRC-mandated shutdowns for design changes and retrofits may allow utilities to delay scheduled refueling outages. All these changes will tend to decrease the discharge of spent fuel so that the values in Table C.3 should be considered to be on the high side for the installed capacity value.

C.3 SPENT FUEL SHIPMENTS

Once the number of spent fuel assemblies discharged has been estimated, the number of spent fuel assemblies shipped is a function of the availability of a receiving location for spent fuel (i.e., either an AFR, a reprocessing plant, or a waste repository) and the capability of the utility to store spent fuel. To cope with the lack of a remote spent fuel receiving facility*, utilities are increasing their on-site spent fuel storage capability and future reactors are expected to have storage capability larger than that of present reactors. Reference 4 contains a listing of planned increases in spent fuel storage capacity and the core sizes. The spent fuel storage capacities can be expressed in years of operation by assuming two years to the discharge of a first fuel, discharge of 1/3 of a PWR core per year (1/4 of a BWR), and maintenance of a full-core-reserve (FCR) storage capacity. With these assumptions, the data in Table C.4 was derived, which show an average storage capability of 10 years.

For purposes of estimating the number of spent fuel shipments, all spent fuel was assumed to be held for 10 years before shipment. Figures C.2 and C.3 show the projected discharge and shipment rates of PWR and BWR fuel assemblies, respectively. Not all fuel can be held for 10 years, and the availability of receiving locations for spent fuel, such as an AFR, will greatly affect the amount shipped. Therefore, the spent fuel shipping curve with a 10-year delay time can be thought of as a low estimate, and the spent fuel discharge number can be thought of as a high bound estimate.

*The Morris facility is a de facto AFR since it is licensed to store some spent fuel; however, it has a very small capacity compared to the needed capacity.

TABLE C.4
EXPANDED SPENT FUEL STORAGE CAPACITY

Reactor Type	Capacity Listed in Reference 5	Years of Storage Capacity		
		Avg.	Max.	Min.
PWR	30	10.6	21.4	4.2
BWR	15	10.1	16.2	4.2

FIGURE C.2
PROJECTED DISCHARGE AND SHIPPING
SCHEDULE FOR PWR FUEL ASSEMBLIES

TABLE C. 3
PROJECTED DISCHARGE AND SHIPPING
SCHEDULE FOR BWR FUEL ASSEMBLIES

C.4 OTHER REACTOR CORE MATERIAL

The other reactor core materials requiring special attention are BWR channel boxes, BWR control blades, and PWR control rods. These materials are not removed and shipped as frequently or on as a determinable schedule, as spent fuel, and it will be shown that the amount of shipments of these items are not significant with respect to spent fuel.

Control Rods and Blades

Control rods and blades are replaced when they exceed one of several limits set by the NRC. The limits are related to hold-down reactivity, helium build-up and stainless steel embrittlement. Recently, some test specimens have indicated that several BWR control blades at the Dresden Nuclear Power Plant are approaching the stainless steel embrittlement limit after 10 years of operation. Since the blades affected are mainly those in the center of the core, it is estimated that $\frac{1}{4}$ of all BWR blades are replaced every 10 years.⁸ Table C.5 was prepared by using this estimate and an assumption of one control blade for every four BWR fuel assemblies. At this rate, 3500 blades will be discharged by the year 2000. Compared with the estimated 206,000 BWR spent fuel assemblies discharged by this date this number of blades does not appear to be significant.

The PWR control rod replacement rate is expected to be lower than that for the BWR control blades because the blades are normally withdrawn during operation as a result of the presence of soluble and burnable poisons. Therefore, shipment of PWR control rods is also neglected.

BWR Channel Boxes

BWR channel boxes must be replaced as a result of bowing, which could restrict the insertion rate of the blades. An estimated half of all channel boxes will be replaced every 10 years,⁸ which results in replacement of about 28,000 boxes by the year 2000. Since there is one channel box for every fuel assembly, the number of channel boxes is eight times as great as the number of blades given in Table C.5. Since the channel boxes are efficiently compacted by cutting them along the

TABLE C.5
BWR BLADE REPLACEMENT

Year	Number of BWR Blades	Number of New BWR Blades	Number of 10-year-old Blades Replaced	Number of 20-year-old Blades Replaced	Number of 30-year-old Blades Replaced	Total Number Replaced
1965	70	70	---	---	---	---
1966	70	0	---	---	---	---
1967	70	0	---	---	---	---
1968	70	0	---	---	---	---
1969	360	290	---	---	---	---
1970	670	310	---	---	---	---
1971	980	310	---	---	---	---
1972	1,600	620	---	---	---	---
1973	1,600	0	---	---	---	---
1974	2,600	1,000	---	---	---	---
1975	3,400	800	20	---	---	20
1976	3,400	0	0	---	---	20
1977	3,800	400	0	---	---	20
1978	4,000	200	0	---	---	20
1979	4,000	0	70	---	---	90
1980	4,300	300	80	---	---	170
1981	4,800	500	80	---	---	250
1982	5,300	500	150	---	---	400
1983	5,700	400	0	---	---	400
1984	6,100	400	250	---	---	650
1985	6,500	400	200	20	---	870
1986	7,000	500	0	0	---	870
1987	7,500	500	100	0	---	970
1988	8,000	500	50	0	---	1,020
1989	8,400	500	0	70	---	1,090
1990	8,900	500	15	80	---	1,285
1991	NA	NA	125	80	---	1,490
1992	NA	NA	125	150	---	1,765
1993	NA	NA	100	0	---	1,865
1994	NA	NA	100	250	---	2,215
1995	NA	NA	100	200	20	2,535
1996	NA	NA	125	0	0	2,660
1997	NA	NA	125	100	0	2,885
1998	NA	NA	125	100	0	3,110
1999	NA	NA	100	0	70	3,200
2000	NA	NA	125	75	80	3,480

NA = Not Applicable since blades loaded after 1990 will be discharged before 2000.

four seams and packing them into 210-liter drums, this is not expected to be a significant transportation item. The LLW values of Section 2.1.5 include channel boxes.

REFERENCES FOR APPENDIX C

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3. USNRC, "Generic Environmental Impact Statement on Handling of Storage of Spent Light Water Power Reactor Fuel (Draft)," NUREG-0404, March 1978.
4. C. W. Alexander et al., "Projections of Spent Fuel to be Discharged by the U.S. Nuclear Power Industry," ORNL/TM 6008, October 1977.
5. U. Y. Park and K. R. Yates, "Nuclear Capacity Projections and Spent Fuel Accumulation," Power Engineering, December 1979.
6. USDOE, "Spent Fuel Storage Requirements - The Need for Away-From-Reactor Storage," DOE/ET-0075, February 1979.
7. USDOE, "Spent Fuel Storage Requirements-The Need for Away-From-Reactor Storage: An Update of DOE/ET-0075," DOE/NE-0002, January 1980.
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APPENDIX D

REPROCESSING WASTES

Projections for reprocessing shipments and waste forms are uncertain due to ~~the Administration's~~ April 1977 decision to indefinitely defer civilian reprocessing and due to NRC's subsequent deferral of the GESMO hearings. For this report, it is assumed that reprocessing is allowed to proceed and that commercial reprocessing begins in the year 1990. It has also been assumed that the spent fuel shipped before 1990 is shipped to reprocessing plant locations, since reprocessing plants do have a substantial capacity for the storage of spent fuel. Note that this assumption minimizes the shipment of spent fuel. This appendix contains a discussion of (1) the amount of fuel reprocessed in the years 1990 to 2000 and (2) the type of material generated by the reprocessing.

D.1 FUEL REPROCESSED

The amount of fuel reprocessed is tied to the spent fuel generation rate from Appendix C and to the minimum cool-down period before reprocessing. For this report, a minimum cool-down period of 10 years is assumed, which is consistent with most waste disposal assumptions.¹ After the year 2000, the cool-down time may be reduced to 5 years or less.

The installed civilian reprocessing capacity in the United States is about 2250 MTHM/yr*--750 MTHM at West Valley, New York (Nuclear Fuel Services), and 1500 MTHM at Barnwell, South Carolina (Allied General Nuclear Services); however, the West Valley complex is not expected to operate again. Exxon has expressed an interest in building a 2100-MTHM plant in Oak Ridge, Tennessee. Construction of this plant would mean that a substantial amount of reprocessing capability can be brought on-line between 1990 and 2000 if necessary. For the purpose of this report, it has been assumed that 1500 MTHM/yr capacity exists in the year 1990 and that a 2100-MTHM plant is added in 1998. These assumptions and the projections from Appendix C were used to calculate the amount of fuel reprocessed between 1990 and 2000, as shown in Table D.1 and Figure D.1.

*These volume throughputs are based on 300 days of throughput per year; for instance, a 1500-MTHM plant has a daily capacity of 5 MTHM.

TABLE D.1
METRIC TONS OF HEAVY METAL REPROCESSED

Year	10-year-old Backlog	Amount of 10-year-old Backlog Generated	Amount Reprocessed	Cumulative Amount Reprocessed	Backlog at End of Year
1990	5,530	1,360	1,500	1,500	5,390
1991	5,390	1,360	1,500	3,000	5,250
1992	5,250	1,630	1,500	4,500	5,380
1993	5,380	1,850	1,500	6,000	5,730
1994	5,730	2,070	1,500	7,500	6,300
1995	6,300	2,280	1,500	9,000	7,080
1996	7,080	2,500	1,500	10,500	8,080
1997	8,080	2,710	1,500	12,000	9,290
1998	9,290	2,980	3,600	15,600	8,670
1999	8,670	3,250	3,600	19,200	8,320
2000	8,320	3,530	3,600	22,800	8,250

FIGURE D-1
CUMULATIVE MTHM GENERATED AND REPROCESSED

D.2 TYPES AND AMOUNTS OF REPROCESSING SHIPMENTS

A reprocessing plant receives 10-year-old spent fuel from the power plants and ships out HLW, hulls, and TRU wastes to a geologic repository and non-TRU waste to LLW waste disposal sites. Also, uranium and plutonium are transported back to the front end of the fuel cycle. There are five sources of information used for this report. Reference 1 is the ORNL contribution to the DEIS for the management of commercial nuclear power wastes. Reference 2 is the DEIS, and References 3 through 5 contain information on the three existing or planned reprocessing plants. The data from these sources has been normalized to a throughput of 1500 MTHM/year for comparison purposes (Table D.2). The value chosen for this report were estimated from these values, as shown in the last column. The amount of plutonium and uranium shipped to fuel fabrication and enrichment plants, respectively, are shown in Table D.3.* These values correspond to 1630 MT UO_2 (1436 MTU) and 14.7 MT PuO_2 (13.1 MT Pu) recycled for every 1500 MTHM processed.

*With the assumptions in this report, these values are for reprocessing "once-through" spent fuel and are not the same as the values from a mature reprocessing cycle.

TABLE D.2
REPROCESSING WASTE VOLUMES

Waste Type	NFS ¹		AGNS ¹		Exxon ¹		Y/OWI/TM-36	DEIS	Value Chosen For Report
	Generated (ft ³)	Shipped (ft ³)	Generated (ft ³)	Shipped (ft ³)	Generated (ft ³)	Shipped (ft ³)	(ft ³)	(ft ³)	(ft ³)
HLW ¹	5,600	5,600	3,000-5,250	3,000-5,250	3,600	3,600	2,250-4,500	3,900	4,000
Hulls	18,400	18,400	30,000	30,000	22,500	22,500	17,700	17,800	20,000
High-Activity TRU	9,600	8,600	10,960	1,840	1,960	1,960	Note 3	Note 3	2,000
LLW-TRU	35,000	3,500	62,900	9,160	61,400	14,100	57,600	50,700	15,000
Non-TRU Resins	62,730	57,200	---	---	4,300	7,100 ⁴	---	32,100	25,000
LLW ⁵	73,000	23,700	71,170	36,580	82,100	23,960	---	34,900	30,000
Failed Equipment	20,720	31,000 ⁶	---	---	930	1,300 ⁶	9,200	30,500	20,000

¹Based on 1500 MTHM.

²When two numbers are given for HLW, the lower value is for calcine waste and the higher value is for glass waste.

³ILW volume is included as LLW TRU.

⁴No explanation is given for the increase.

⁵Includes combustible, noncombustible, and compactible.

⁶Volume increase is due to cementing of the waste.

TABLE D.3
URANIUM AND PLUTONIUM RECOVERY RATE

	PWR		BWR		Report Value ¹	
	kg/MTHM	Fissile %	kg/MTHM	Fissile %	kg/MTHM	Fissile %
U	955	0.84	962	0.89	957	0.79
Pu	8.9	69	8.2	69	8.7	69

¹Report value is a composite average which is weighted by a factor of 2 MTHM of PWR spent fuel to 1 MTHM of BWR. *spent fuel.*

REFERENCES FOR APPENDIX D

1. Office of Nuclear Waste Isolation, "Technical Support for the GEIS: Radioactive Waste Isolation in Geologic Formations," Y/OWI/TM-36, April 1978.
2. USDOE, "Draft Environmental Impact Statement: Management of Commercially Generated Radioactive Waste," DOE/EIS-0046-D, April 1979.
3. Personal communication with J. P. Duckworth, Nuclear Fuel Services, Inc., January 1980.
4. R. T. Anderson et al., "Current Status and Future Considerations for a Transportation System for Spent Fuel and Radioactive Waste," Y/OWI/SUB-77/42513, February 1978.
5. Exxon Nuclear Company, "Nuclear Fuel Recovery and Recycling Center Environmental Report," XN-FR-3, Rev. 1.